40th AIVC - 8th TightVent & 6th venticool Conference

From energy crisis to sustainable indoor climate - 40 years of AIVC

15-16 October 2019

Het Pand, Ghent University, Belgium



PRESENTATIONS

www.aivc2019conference.org

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AIVC

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TightVent Europe
BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

venticool
the international platform for ventilative cooling

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EBC
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40th AIVC - 8th TightVent & 6th venticool Conference

From energy crisis
to sustainable indoor climate
40 years of AIVC

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General Information

Congress Venue

Het Pand, Ghent University, Onderbergen 1, 9000 Gent

Secretariat Hours

Secretariat will be open during the following dates and times:

Monday October 14th, 2019, 18:30 – 20:00, Castle of the Counts (Gravensteen)

Tuesday October 15th, 2019, 07:30 – 19:00, Het Pand, Ghent University

Wednesday October 16th, 2019, 08:00 – 18:30, Het Pand, Ghent University

Poster display information

- Posters should be set up on **Tuesday October 15th, 2019** from **09:30**
- Dismantling of posters should be finished by **Wednesday October 16th, 2019** at **18:30**

Secretariat and Organizers have no liability for posters left behind

Poster dimensions

(A0) size, 120cm Height X 80cm Width

Poster presentation session

Authors are expected to be in front of their poster in order to reply to any questions as per schedule below:

Tuesday October 15th, 2019 from 19:00 to 21:00

Long & Short Oral Presentations information

- Long Oral Presentations (indicated within the programme) are expected to last 12 minutes; another 3 minutes are foreseen for questions and answers (15 minutes in total).
- Short Oral Presentations (indicated within the programme) are expected to last 3 minutes; another 2 minutes are foreseen for questions and answers (5 minutes in total).

Social Events

Welcome Reception

Monday, October 14th, 2019 / 19:00

Castle of the Counts (Gravensteen)
Sint-Veerleplein 11, 9000, Ghent, Belgium
*(*all registered delegates are welcome to participate)*
https://visit.gent.be/en/see-do/castle-counts

Gala Dinner

Wednesday, October 16th, 2019

Kindly note that admission to the Gala Dinner is not included in the conference registration fees.Tickets are available here:
https://www.aivc.org/40th-aivc

Tuesday October 15th, 2019

ROOM I / REFTER

08:30-10:00 — **Opening - Plenary session**

Chairs: **Peter Wouters, Paula Wahlgren**

Welcome on behalf of Ghent University & Belgian AIVC Board members
Arnold Janssens, *Ghent University, Belgium &* **Samuel Caillou,** *BBRI, Belgium*

Welcome on behalf of AIVC, venticool, TightVent
Peter Wouters, *Manager, INIVE EEIG, Belgium*

History of the AIVC
Peter Wouters, *Operating Agent, AIVC, Belgium*

Building for People & Performance. Achieving Operational Excellence
Darryl K. Boyce *(Invited Speaker), ASHRAE President, USA*

Facing the global overheating through mitigation and adaptation technologies - the role of ventilation
Mattheos Santamouris *(Invited Speaker), UNSW, Australia*

CurieuzeNeuzen: Monitoring air quality together with 20.000 citizens
Sam de Craemer *(Invited Speaker), University of Antwerp, Belgium*

Industry views on the future of ventilation
Yves Lambert *(Invited Speaker), EVIA, Belgium*

10:00-10:30 — Coffee Break

10:30-12:00 — **Session 1A - Topical Session**
(Performance-based assessment methods for ventilation systems)

Chairs: **Gaëlle Guyot, Samuel Caillou**

In most of the current standard and regulations, the design of ventilation system is mainly based on prescriptive approaches. In such prescriptive approaches, the requirements are expressed in the form of minimum flowrates, size of openings, places of supply and exhaust, etc. The prescriptive approaches set the means and not the final goal, possibly limiting then innovation. In the context of energy performance regulations and of new innovative ventilation systems (i.e. Demand Controlled Ventilation or Smart systems), a few performance-based approaches have been developed in some countries for the assessment of these systems on the energy savings. Performance-based assessment methods open the opportunities to evaluate more equitably innovative smart ventilation systems as well as more complex systems (such as natural ventilation) for energy performance calculation but also to assess the ventilation performances on IAQ at the design stage.

This topical session will explain why and what is performance-based assessment methods, present some existing approaches in different countries, and discusses the challenges and perspectives for the future. The objectives of this session are to: provide an overview of the performance-based assessment methods; present current methods in a few countries; and identify challenges of these methods; draw perspectives for the future.

10:30-12:00

Introduction: Why performance-based assessment methods? Overview of the needs and the possibilities
Gaëlle Guyot, *Cerema, France*

Performance-based assessment methods for ventilation systems: Overview of on-going work in France and in Europe
François Parsy, *AERECO, France* **& Gaëlle Guyot,** *Cerema, France*

Performance-based Spanish regulations relating to indoor air quality
Pilar Linares-Alemparte, *Eduardo Torroja Institute for construction sciences-CSIC, Spain*

Challenges and limitations of performance-based approaches: the Belgian experience
Samuel Caillou & Sébastien Pecceu, *BBRI, Belgium*

Demand controlled ventilation: Sensitivity and robustness of the performances
Xavier Faure, *Univ Paris Saclay, France*

Discussion with the audience
Iain Walker, *LBNL, USA*

Conclusions & Perspectives
Samuel Caillou, *BBRI, Belgium*

ROOM II / AUGUST VERMEYLEN

10:30-12:00

Session 1B - Long Oral Presentation Session
(Test methods for building air tightness)

Chairs: **François Rémi Carrié, Adeline Bailly Mélois**

Applicability of a simple and new airtightness measuring method and further comparisons with blower door measurements
Timothy Lanooy, *ACIN instrumenten, The Netherlands*

Refined assessment and comparison of airtightness measurement of indoor chambers using the blower door and Pulse methods
Christopher Wood, *University of Nottingham, United Kingdom*

Evaluation of indoor pressure distributions in a detached house using the Pulse airtightness measurement technique
Yun-Sheng Hsu, *University of Nottingham, United Kingdom*

Insights into the impact of wind on the Pulse airtightness test in a UK dwelling
Yun-Sheng Hsu, *University of Nottingham, United Kingdom*

Estimation of Air Leakage Sizes in Building Envelope using High-Frequency Acoustic Impulse Response Technique
Benedikt Kolsch, *German Aerospace Center (DLR), Germany*

Deviation of blower-door fans over years through the analysis of fan calibration certificates
Valérie Leprince, *PLEIAQ, France*

Tuesday October 15th, 2019

ROOM III / PRIORZAAL

10:30-12:00 **Session 1C - Topical session (IEA EBC Annex 79: What information do we need for occupant-centric building design and operation?)**

Chairs: **Andreas Wagner, Ardeshir Mahdavi**

Buildings account for approx. 40% of the energy use in industrialized countries. Although various policies (e.g., building codes and incentives) were introduced to improve the quality of building envelopes and HVAC efficiency, very often a performance gap between designed and actually monitored energy consumption of buildings can be observed. Depending on the building type and degree of automation, occupants have a great influence of building energy use. For instance, Hong and Lin (2013) performed a simulation study to show that occupant behaviour at the office scale could increase energy use by 80% or reduce it by 50% from standard assumptions. This topic is exactly in the focus of the new IEA EBC Annex 79, which intends to integrate and implement occupancy and occupant behaviour into the design process and building operation to improve both energy performance and occupant comfort. The main objectives of the Annex are: developing new scientific knowledge about adaptive occupant actions driven by multiple interdependent indoor environmental parameters; understanding interactions between occupants and building systems in view of adaptive opportunities for improving the comfort situation, and regarding building energy use; deploying 'big data' (e.g. data mining and machine learning) for the building sector based on various sources of building and occupant data as well as sensing technologies; developing methods, guidelines, and recommendations for standards that integrate occupant models in building design and operation; and performing focused case studies to test the new methods and models in different design and operation phases in order to obtain valuable feedback for researchers and practitioners. The workshop will briefly introduce different fields of related research followed by a discussion about the needs and expectations of planners with regard to occupant models. In this context we want to gather views, opinions, and experiences regarding the following questions:

- *What information about occupants is necessary for developing occupant-centric building and systems designs? What do planners rely on when they assess building energy performance?*
- *Who has/provides this information about occupants/occupancy in the early design process/for building operation? What is the quality of this information?*
- *Who is responsible to collect and further process this information?*
- *What models are needed to use the available information about occupancy/occupant behaviour in design tools (sizing of components, energy calculation routines, performance simulation)*

The objectives of this session are to: inform about activities and first outcomes of the IEA EBC Annex 79; gather information about the needs and expectations of planners with regard to occupant models; and discuss obstacles and possible solutions for implementing advanced occupant behaviour/occupancy models in building design and operation tools.

Occupant-centric building design and operation – objectives, scope and activities of IEA EBC Annex 79
Andreas Wagner, *Karlsruhe Institute of Technology, Building Science Group, Germany*

10:30-12:00 **Occupant-centric building design and operation – remarks on advanced occupant models and the role of 'big data'**
Ardeshir Mahdavi, *Technical University of Vienna, Austria*

60 min structured discussion on questions outlined under description of session
Workshop participants

12:00-13:30 Lunch Break

ROOM I / REFTER

13:30-14:45 **Session 2C - Topical Session (40 years of AIVC)**

Chairs: **Max Sherman, Willem De Gids**

This session will take a look at the AIVC over the 40 years from its first conference until today. The chairs of this session attended that first conference and have served as long-time members of the AIVC Board of Directors for their respective countries. As the senior statesmen of the AIVC they will oversee a historical review of the AIVC and of the current Tech Note that looks back on key contributions that AIVC has made to the field.

The AIVC of the 20th Century
Martin Liddament, *VEETECH Ltd, United Kingdom*

The AIVC of the 21st Century
Peter Wouters, *INIVE, Belgium*

40 years of Modeling Airflows
Iain Walker, *LBNL, USA*

The Role of Carbon Dioxide in Ventilation and IAQ Evaluation: 40 years of AIVC
Andy Persily, *NIST, USA*

ROOM II / AUGUST VERMEYLEN

13:30-14:45 **Session 2A - Topical Session**
(Ventilation design and control in residences - current challenges, innovative solutions and case studies gathered by IEA-EBC Annex 68)

Chairs: **Esfand Burman, Carsten Rode**

This session will provide a summary of the activities carried out as part of Subtask 4 of the IEA-EBC Annex 68 project. This research project is focused on Indoor Air Quality Design and Control in Low Energy Residential Buildings. Subtask 4 of this project aims to devise optimal and practical design and control strategies for high indoor air quality in residential buildings. These strategies are informed by a review of the state of the art and synthesis of research undertaken in other subtasks of the project. An overview of the current practices and challenges facing the industry in procurement of ventilation systems in low-energy dwellings will be presented based on the outcomes of a stakeholder survey in seven European countries. This will be followed by a brief introduction of the report developed for this subtask. The report contains several case studies that identify current challenges and innovative solutions in various contexts. Five short presentations by participants in IEA-EBC Annex 68 will provide a synopsis of the research undertaken and body of knowledge collated in this project. Each presentation will be followed by a brief Q&A session with a more general discussion about IEA-EBC Annex 68 and its key outcomes in the end.

Introduction: How IEA EBC Annex 68 identified challenges and potential solutions in design and control of ventilation system in residences
Esfand Burman, *UCL, United Kingdom* **& Carsten Rode,** *DTU, Denmark*

Tuesday October 15th, 2019

13:30-14:45

HVAC and VOCs: interaction between building systems and indoor VOC concentrations
Klaas De Jonge, *Ghent University, Belgium*

Alternative ducting options for balanced mechanical ventilation systems in multifamily housing
Gabriel Rojas, *University of Innsbruck, Austria*

Lessons learned from a ten-year monitoring in residential buildings equipped with humidity-based demand controlled ventilation in France
Gaëlle Guyot, *Cerema, France*

Practical use of the Annex 68 IAQ Dashboard
Marc Abadie, *University of La Rochelle, France*

Lessons learned from design and operation of ventilation systems in low-energy dwellings in the UK
Esfand Burman, *UCL, United Kingdom*

ROOM I / REFTER

15:00-16:30

Session 3A - Topical Session (Controlling moisture for improved IAQ)

Chairs: **Arnold Janssens, Paula Wahlgren**

Moisture in the air is one of the reasons for ventilating a building, as is removing contaminants and odours. Since there are major health issues related to high moisture levels in buildings, moisture is an important aspect to consider. Fungal spores and dust mites proliferate under high levels of moisture and have been identified as aggravating conditions such as allergy, asthma and other bronchial problems. Furthermore, water vapour in contact with cold surfaces leads to high surface humidities or condensation, where it can cause considerable damage through mould growth and fabric decay. In the last 40 years our understanding of the relation between indoor humidity, ventilation, building envelope design and mechanisms for biological decay has increased a lot. Still, new research is going on to better control humidity and microbial growth and associated health issues or damage in buildings.

This session gives an historic overview of the findings on this topic during 40 years AIVC activities, and presents new advances in the field. The objectives of this session are to: create understanding of factors defining indoor air humidity and the consequences of humid indoor environments; and give information on advances in controlling indoor humidity through smart ventilation technology and quality assessment schemes.

Moisture in indoor air: findings of 40 years
Paula Wahlgren, *Chalmers University of Technology, Sweden*

Issues on humidity environment and health problem
Hiroshi Yoshino, *Tohoku University, Japan*

Fungal growth on timber frame houses
Michiel Vanpachtenbeke, *KU Leuven, Belgium*

Big humidity data from smart ventilation systems
Jelle Laverge, *Ghent University, Belgium*

ByggaF - A Method to Include Moisture Safety in the Construction Process
Kristina Mjörnell, *RISE, Sweden*

Analysis of the Effects of Ventilation Method on Indoor Humidity Distribution and Condensation by CFD method
Fangyuan Zhang, *Kitakyushu University, Japan*

ROOM II / AUGUST VERMEYLEN

15:00-16:30 Session 3B - Long Oral Presentation Session
(Energy performance of ventilation systems)

Chairs: **Samuel Caillou, Andy Persily**

Performance of an Advanced Heat Recovery Ventilation System in the Canadian Arctic
Justin Berquist, *National Research Council, Canada*

Long-term performance and resiliency testing of a dual core energy recovery ventilation system for the Arctic
Boualem Ouazia, *National Research Council, Canada*

Experimental investigation of frost formation on air to air counter flow heat exchanger in air handling unit and climatic influence on dry, wet, frost operation condition
Michal Pomianowski, *Aalborg University, Denmark*

Efficiency of heat recovery ventilation in real conditions: feedback from several measurement campaigns
Sebastien Pecceu, *BBRI Institute, Belgium*

Impact of ductwork leakage on the fan energy use and sound production of central mechanical ventilation units in houses
Valérie Leprince, *PLEIAQ, France*

The contribution of a solar air heater collector to the cooling load in a building
Pavlos Toumpoulidis, *Democritus University of Thrace, Greece*

ROOM III / PRIORZAAL

15:00-16:35 Session 3C - Long Oral Presentation Session
(Optimized HVAC design and operation)

Chairs: **Martin Liddament, Willem de Gids**

Evolution of ventilation strategies in air-conditioned buildings in Singapore – IAQ and Energy perspectives
Chandra Sekhar *(Invited Speaker), National University of Singapore, Singapore*

Dynamic performance of displacement ventilation in a lecture hall
Natalia Lastovets, *Aalto University, Finland*

Numerical Modelling of Large Air-Conditioned Space: Comparison of Two Ventilation Systems
Maria Kolokotroni, *Brunel University London, United Kingdom*

Proposal of Optimal Control Method in order to reduce Mutual Interference of Air Conditioning Indoor Units
Yuga Urata, *University of Kitakyushu, Japan*

Minimizing the influence of the stack effect and wind on the operation of mechanical exhaust ventilation systems
Samuel Caillou, *BRRI, Belgium*

Multi-Objective Optimization of Energy Saving and Thermal Comfort in Thermo Active Building System based on Model Predictive Control
Yohei Ogawa, *University of Kitakyushu, Japan*

16:30-17:00 Coffee Break

Tuesday October 15th, 2019

ROOM I / REFTER

17:00-18:15 **Session 4A – Short Oral Presentation session**

Chairs: **Wendy Miller, Christophe Delmotte**

Two Case Studies on Ventilation for Indoor Radon Control
Justin Berquist, *National Research Council, Canada*

Influence of ventilation on radon concentration in a study case in Spain
Pilar Linares-Alemparte, *Eduardo Torroja Institute for construction sciences-CSIC, Spain*

Energy and Indoor Air Quality Analysis of Mixed Air and Displacement Ventilation Systems
Walid Chakroun, *Kuwait University, Kuwait*

Investigation of The Combined Effect of Indoor Air Stability and Displacement Ventilation on Pollutant Transport in Human Breathing Microenvironment
Xiaorui Deng, *Hunan University, United Kingdom*

Indoor environment and adverse health symptoms among children under home damp conditions
Kenichi Hasegawa, *Akita Prefectural University, Japan*

Relationship between indoor allergen and occupants' allergic symptoms before and after moving in the house with the countermeasure against allergy
Teruaki Mitamura, *Maebashi Institute of Technology, Japan*

Learning Performance in Odor Environment with aroma oils: Influence of Odor of Essential Oils on Learning Performance in Classroom
Aya Eto, *Osaka University, Japan*

A large-scale longitudinal indoor air quality study: is low-cost sensor deployment a viable approach?
James McGrath, *National University of Ireland, Galway, Ireland*

An argument for a reality check in the ventilation industry: We still have an energy crisis, in practice, and are not generally, in practice, achieving better indoor climate
Sergio Fox, *AWE, Denmark*

Status of Air filter energy performance and product characteristics
Kiyan Vadoudi, *Eurovent Certita Certification, France*

Influence of Building Envelope's Solar Reflectivity, Wind Speed and Building Coverage Ratio on Urban Heat Environment
Haruto Kitakaze, *Osaka University, Japan*

The influence of external environment characteristics on the heating and cooling load of super-tall residential building
Hygeong-Tae Kim, *Seoul National University, Korea*

Improvement Method of Thermal Environmental Near Windows During Heating Period -Thermal and Air Flow Characteristics of Two-Dimensional Jet from Breeze Line Diffuser in Free Field
Shaoyu Sheng, *Osaka University, Japan*

ROOM II / AUGUST VERMEYLEN

17:00-18:15

Session 4B - Short Oral Presentation session

Chairs: **Hiroshi Yoshino, Adeline Bailly Mélois**

Airtightness and energy impact of air infiltration in residential buildings in Spain
Irene Poza-Casado, *Universidad de Valladolid, Spain*

Exist'air: airtightness measurement campaign and ventilation evaluation in 117 pre-2005 French dwellings
Sylvain Berthault, *Cerema, France*

New findings on measurements of very airtight buildings and apartments
Stefanie Rolfsmeier, *BlowerDoor GmbH, Germany*

Comparison between infiltration rate predictions using the divide-by-20 rule of thumb and real measurements
Alan Vega Pasos, *The University of Nottingham, United Kingdom*

On the experimental validation of the infiltration model DOMVENT3D
Alan Vega Pasos, *The University of Nottingham, United Kingdom*

How Accurate is our Leakage Extrapolation? Modeling Building Leakage Using the Darcy-Weisbach Equation
Steven Rogers, *The Energy Conservatory, USA*

Vertical Distribution of Temperature and Contaminant Concentration in a Room with Impinging Jet Ventilation System
Mako Matsuzaki, *Osaka University, Japan*

Analysis of convective heat transfer coefficient correlations for ventilative cooling based on reduced-scale measurements
Twan Van Hoof, *KU Leuven, Belgium*

Overheating reduction in a house with balanced ventilation and postcooling
Bart Cremers, *Zehnder Group, The Netherlands*

Modelling thermal comfort and energy consumption of a typical mixed-cooling apartment in Guilin, China
Jie Han, *Guilin University of Electronic Technology, China*

Comfort at Hospital Reception Desks
Regina Bokel, *Delft University of Technology, The Netherlands*

Prediction of the influence of solar radiation on adaptive thermal comfort using CFD simulation
Juti Hu, *Hunan University, China*

Tuesday October 15th, 2019

ROOM III / PRIORZAAL

17:00-18:15 **Session 4C - Short Oral Presentation session**

Chairs: **Maria Kolokotroni, Hilde Breesch**

Developing a new passive tracer gas test for air change rate measurement
Sarah Paralovo, *University of Ghent, Belgium*

Measuring the ventilation rate in occupied buildings and adapting the CO2 tracer gas technique
Jessica Few, *University College London, United Kingdom*

Airtightness and non-uniformity of ventilation rates in a naturally ventilated building with trickle vents
Jessica Few, *University College London, United Kingdom*

Effects of Outdoor Environment on Air Exchange Rate
Maria Marrero, *University of Coimbra, Portugal*

Successive Indoor Air Pressure Calculation Method for Natural Ventilation Rate Prediction
Haruna Yamasawa, *Osaka University, Japan*

Using CFD simulation to improve estimation of wind pressure coefficient for naturally ventilated buildings in tropical climate
Matthieu Zubialde-Elzaurdia, *University of French Polynesia, French Polynesia*

Experimental study of the combination of a positive input ventilation and active air vents on the air change rates of a house
Antoine Leconte, *CEA, France*

An investigation of ventilation control strategies for louver windows in different climate zones
Leonie Scheuring, *Technische Universität Dresden, Germany*

Cooling Performance of Air-Conditioning System with Ceiling Suspended Packaged Air Conditioning Unit over Divided-Type Membrane Ceilings in Large Classroom
Ito Shogo, *Osaka University, Japan*

Modelling of Supply Air Jet from Diffusers of Four-way packaged Air-conditioner for CFD Analysis on Unsteady Airflow in Room
Norikazu Yasuda, *Osaka University, Japan*

Multi-objective design of single room ventilation units with heat and water recovery
Vincent Lemort, *University of Liege, Belgium*

Review of building services solution fitted for a low emission building stock in urban areas
Matthias Haase, *SINTEF, Norway*

Comparative life-cycle assessment of constant air volume, variable air volume and active climate beam systems for a Swedish office building
Nadeen Hassan, *Lund University, Sweden*

Tuesday October 15th, 2019

ROOM I / REFTER

18:15-18:45	**Indoor Environmental Quality – Global Alliance (IEQ-GA) official launch** *Chairs:* **Anita Derjanecz,** *REHVA Managing Director* **Welcome speech** **Donald Weekes,** *IEQ-GA President* **Presentation of IEQ-GA founding members and their industries:** • **Atze Boerstra,** *REHVA Vice President* • **Peter Wouters,** *Manager of INIVE/AIVC* • **Darry K Boyce,** *ASHRAE President* • **Bjarne W. Olesen,** *ASHRAE Past President 2017/18* • **Vishal Kapur,** *Presidential Member of ISHRAE* • **Luca Alberto Pitera,** *Secretary General of AiCARR* **Official delivery of incorporation certificate to IEQ-GA founding members**
18:45-19:00	**90 seconds industry presentations** *Chairs:* **François Rémi Carrié** *Presentations by:* **Acin, Blowerdoor, Efficiency Matrix, Eurima, Lindab, Renson, Retrotec, Soudal**
19:00-21:00	**Poster presentations – Industry stands – Cocktail reception with snacks**

Wednesday October 16th, 2019

ROOM I / REFTER

08:30-09:45 Session 5A - Long Oral Presentation Session (IEQ field studies)

Chairs: **Pilar Linares-Alemparte, Shamila Haddad**

Enhancing thermal comfort and indoor air quality in Australian school classrooms
Shamila Haddad, *UNSW, Australia*

Indoor air and environmental quality in social housing dwellings in Australia
Mattheos Santamouris, *UNSW, Australia*

Radiant heating and cooling systems combined with displacement ventilation in schools; strategies to improve IAQ
Michel Tardif, *Natural Resources Canada, Canada*

The evaluation of real-time indoor environment parameters measured in 297 Chilean dwellings
Benjamin Jones, *University of Nottingham, United Kingdom*

Ventilation and Measured IAQ in new US homes
Iain Walker, *LBNL, United States of America*

ROOM II / AUGUST VERMEYLEN

08:30-10:00 Session 5C - Topical Session (Model based control and concepts for ventilation systems)

Chairs: **Hilde Breesch, Maarten Sourbron**

Simulation models are nowadays an essential part of design, control and commissioning of HVAC systems. Product developers, engineers in engineering offices as well as researchers use building energy simulation (BES) models, ventilation airflow models, system simulation models, CFD, etc. This topical session focusses on the use of simulation models in (1) control and (2) development of ventilation products and concepts. First, a model based predictive control (MPC) takes into account the current situation and the future demand, enabling a more robust control of the ventilation system. The operation of an MPC is contrary to a standard rule-based control strategy that is reactive and causes the system 'lags behind' in relation to the demand. Reliable, model-based prediction of occupancy and weather forecast for ambient temperature and solar radiation are needed for future control actions of the supply air flow rate and temperature. MPC already has shown an energy saving potential in real cases for buildings with hydraulic thermal energy systems. The question arises what the potential is of a model based predictive control in ventilation and all-air systems. On the one hand, all-air systems are fast responding systems compared to systems with thermal energy storage. On the other hand, MPC could be interesting for heating and cooling by ventilation if the interaction between the air and the thermal mass of the building is considered.

Second, model-based product development ensures to offer the optimum total package of ventilation, solar protection, heating and cooling. Every application is very different and case specific because of user behaviour and configuration possibilities of the used techniques. As a result, model-based approach of product development and quotation is necessary.

08:30-10:00

The objective of this session is to open the discussion about the use of (simulation) models in ventilation control and concepts: What are opportunities, challenges, benefits and difficulties of model based (predictive) control for ventilation and all-air systems? How can simulation models improve the development of new ventilation concepts and products?

Overview of model-based control strategies for ventilation systems
Hilde Breesch, *KU Leuven, Belgium*

Predictive control for an all-air ventilation system in an educational nZEB building
Bart Merema, *KU Leuven, Belgium*

Model based design of intelligent ventilation concepts
Koen Maertens, *Duco Ventilation & Sun Control, Belgium*

A case study on residential mixed-mode ventilation using the Ventilation Controls Virtual Test Bed
Bert Belmans, *Vrije Universiteit Brussel, Belgium*

Discussion with the audience

ROOM III / PRIORZAAL

08:30-10:00

Session 5B - Topical Session (Integrating uncertainties due to wind and stack effect in declared airtightness results)

Chairs: **Valérie Leprince, Dimitrios Kraniotis**

Building airtightness tests have become very common in several countries, either to comply with minimum requirements of regulations or programmes, or to justify input values in calculation methods. This raises increasing concerns for the reliability of those tests. There are four key sources of uncertainty in airtightness testing: 1) Measurement devices (accuracy and precision); 2) Calculation assumptions (e.g. reference pressure, regression analysis method); 3) External conditions (wind and stack effect impact); and 4) Tester's behaviour. While competent tester schemes and independent checking procedures show potential to contain errors due to the tester's behaviour, there have been extensive yet sterile debates about how the building pressurisation test standard ISO 9972 should address other sources of uncertainties. As a result, no change has been made on these aspects on the new version of the standard which was published in September 2015. With the present standard, the zero-flow pressure shall not exceed 5 Pa for the test to be valid. Consequently, in moderately windy conditions, it may be impossible to perform a pressurisation test in accordance with the standard, even using precautions with a careful uncertainty analysis.

This is the third topical session on this subject. The objectives of this new session are to: better understand and improve the pressure measurement on site; estimate the impact of wind through CFD modelling and model-scale measurement.

Influence of the external pressure tap position on the airtightness test result
Jiří Novák, *Czech Technical University, Czech Republic*

Wednesday October 16th, 2019

08:30-10:00

Airtightness of buildings – Considerations regarding place and nature of pressure taps
Christophe Delmotte, *CSTC-WTCB, Belgium*

Quantification of uncertainty in zero-flow pressure approximation
Martin Prignon, *Université catholique de Louvain, Belgium*

Designing a model-scale experiment to evaluate the impact of steady wind on building air leakage measurements
Adeline Bailly Mélois, *Cerema, France*

CFD modelling of fan pressurization method in buildings – The impact of dynamic wind on airtightness tests
Dimitrios Kraniotis, *Oslo Metropolitan University, Norway*

10:00-10:30 Coffee Break

ROOM I / REFTER

10:30-11:30 Session 6A - Long Oral Presentation Session (Smart ventilation performance)

Chairs: **François Durier, Benjamin Jones**

Using co-simulation between EnergyPlus and CONTAM to develop IAQ and energy-centric demand-controlled ventilation systems
Maria Justo Alonso, *NTNU, Norway*

Performances of a demand-controlled mechanical supply ventilation system under real conditions: indoor air quality and power distribution for thermal comfort
Clement Laffeter, *Ventilairsec, France*

Large-scale performance analysis of a smart residential MEV system based on cloud data
Ivan Pollet, *Renson Ventilation, Belgium*

Individualised Dynamic Model-Based Monitoring of Occupant's Thermal Comfort for Adaptive HVAC Controlling
Ali Youssef, *KU Leuven, Belgium*

ROOM II / AUGUST VERMEYLEN

10:30-11:30 Session 6C - Topical Session (EBC Annex 80- Resilient Cooling)

Chairs: **Peter Holzer, Chen Zhang**

The world is facing a rapid increase of air conditioning of buildings. It is driven by multiple factors, such as urbanisation and densification, climate change and elevated comfort expectations together with economic growth in hot and densely populated climate regions of the world. Given this mega-trend, it is mandatory to guide this development towards sustainable solutions. The development of cooling solutions has to be guided towards:

- *Energy efficiency and carbon neutrality;*
- *Social inclusiveness, affordability and accessibility;*
- *Reliability and failure safety;*

10:30-11:30

- *Resilience, understood as a cooling system's qualities of toughness, elasticity or adaptability against happenings such as: climate change, weather extremes, changes of physical outdoor conditions; grid blackouts and other breakdowns in supply chains; changes in economic and social conditions*

To support the cooling-development towards these qualities of sustainability and resilience is the target of the new IEA-EBC Annex 80. The topical session will present its scope and work programme, as well as exemplary resilient cooling technologies.

Introduction to Annex 80
Peter Holzer, *IBR&I, Austria*

Outlook on Resilient Cooling Technologies
Bjarne Olesen, *ICIEE.DTU, Denmark*

Experience with Resilient Cooling Technologies in Australia.
Wendy Miller, *QUT, Australia*

Resilience-Indicators of Cooling Technologies.
Shady Attia, *University of Liege, Belgium*

ROOM III / PRIORZAAL

10:30-11:15

Session 6B - Long Oral Presentation Session (Durability of building airtightness)

Chairs: **Valérie Leprince, Arnold Janssens**

Assessment of long-term and mid-term building airtightness durability: field study of 61 French low energy single-family dwellings
Bassam Moujalled, *CEREMA, France*

Assessment of the durability of airtightness products in laboratory controlled conditions: development and presentation of the experimental protocol
Andres Litvak, *CEREMA, France*

Moisture impact on dimensional changes and air leakage in wooden buildings
Paula Wahlgren, *Chalmers University of Technology, Sweden*

ROOM I / REFTER

11:45-12:45

Session 7A - Topical Session (Bedroom ventilation, IAQ and sleep)

Chairs: **Jelle Laverge, Arnold Janssens**

In this session, we would like to give an overview of the state of the art related to IAQ in bedrooms, bedroom ventilation and sleep quality and engage the audience to list research priorities in this area for the near future.

The bedroom is the most intensively used room in the dwelling (both in terms of occupancy density and total time spent) but is unfortunately heavily understudied in ventilation and IAQ sciences. By pooling presentations on this topic into a single session, we hope to increase the visibility of this area of research. Additionally, we feel it is important to link the different sub-fields (ventilation, IAQ and sleep quality) that are looking into the topic together, to stimulate a holistic approach to the challenges in this area.

The objectives of this session are to: provide an overview of the state of the art; support interdisciplinary initiatives; list challenges; and set a research agenda for the future.

Association between Indoor Air Quality and Sleep Quality
Chenxi Liao, *Ghent University, Belgium*

11:45-12:45 **IAQ in Belgian bedrooms**
Marianne Stranger, *VITO, Belgium*
Measurements of sleep quality with low-cost sleep monitors: Effect of bedroom air quality and sleep quality
Pawel Wargocki, *DTU, Denmark*
CO_2-concentration of the surrounding air of sleeping infants inside a crib
Wim Zeiler, *TU Eindhoven, The Netherlands*

ROOM II / AUGUST VERMEYLEN

11:45-12:45 **Session 7C - Long Oral Presentation Session (Measurement and commissioning of ventilation systems and ductwork)**

Chairs: **Gaëlle Guyot, Wouter Borsboom**

Quality framework for residential ventilation systems in Flemish Region in Belgium – feedback after three years' experience
Maarten De Strycker, *BCCA, Belgium*
Commission and performance contracting of ventilation systems in practice. Determination, analyses and consequences for practitioners and contractors
Wouter Borsboom, *TNO, The Netherlands*
Test of new analysis methodologies to assess dynamic airflow rate with the tracer gas decay method
Gabriel Remion, *Cerema, France*
Reliability of ductwork airtightness measurement: impact of pressure drop and leakage repartition on the test result
Sylvain Berhault, *Cerema, France*

ROOM III / PRIORZAAL

11:30-12:45 **Session 7B - Long Oral Presentation Session (Modelling of infiltration and ventilation)**

Chairs: **Chandra Sekhar, Maria Kapsalaki**

Techniques to Estimate Commercial Building Infiltration Rates
Andrew Persily, *NIST, USA*
Wind Pressure Coefficient and Wind Velocity around Buildings in High Density Block of Metropolis for Natural Ventilation Design
Toshio Yamanaka, *Osaka University, Japan*
Alternative solution proposal to improve the air change in light shafts based on flaps
Miguel Angel Padilla-Marcos, *Universidad de Valladolid, Spain*
Probabilistic modelling of wind induced air exchange in buildings
Krystyna Pietrzyk, *Chalmers University of Technology, Sweden*
Impact of an occupancy and activity based window use model on the prediction of the residential energy use and thermal comfort
Silke Verbruggen, *Ghent University, Belgium*

12:45-13:45 Lunch Break

ROOM I / REFTER

13:45-14:45 Session 8A - Long Oral Presentation Session (Reducing exposure to outdoor pollutants)

Chairs: **Max Sherman, Manfred Plagmann**

Ambient air filter efficiency in airtight, highly energy efficient dwellings – A simulation study to evaluate benefits and associated energy costs
Gabriel Rojas, *University of Innsbruck, Austria*

Out2In: impact of filtration and air purification on the penetration of outdoor air pollutants into the indoor environment by ventilation
Joris Van Herreweghe, *BBRI, Belgium*

Future trends in laboratory methods to predict HVAC in service filter performance
Paolo Tronville, *Politecnico di Torino, Italy*

A study of the influence of the position of a chimney terminal on the vertical walls of a building on the air quality of the ventilation air supply
Xavier Kuborn, *BBRI, Belgium*

ROOM II / AUGUST VERMEYLEN

13:45-14:45 Session 8B - Topical Session (When the EPR hits the fan, or…the killing of the fan energy)

Chairs: **Per Heiselberg, Ad van der Aa**

The last decades big steps have been made on the road to develop and design energy neutral buildings. Despite the large list of developments and improvements of all kind of energy saving technologies we see specifically for the larger non-residential buildings that the electric energy use for fans hardly show any reduction and becomes a dominant factor in the total energy use of these buildings. The fan energy currently counts already for approximately 15-20% of the total building related energy and becomes increasingly important.

Among other developments, the work of IEA Annex 35 "Hybrid ventilation in new and retrofitted office buildings" revealed new directions in the design of ventilation systems. However, in daily practice the HVAC designers and installers do not seriously pick up the (new) knowledge and keep up going the well-known traditional way: designing and realizing mechanical ventilation systems with a total pressure drop of over 800 Pa. The reason not to do so, does not only lie in financial arguments, but is based in a much broader range of barriers. Of course, the unfamiliarity and knowledge gap of how to design low-pressure systems is a relevant stumbling block, but also the "wish to control" the air flow, the IAQ and the comfort conditions results in installations that are fully equipped. All kind of provisions are foreseen that filter, heat, cool, humidify and control the air. And this ends up in the well-known high-pressure system, that needs to be equipped with big fans to get the air on the right place. To come to a serious reduction in fan energy for ventilation the above described circle must be broken.

The objective of this session is to present some views on why the outcomes of these activities are not more widely used today as basis for a discussion on the workshop

13:45-14:45 *on what can be done in the future to overcome the barriers and reduce fan energy considerably. The session will be closed with a discussion where the following topics will be addressed: What steps must be undertaken to come to a reduction of fan energy? What research work must be done? What interest/contribution is available to solve to the topic discussed?*

History and background in the development of low pressure ventilation systems
Per Heiselberg, *Aalborg University, Denmark*

Low pressure systems design examples and practical barriers
Ad van der Aa, *ABT, The Netherlands*

Options for improvement and future research topics on low pressure ventilation systems
Willem de Gids, *VentGuide, The Netherlands*

ROOM III / PRIORZAAL

13:45-14:45 **Session 8C - Topical Session (EBC Annex 78 - Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications)**

Chairs: **Bjarne W. Olesen, Pawel Wargocki**

Worldwide, there is an increasing number of publications related to air cleaning and there is an increasing sale of gas phase air cleaning products. This puts a demand for verifying the influence of using air cleaning on indoor air quality, comfort, well-being and health. It is thus important to learn whether air cleaning can supplement ventilation with respect to improving air quality i.e. whether it can partly substitute the ventilation rates required by standards. There is also a need to evaluate the energy impact of using air cleaning as supplement to ventilation.

In many locations in the world, the outdoor air quality is so bad that it is better to avoid supplying outdoor air to the buildings. In such cases, the alternative to use ventilation is to substitute supply of outdoor air with air cleaning. Even when outdoor air is of a good quality, the use of air cleaning substituting ventilation air could reduce the rate of outdoor air supplied indoors. Therefore, it is possible to save energy for pre heating/cooling the ventilation air and for transporting the air (fan energy). To verify the performance of gas phase air cleaning technologies there is a need to develop appropriate standard test methods.

This is some of the issues that is part of a new IEA-EBC Annex 78, and which will be covered by presentations and discussion in this session. The main objective of this workshop is to present and discuss specific tasks related to the new IEA-EBC annex 78. The annex work will include the presentations and discussions during the future work of the annex.

Introduction to Annex 78
Bjarne W. Olesen, *ICIEE.DTU, Denmark*

Existing air cleaning technologies
Alireza Afshari, *Sbi-AAU, Denmark*

Existing standards for testing gas phase air cleaners
Paolo Tronville, *Polito, Ital*

Methods to evaluate gas phase air-cleaning technologies
Pawel Wargocki, *ICIEE.DTU, Denmark*

ROOM I / REFTER

15:00-16:30 Session 9A - Long Oral Presentation Session (IEQ-metrics and evaluation)

Chairs: **Donald Weekes, Wendy Miller**

Development of Subjective Evaluation Tool of Work Environment for Office Workers' Work Performance and Health Promotion
Yuko Abe, *University of Kitakyushu, Japan*

Evaluation potential of indoor environments' ecological valency
Ardeshir Mahdavi, *TU Wien, Austria*

Residential Application of an Indoor Carbon Dioxide Metric
Andrew Persily, *NIST, USA*

Trade-offs between ventilation rates and formaldehyde concentrations in new-build dwellings in the UK
Esfand Burmam, *UCL, United Kingdom*

Modeling Dynamic Behavior of Volatile Organic Compounds in a Zero Energy Building
Klaas De Jonge, *Ghent University, Belgium*

Indoor air quality in Nearly Zero Energy Buildings, reduction of exposure
Wouter Borsboom, *TNO, The Netherlands*

ROOM II / AUGUST VERMEYLEN

15:00-16:30 Session 9B - Topical Session (EPBD 2018/844/EU Article 19a feasibility study on the "inspection of stand-alone ventilation systems")

Chairs: **Peter Wouters, François Durier**

Article 19a of the Energy Performance of Buildings Directive (EPBD) introduces the requirement for the European Commission to perform a feasibility study addressing two issues: 1)the possible introduction of EU provisions on the inspection of stand-alone ventilation systems and 2)the possible introduction of EU provisions on an optional building renovation passport. DG ENER from the European Commission awarded the contract (December 2018 – December 2019) to perform a technical study to a consortium led by INIVE and BPIE (www.epbd19a.eu).

The session will share outcomes of the study, the outcome of the online survey, as well as related field analyses, to give an overview of the state of the art regarding regulations, standards and guidelines available in the EU and beyond, as well as the stock of ventilation systems and their performances. Existing approaches and those currently under development will be presented and we will discuss the feasibility and expected impact of potential relevant measures at EU level.

Overall introduction on the EPBD article 19a with specific attention on inspection of stand-alone ventilation systems (www.epbd19a.eu)

Overview of existing experiences with relevance to the inspection of stand-alone ventilation systems

Description of the scenarios analysed in the context of the feasibility study

Preliminary results

Interactive voting

Wednesday October 16th, 2019

ROOM III / PRIORZAAL

15:00-16:30 **Session 9C - Topical Session (Better implementation of ventilative cooling (cooling of buildings using outside air as main source) in national building standards, legislation and compliance tools)**

Chairs: **Christoffer Plesner, Jannick K. Roth**

This session will discuss the national and international use of Ventilative cooling (cooling of buildings using outside air as main source either by mechanical or natural means or a combination) in national building standards, legislation and compliance tools. There will be presentations based on national inputs for the status and recommendations to better implementation of Ventilative cooling from 4 countries.

The session ends with an open discussion, asking if the participants feel inspired to use the input and recommendations given during the workshop to be used in their country or for new and upcoming technical documents. Questions to think about prior to joining the workshop: Do you see a clear potential of including ventilative cooling in your national building legislation/guideline? Is new work/research (in your country) needed to reach a better implementation of ventilative cooling? Are there some national barriers for implementation of Ventilative cooling? How is the air flow rate determined for ventilative cooling in your national building legislation/guideline?

The objective of the session is to give the participants an insight into how "Ventilative cooling" currently is integrated into EN, ISO and national standards, as well as in national legislation and compliance tools - with input given by national experts. Finally, the participants will join the discussion on how to improve the implementation of ventilative cooling seen from their perspective.

Introduction
Christoffer Plesner, *Velux, Denmark* **& Jannick Roth,** *WindowMaster, Denmark*

Standardisation projects in CEN and ISO relevant to ventilative cooling systems
Christoffer Plesner, *Velux, Denmark* **& Jannick Roth,** *WindowMaster, Denmark*

Status and recommendations for better implementation of ventilative cooling in UK technical documents
Benjamin Jones, *University of Nottingham, United Kingdom*

Status and recommendations for better implementation of ventilative cooling in Belgium (Flanders)
Hilde Breesch, *Ku Leuven, Belgium*

Status and recommendations for better implementation of ventilative cooling in Switzerland
Flourentzos Flourentzou, *ESTIA SA, Switzerland*

Status and recommendations for better implementation of ventilative cooling in Denmark
Per Heiselberg, *Aalborg University, Denmark*

Findings and road ahead for better implementation of ventilative cooling
Per Heiselberg, *Aalborg University, Denmark*

Discussion with the audience

16:30-17:00 Coffee Break

ROOM I / REFTER

17:00-18:30	**Closing Session** *Chairs:* **Arnold Janssens, Iain Walker** **IAQ and energy performance GHG emission: how to translate to occupiers and landlords** **Frank Hovorka** *(Invited Speaker), REHVA President, France* **Ventilative Cooling– Time for large scale implementation?** **Per Heiselberg** *(Invited Speaker), Aalborg University, Denmark* **Summing up of the 'Smart ventilation, IAQ & Health' track** **Benjamin Jones,** *University of Nottingham, United Kingdom* **Summing up of the 'Airtightness' track** **Paula Wahlgren,** *Chalmers University, Sweden* **Summing up of the 'Ventilative cooling and HVAC' track** **Hilde Breesch,** *KU Leuven, Belgium* **Best paper & poster award** **Max Sherman,** *LBNL, USA* **Announcement of 2020 conference** **Dimitris Charalambopoulos,** *ASHRAE Hellenic Chapter, Greece*
18:30	End of conference

Conference Secretariat



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Mrs Georgia Kateriniou
Email: secretariat@aivc2019conference.org

40th AIVC - 8th TightVent & 6th venticool Conference

Welcome on behalf of AIVC, venticool and TightVent

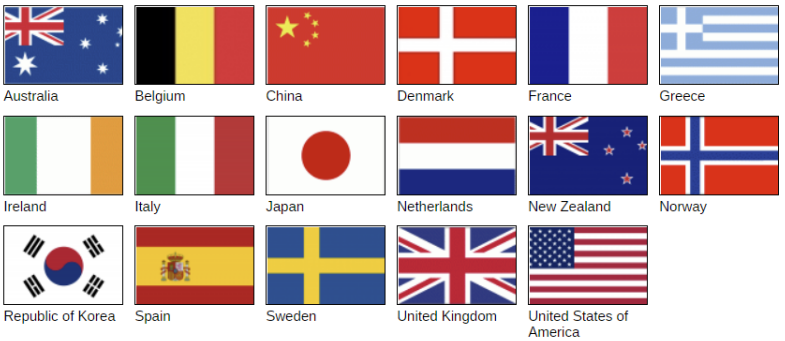
Peter Wouters

Operating Agent AIVC - Manager INIVE EEIG

1

Welcome on behalf of AIVC (1979 - …)

Celebrating 40 Years



2

Welcome on behalf of TightVent (2011 - …)

TightVent® Europe

BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

3

2011: The future

Before 2020 :
Many countries will impose near zero energy buildings

BUILD Tight
VENTILATE Right

Building Airtightness *will implicitly become a mandatory point of attention*

→

Energy efficient ventilation systems will become mandatory

4

2011

TightVent® Europe

BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

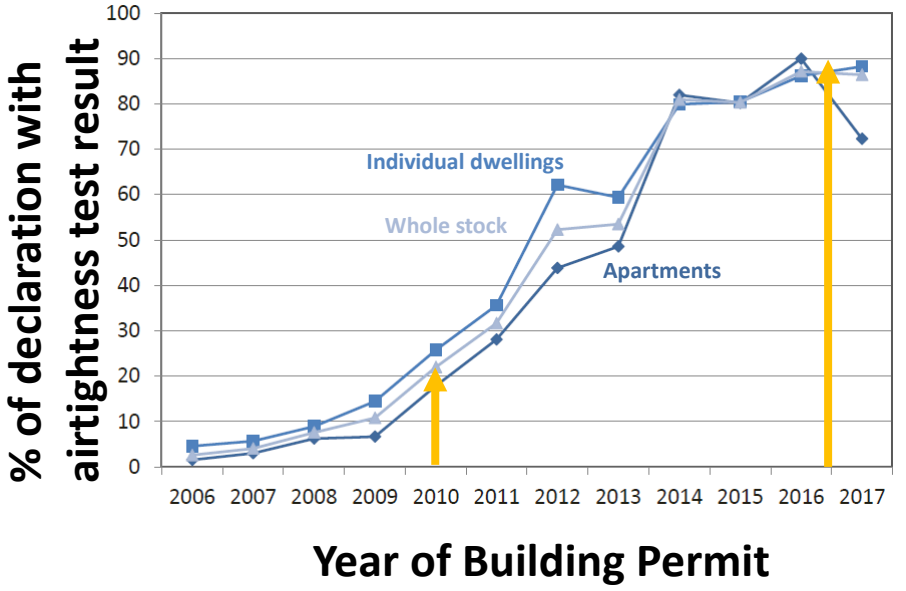
Present situation - most cases poor airtightness performances



Appropriate and durable airtighness performances of the whole stock

5

Evolution in Flemish Region of Belgium



6

Tightvent partners

Diamond partners

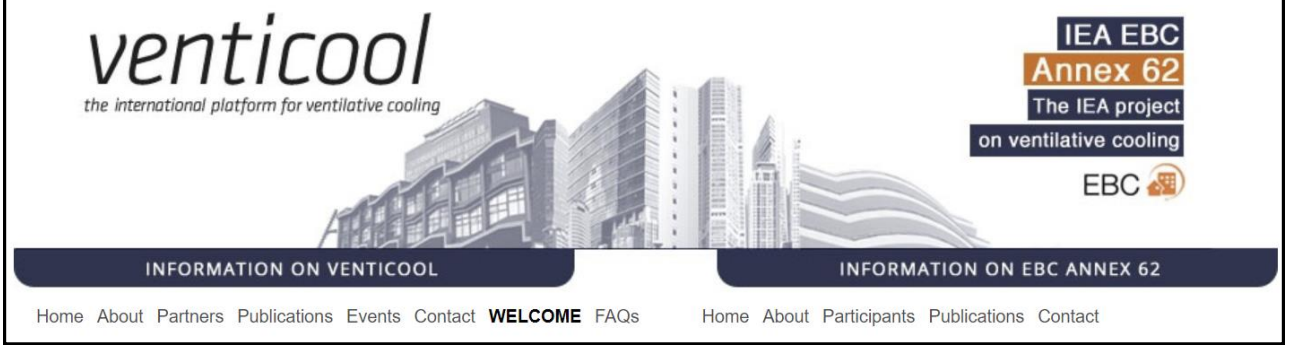
Silver partners

Gold partners

Associate partners

7

Welcome on behalf of Venticool (2013 - …)



8

venticool (2013 - …)

- Raise awareness about the potential of ventilative cooling
- Raise awareness about existing bottlenecks
- Raise awareness about interesting approaches
- (Support to) Planning of priority actions

9

Venticool partners

Diamond partners:

AGORIA naventa

VELUX®

RENSON® Creating healthy spaces

DUCO Ventilation & Sun Control

Gold partners:

Window Master® Fresh Air. Fresh People.

Associate partners:

CIBSE

Covenant of Mayors for Climate & Energy

REHVA

Platform facilitator:

INIVE

10



History of AIVC

P. Wouters

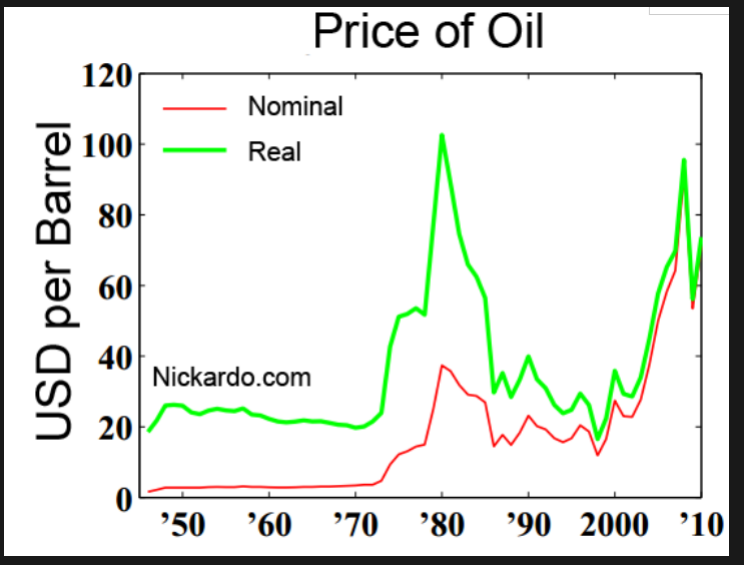
Operating Agent AIVC

Manager INIVE EEIG

1



2



3

IEA and energy in buildings

- 1977: Start of IEA implementing agreement **ECBCS**: Energy conservation in Buildings and Community Systems
  - **Annex 1**: Belgium, Canada, Denmark, Germany, Greece, Italy, Netherlands, Sweden, Switzerland, UK, USA
  - **Jean Lebrun** was Belgian ExCo member
- Observations:
  - Annex 1 highlighted that very little was known about **air infiltration**
    - Most countries: limited interest and almost no knowledge nor interest for air infiltration
    - Few countries were ahead: Sweden, Canada, Netherlands, …
  - 1979: **Annex 5** was launched as the Air Infiltration Centre (AIC)

4

How works the International Energy Agency (IEA)?

Committee on Energy Research and Technology (CERT)

4 Working Parties

38 Technology Collaboration Programmes

5

Explore the TCPs

Buildings | Cross-cutting | Electricity | Fossil fuels | Fusion power | Industry | Renewable power | Transport



The IEA Technology Collaboration Programme supports the work of 38 independent, international groups of experts that enable governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues.

38 Technology Collaboration Programmes

6

Explore the TCPs

Buildings | Cross-cutting | Electricity | Fossil fuels | Fusion power | Industry | Renewable power | Transport

Buildings

Innovation activities relating to efficiency gains in buildings, such as heat pumps, district heating and cooling and energy storage.

- Buildings and Communities (EBC TCP)

www.iea-ebc.org

EBC Energy in Buildings and Communities Programme



7

How works EBC TCP?

EBC Energy in Buildings and Communities Programme

- Executive Committee with 1 member for each of 24 countries
- Executive Committee can decide to set up a project ("Annex")

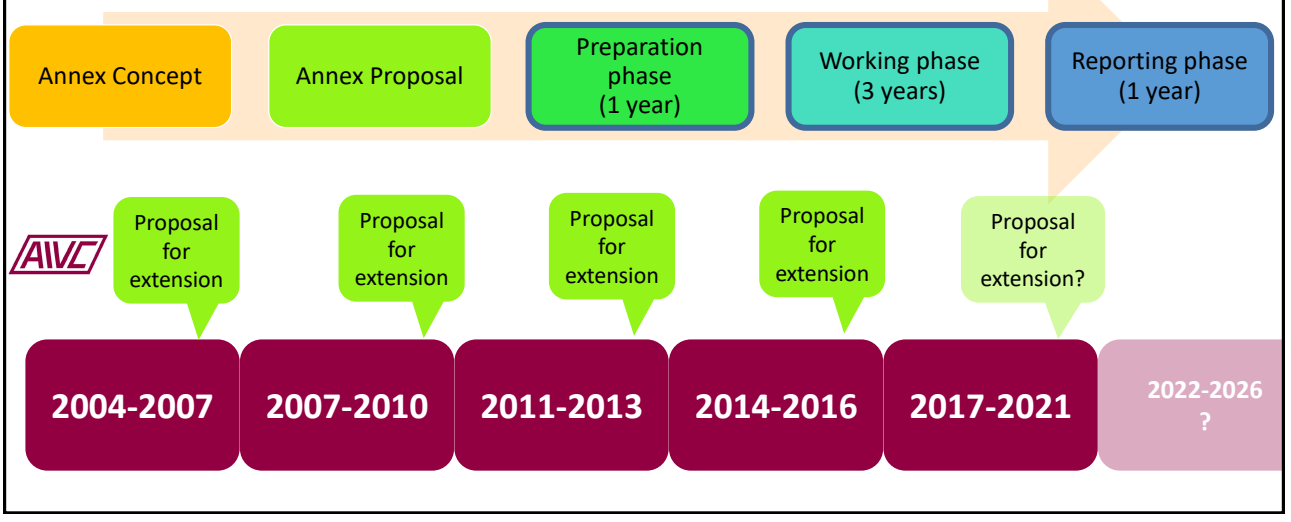
Annex Concept → Annex Proposal → Preparation phase (1 year) → Working phase (3 years) → Reporting phase (1 year)

8

How works EBC TCP?

- Annex 1 (1977-1980)
- …
- **Annex 5 AIVC (1979 - …)**
- …
- …
- **Annex 65 (2013-2019)**
- **…**
- **Annex 80 (most recent annex → 2018 - 2023)**

How works EBC TCP?



EBC TCP and ventilation research

Energy in Buildings and Communities Programme

- Annex 8 – Inhabitant behaviour with regard to ventilation (1984 – 1987)
- Annex 9 – Minimum ventilation rates
- Annex 18 – Demand controlled ventilation systems
- Annex 20 – Air flow patterns in buildings
- Annex 23 – Multizone air flow modelling
- Annex 26 – Energy efficient ventilation of large enclosures
- Annex 27 – Evaluation and demonstration of domestic ventilation systems
- Annex 35 – Control strategies for hybrid ventilation
- Annex 44 – Integrating environmentally responsive elements in buildings

11

EBC TCP and ventilation research

Energy in Buildings and Communities Programme

- Annex 62 – Ventilative cooling
- Annex 66 – Definition and simulation of occupants behaviour
- **Annex 68 – Design and operational strategies for high IAQ in low energy buildings**
- **Annex 78 – Supplementing ventilation with gas-phase air cleaning**
- **Annex 79 – Occupant-centric building design and operation**
- **Annex 80 – Resilient cooling**

= Topical session during this conference

12



13

This afternoon 13:30-14:45

Session 2C - Topical Session (40 years of AIVC)

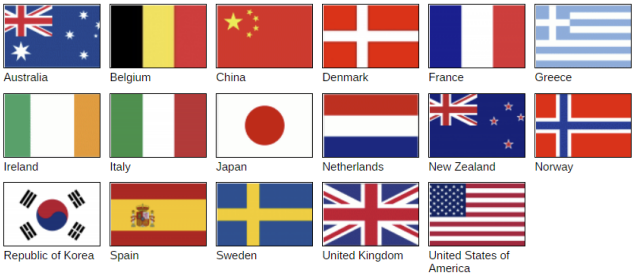
Chairs: Max Sherman, Willem De Gids

- **The AIVC of the 20th Century**
  Martin Liddament, VEETECH Ltd, United Kingdom
- **The AIVC of the 21st Century**
  Peter Wouters, INIVE, Belgium
- **40 years of Modeling Airflows**
  Iain Walker, LBNL, USA
- **The Role of Carbon Dioxide in Ventilation and IAQ Evaluation:40 years of AIVC**
  Andy Persily, NIST, USA

14

40 years of AIVC was not possible without..

the AIVC member countries and the board members



AIVC



15

40 years of AIVC was not possible without..

INIVE (2001 - ...)

International Network for Information on Ventilation and Energy Performance

CETIAT bbri.be SINTEF

TNO innovation for life Fraunhofer IBP CSTB le futur en construction eERG end-use Efficiency Research Group

16

40 years of AIVC was not possible without..

1979-2000

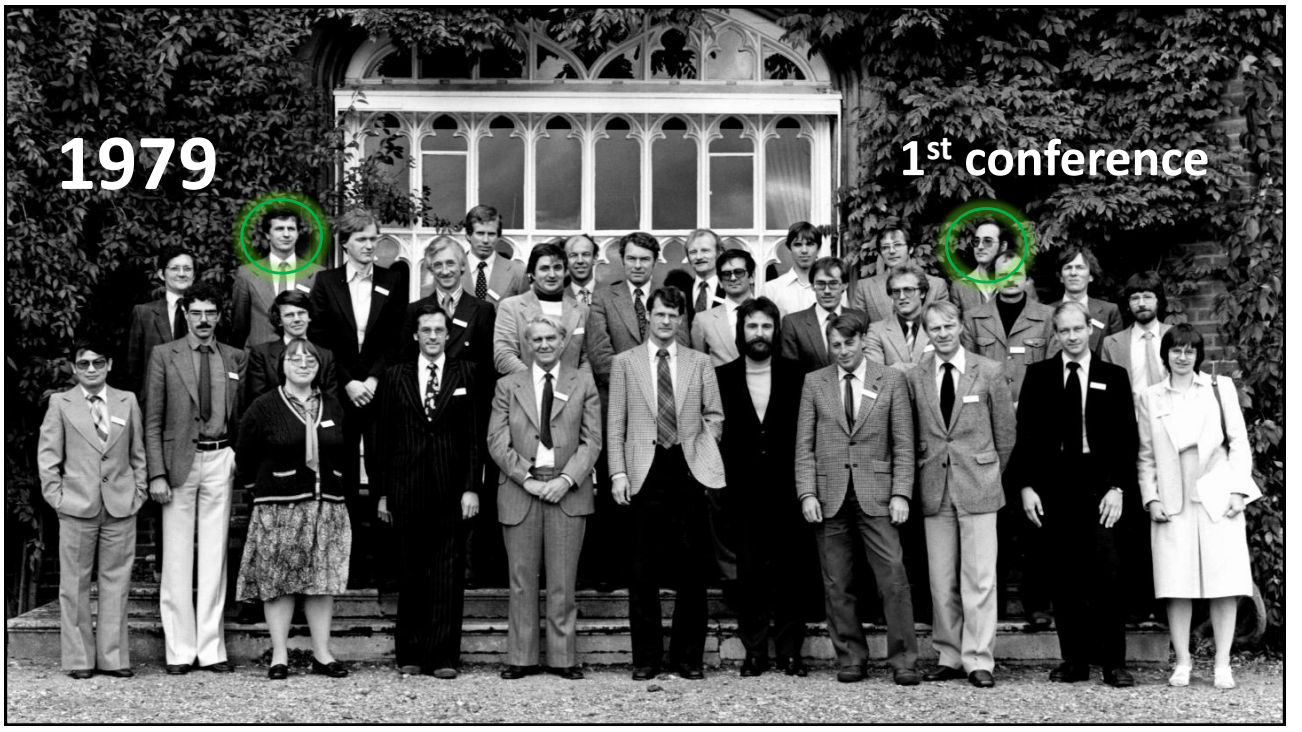
- Martin Liddament
- Malcolm Orme
- Other staff members at Oscar Faber



- Local teams at AIVC conferences and workshops

2000-2019

- Stéphane Degauquier
- Christophe Delmotte
- Rémi Carrié
- Maria Kapsalaki
- Valérie Leprince
- Georgia Kateriniou (conferences)
- Alexander Deliyannis (website)
- Javier Fientes (website)
- …





VINTAGE 1979 orginal parts

The AIVC board presents

Certificate for outstanding performance

Willem De Gids

Dutch member and guest of the AIVC board

For his leadership in AIVC related activities during its whole lifetime (1979-2019)

Dr. Peter Wouters

AIVC Operating Agent

19



VINTAGE 1979 orginal parts

The AIVC board presents

Certificate for outstanding performance

Max Sherman

AIVC board member for the USA

For his leadership in AIVC related activities during its whole lifetime (1979-2019)

Dr. Peter Wouters

AIVC Operating Agent

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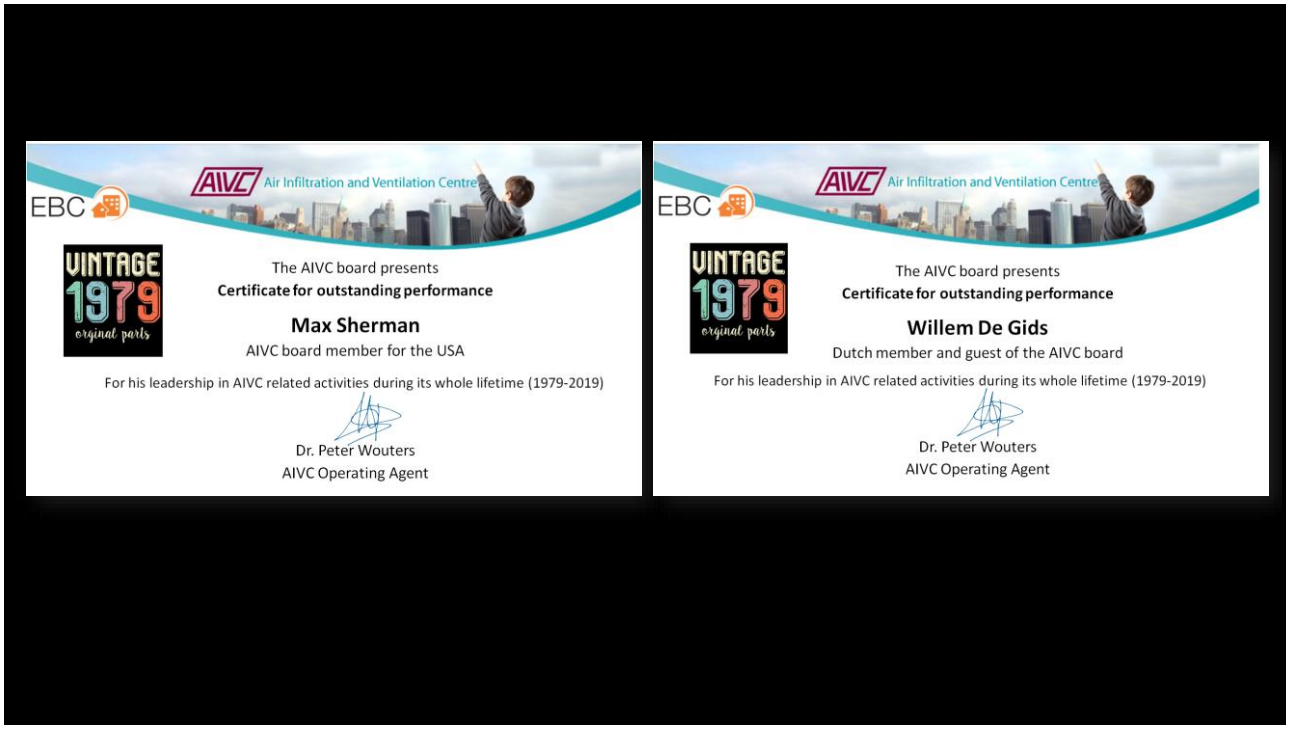
EBC
AIVC Air Infiltration and Ventilation Centre
VINTAGE 1979 original parts
The AIVC board presents
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AIVC board member for the USA
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AIVC Operating Agent
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Willem De Gids
Dutch member and guest of the AIVC board
For his leadership in AIVC related activities during its whole lifetime (1979-2019)
Dr. Peter Wouters
AIVC Operating Agent

21


Celebrating
40
Years

22



23

EBC

AIVC Air Infiltration and Ventilation Centre

VINTAGE 1979 orginal parts

The AIVC board presents

Certificate for outstanding performance

Martin Liddament

For his leadership in AIVC related activities (1979-2000) and as founding editor of the International Journal of Ventilation

Dr. Peter Wouters
AIVC Operating Agent

24

Celebrating 40 Years

25

EBC

AIVC Air Infiltration and Ventilation Centre

The AIVC board presents

Certificate for outstanding performance



Jean Lebrun

Belgian member of IEA ECBCS

For his leadership in IEA ECBCS related activities since 1977 and for his long-term support of the AIVC activities

Dr. Peter Wouters

AIVC Operating Agent

26

Celebrating 40 Years

27

EBC

AIVC Air Infiltration and Ventilation Centre

The AIVC board presents

Certificate for outstanding performance

Mat Santamouris

AIVC board member for Greece and for Australia

For his leadership in indoor climate and environmental activities and for his support to the AIVC



Dr. Peter Wouters
AIVC Operating Agent

28

Celebrating

40

Years

29



Ghent

Tuesday 15 October 2019

09:08

40

Years

Honolulu

Monday 14 October 2019

21:08

30



The AIVC board presents

Certificate for outstanding performance

Maria Kapsalaki

for her 40 years of life exactly overlapping with the duration of the AIVC
and in particular for her very active support of the AIVC activities in recent years

Celebrating 40 Years

Dr. Peter Wouters
AIVC Operating Agent

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Celebrating 40 Years

32

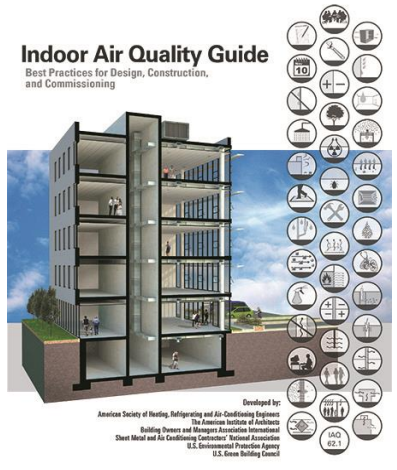
Shaping Tomorrow's
Built Environment Today

40th AICV Conference

Keynote Presentation
Darryl K. Boyce, P.ENG., 2019-20 ASHRAE President
October 15, 2019

1

The built environment highly impacts all aspects of life, yet few have a thorough understanding of this complex industry



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2

Building for People and Performance. Achieving Operational Excellence.

ASHRAE's Society Year theme focuses on ensuring operational performance for the people who live, work and interact in the buildings we create and aligns with AICV's work in establishing an acceptable IEQ.



3

Obstacles to Improving IEQ

The value of the health and productivity of occupants can be more than **10 times** the cost of operation – including energy costs.





4

IAQ as a Public Health Issue



ASHRAE published a position paper on IAQ in 1989 asserting the importance of IAQ as a public health issue and continues to advance IAQ knowledge through educational opportunities, published documents, written standards and related documents.

5

Standard 62.1

The outdoor air ventilation rate requirements for Standard 62.1, *Ventilation for Acceptable Indoor Air Quality,* have been adopted into the International Mechanical Code and Uniform Mechanical Code, as well as referenced by most green building programs including LEED.



6

ISO 16814-2008

ISO 16814-2008 is an international standard that refers to ASHRAE Standards 62.1 and 62.2 and is intended to specify methods to express the quality of indoor air suitable for human occupancy, to allow several acceptable target levels of indoor air quality, depending on local requirements, constraints and expectations.

7

EN15251

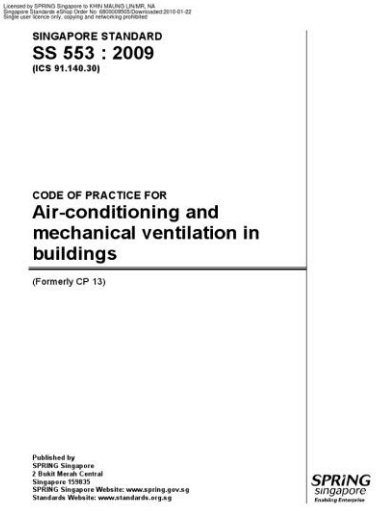
Although there are significant differences compared to Standards 62.1 and 62.2, a key European Standard, EN15251*: Indoor Environmental Criteria for Design and Calculation of Energy Performance of Buildings*, also references these U.S. standards.

It forms part of a series of standards aimed at European harmonization of the methodology for the calculation of the energy performance of buildings under the Energy Performance of Buildings Directive (EPBD).

REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

8

SS 553-2009



Singapore Standard, SS 553-2009 has had a strong influence from ASHRAE Standard 62.1. SS 553-2009 is the Code of practice for air-conditioning and mechanical ventilation in buildings and SS 554-2009 is the Code of practice for indoor air quality for air-conditioned buildings.

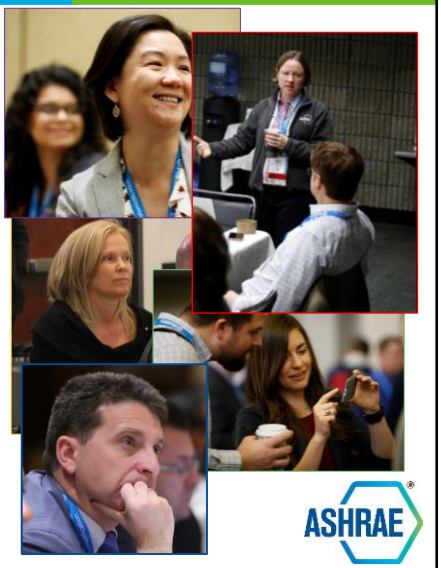
Additional Examples

Examples of other international standards, codes and guidelines that reference ASHRAE Standards 62.1 or 62.2 include:

- **Australian** Standard 1668.2-2002 which sets out design requirements for natural ventilation systems and mechanical air-handling systems that ventilate enclosures
- Guidance Notes for the Management of Indoor Air Quality, **Hong Kong** - 2003 which aims to provide comprehensive guidelines for the total management of IAQ
- Ventilation Requirements for Acceptable Indoor Air Quality, SHASE 2003 which addresses the ventilation requirements for both building emissions and occupants; and Indoor Air Quality Control in Public Use Facilities, etc. Act, **South Korea**, 2004 - a rare example of a country regulating indoor air quality

ASHRAE's Open Membership Process

ASHRAE's open membership process on technical committees, the global reach of ASHRAE publications and the intergovernmental work done by AIVC makes global collaboration a reality!



Creating Sustainable Built Environments

Our continued work can dramatically change how buildings impact the people who occupy them.

We must continue to work together to provide the innovation required to create sustainable built environments around the globe!



Building for People and Performance. Achieving Operational Excellence.

To learn more: ashrae.org/president

Follow me on Facebook:
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ASHRAE

ashrae.org

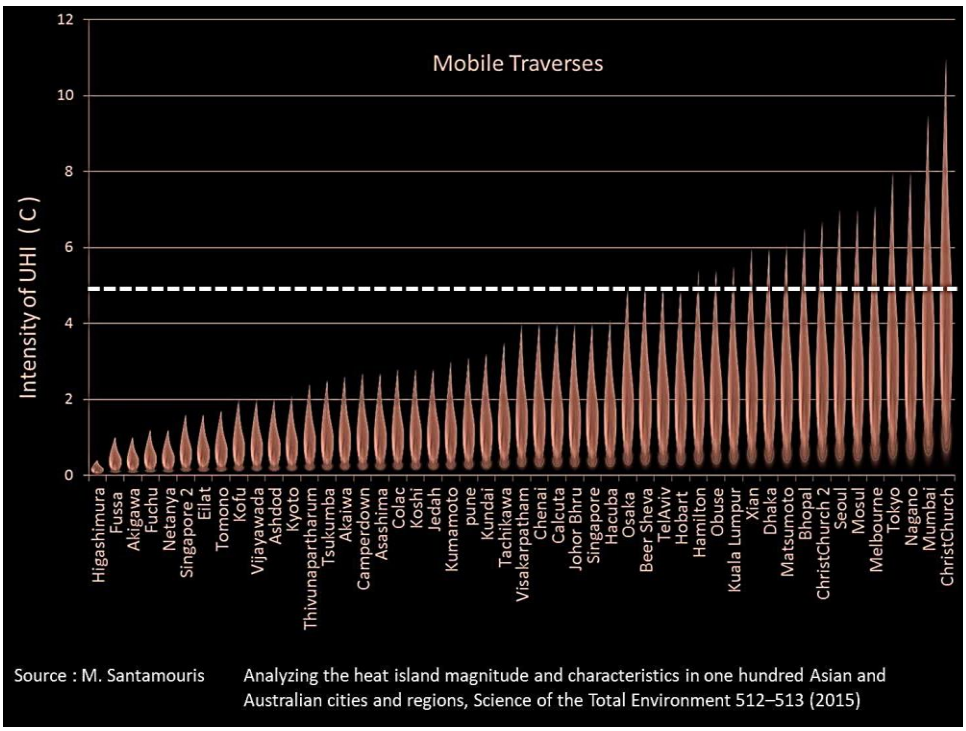
FACING THE URBAN OVERHEATING THROUGH MITIGATION AND ADAPTATION TECHNOLOGIES – THE ROLE OF VENTILATION

Scientia Professor Mat Santamouris,
The Anita Lawrence Chair in High Performance Architecture at UNSW Built Environment



AIVC Conference – Gent Belgium– October 2019

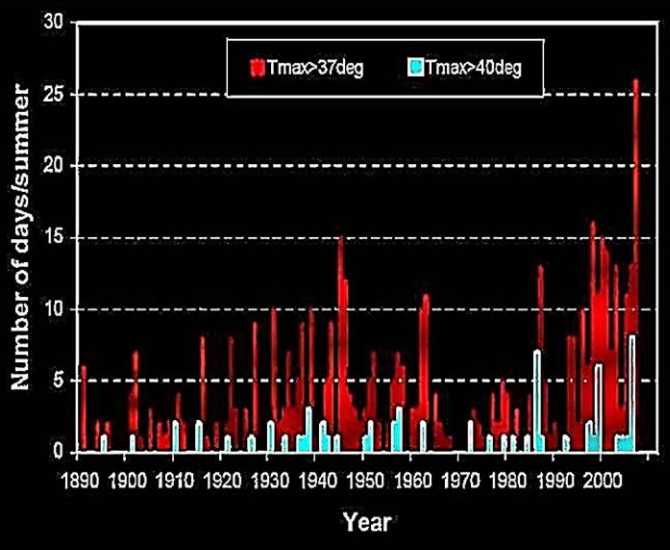
1



Source : M. Santamouris Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions, Science of the Total Environment 512–513 (2015)

2

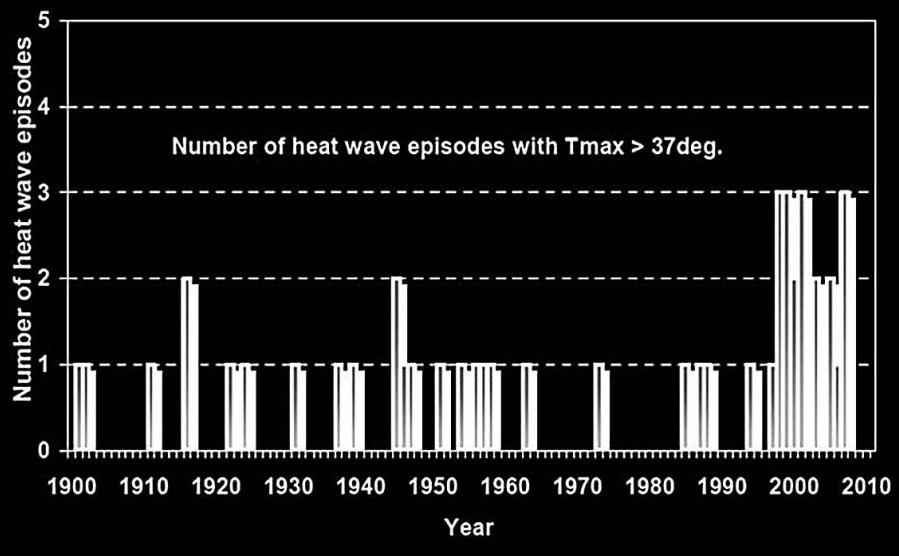
INCREASE OF THE DURATION OF HOT SPELLS



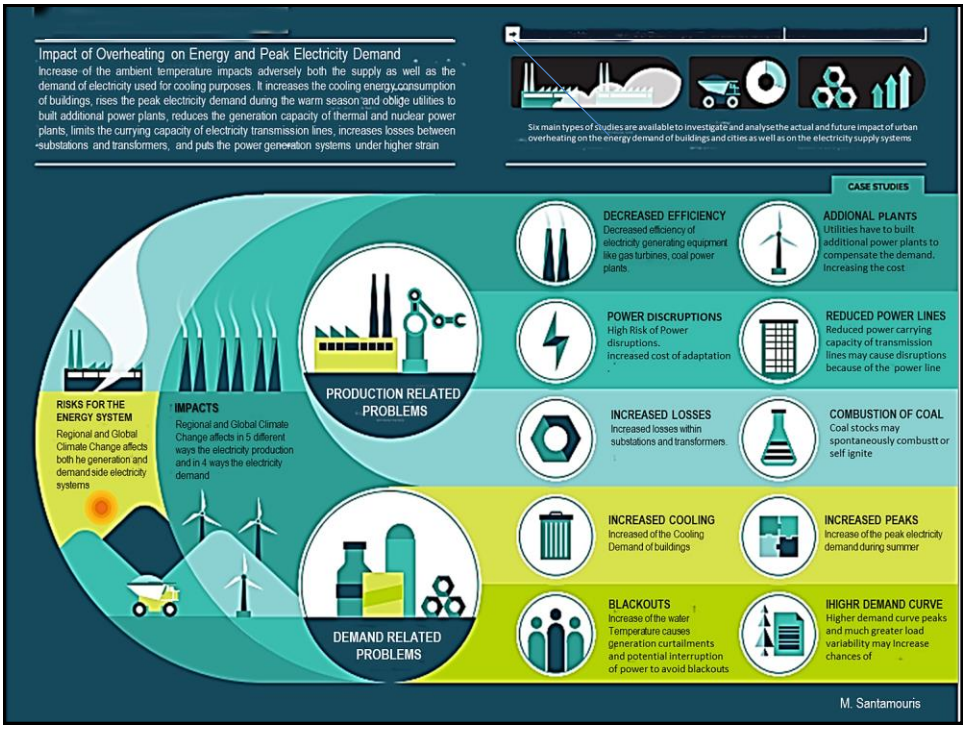
Source : M. Santamouris : Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions, Science of the Total Environment 512–513 (2015) 582–598

3

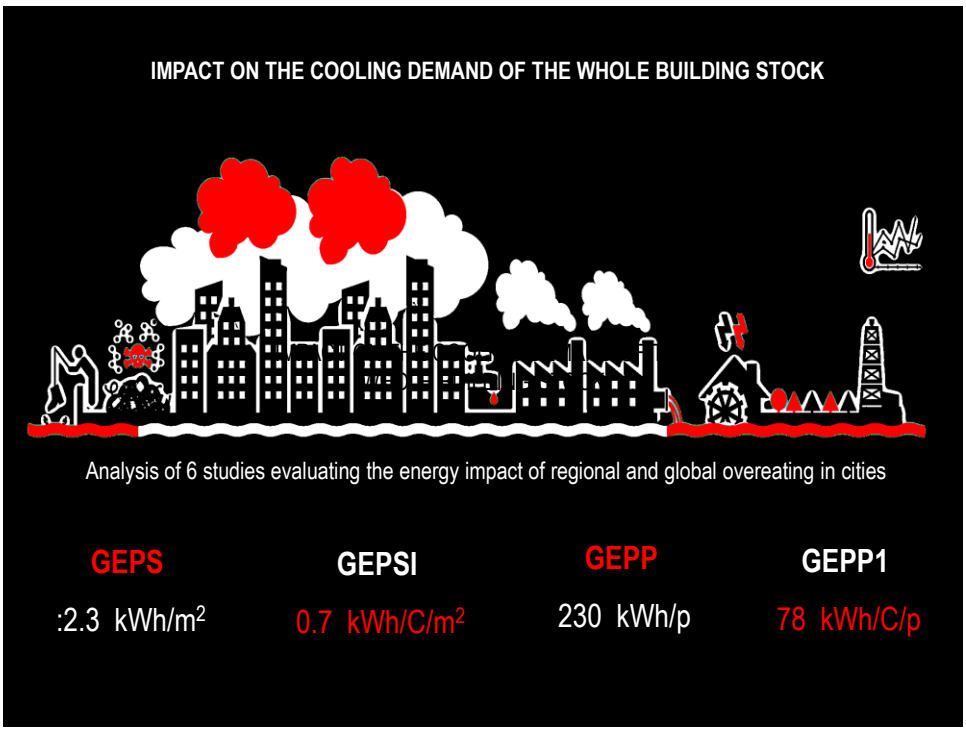
URBAN HEAT ISLAND AND LOCAL CLIMATE CHANGE



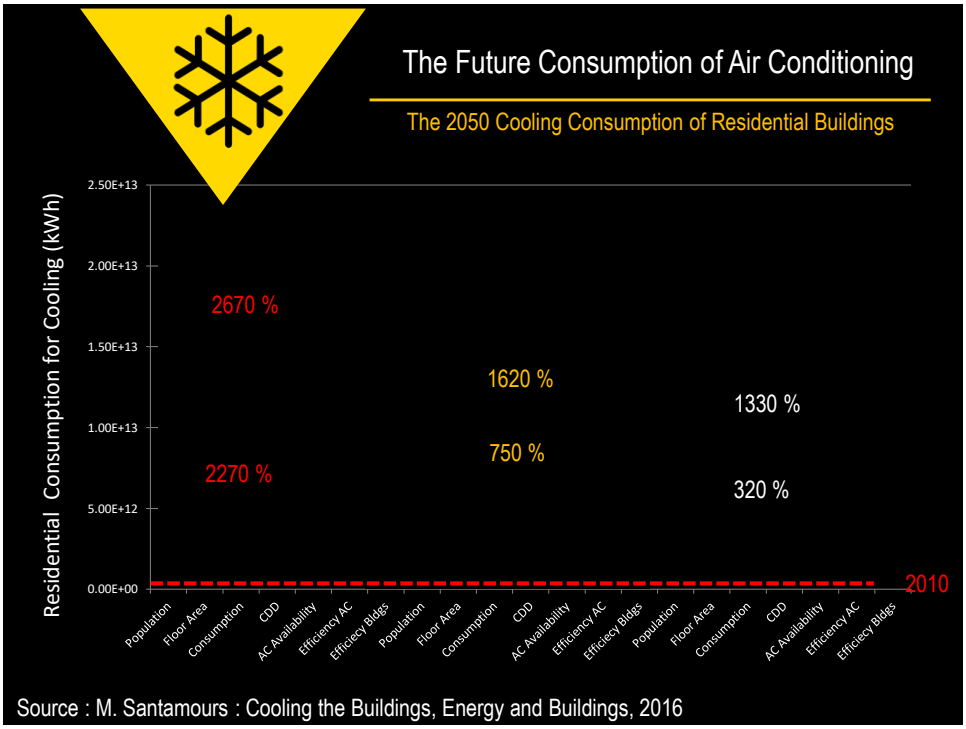
4


Impact of Overheating on Energy and Peak Electricity Demand
Increase of the ambient temperature impacts adversely both the supply as well as the demand of electricity used for cooling purposes It increases the cooling energy consumption of buildings, rises the peak electricity demand during the warm season and oblige utilities to built additional power plants, reduces the generation capacity of thermal and nuclear power plants, limits the currying capacity of electricity transmission lines, increases losses between substations and transformers, and puts the power generation systems under higher strain
Six main types of studies are available to investigate and analyse the actual and future impact of urban overheating on the energy demand of buildings and cities as well as on the electricity supply systems
CASE STUDIES
RISKS FOR THE ENERGY SYSTEM
Regional and Global Climate Change affects both he generation and demand side electricity systems
IMPACTS
Regional and Global Climate Change affects in 5 different ways the electricity production and in 4 ways the electricity demand
PRODUCTION RELATED PROBLEMS
DEMAND RELATED PROBLEMS
DECREASED EFFICIENCY
Decreased efficiency of electricity generating equipment like gas turbines, coal power plants
ADDIONAL PLANTS
Utilities have to built additional power plants to compensate the demand, increasing the cost
POWER DISCRUPTIONS
High Risk of Power disruptions. increased cost of adaptation
REDUCED POWER LINES
Reduced power carrying capacity of transmission lines may cause disruptions because of the power line
INCREASED LOSSES
Increased losses within substations and transformers.
COMBUSTION OF COAL
Coal stocks may spontaneously combustt or self ignite
INCREASED COOLING
Increased of the Cooling Demand of buildings
INCREASED PEAKS
Increase of the peak electricity demand during summer
BLACKOUTS
Increase of the water Temperature causes generation curtailments and potential interruption of power to avoid blackouts
IHIGHR DEMAND CURVE
Higher demand curve peaks and much greater load variability may Increase chances of
M. Santamouris

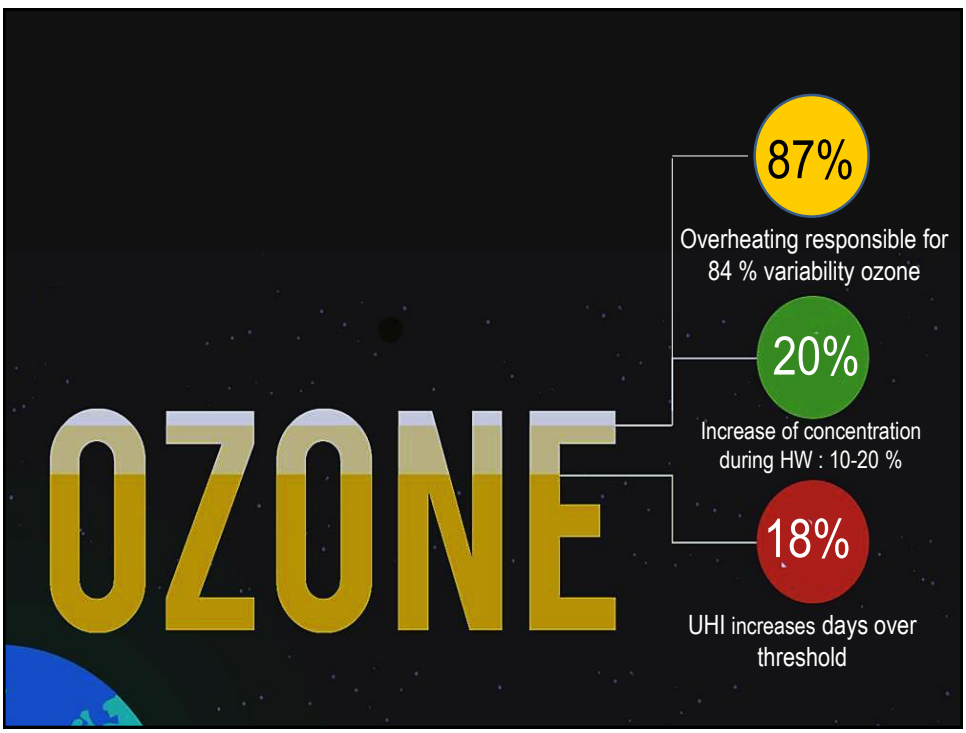
5


IMPACT ON THE COOLING DEMAND OF THE WHOLE BUILDING STOCK
Analysis of 6 studies evaluating the energy impact of regional and global overeating in cities
GEPS
:2.3 kWh/m2
GEPSI
0.7 kWh/C/m2
GEPP
230 kWh/p
GEPP1
78 kWh/C/p

6


The Future Consumption of Air Conditioning
The 2050 Cooling Consumption of Residential Buildings
Residential Consumption for Cooling (kWh)
2.50E+13
2.00E+13
1.50E+13
1.00E+13
5.00E+12
0.00E+00
2670 %
2270 %
1620 %
750 %
1330 %
320 %
2010
Population
Floor Area
Consumption
CDD
AC Availability
Efficiency AC
Efficiecy Bldgs
Source : M. Santamours : Cooling the Buildings, Energy and Buildings, 2016

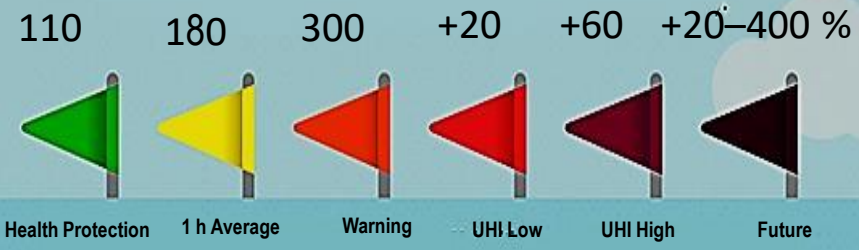
7


OZONE
87%
Overheating responsible for 84 % variability ozone
20%
Increase of concentration during HW : 10-20 %
18%
UHI increases days over threshold

8

Overheating Affects the concentration of Ground Ozone

Urban overheating affects seriously the air quality of cities. High temperatures speed up photochemical reactions in ambient air through chemical interactions with nitrogen oxides and hydrocarbons, resulting in the formation of tropospheric ozone.



Predicted percentage future increase of the concentration between 20- 60 % in 2050, 80 % in 2080, and 400 % by 2100

In µg/m3

9



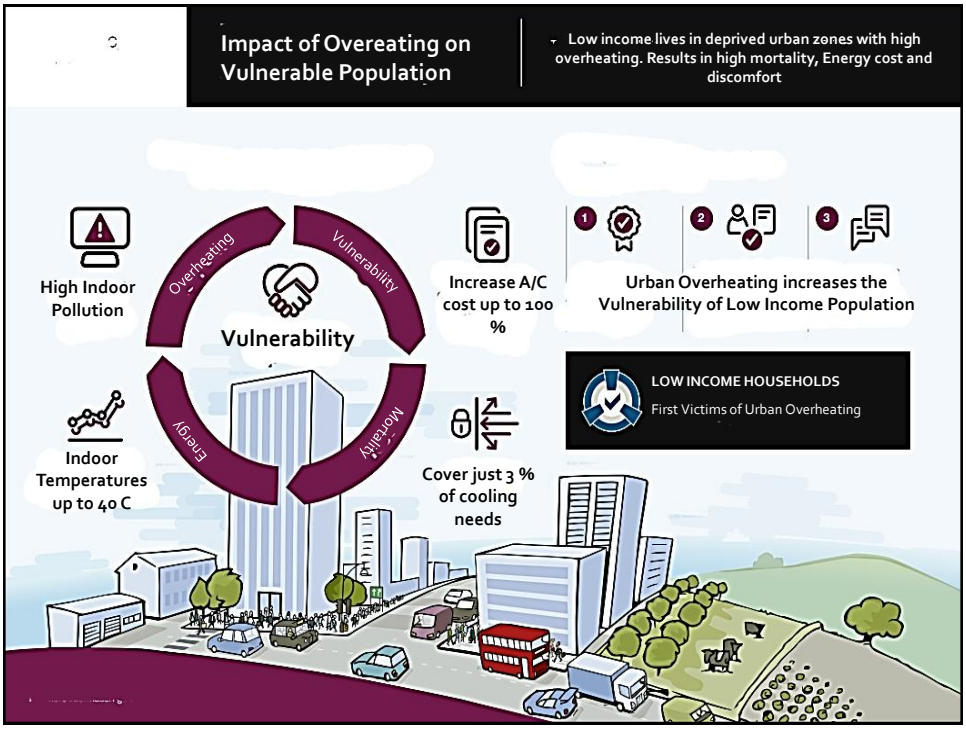
Increased emission of pollutants by power plants per degree of temperature increase

3.32%/°C ± 0.36%/°C increase in CO_2 emissions,

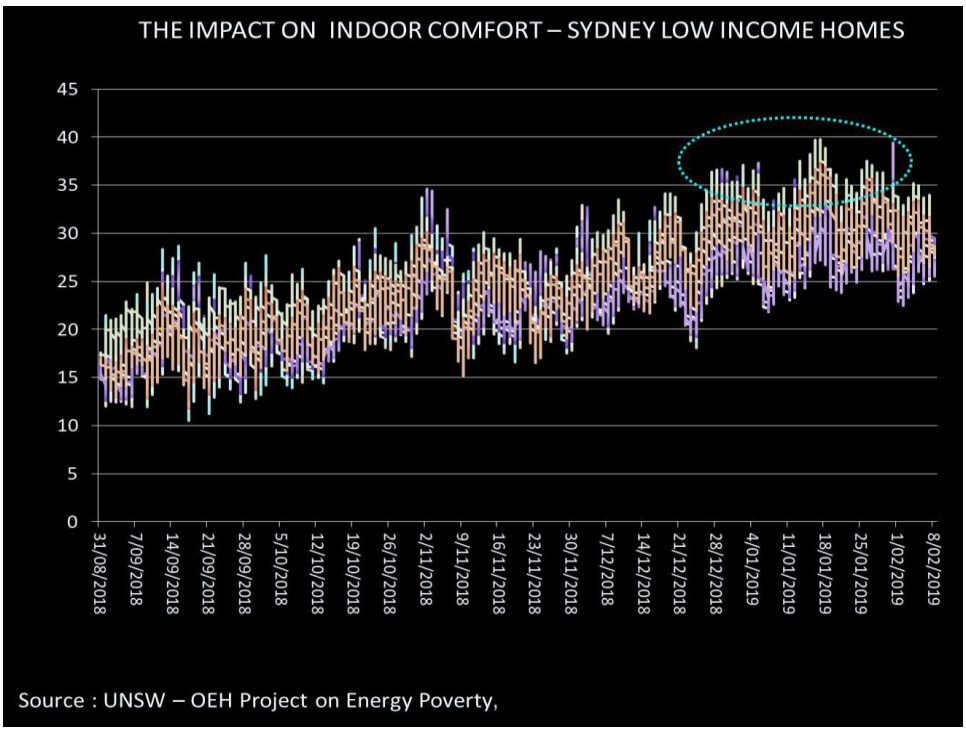
3.35%/°C ± 0.50%/°C increase in SO_2 emissions, and

3.60%/°C ± 0.49%/°C increase in NO_X emissions

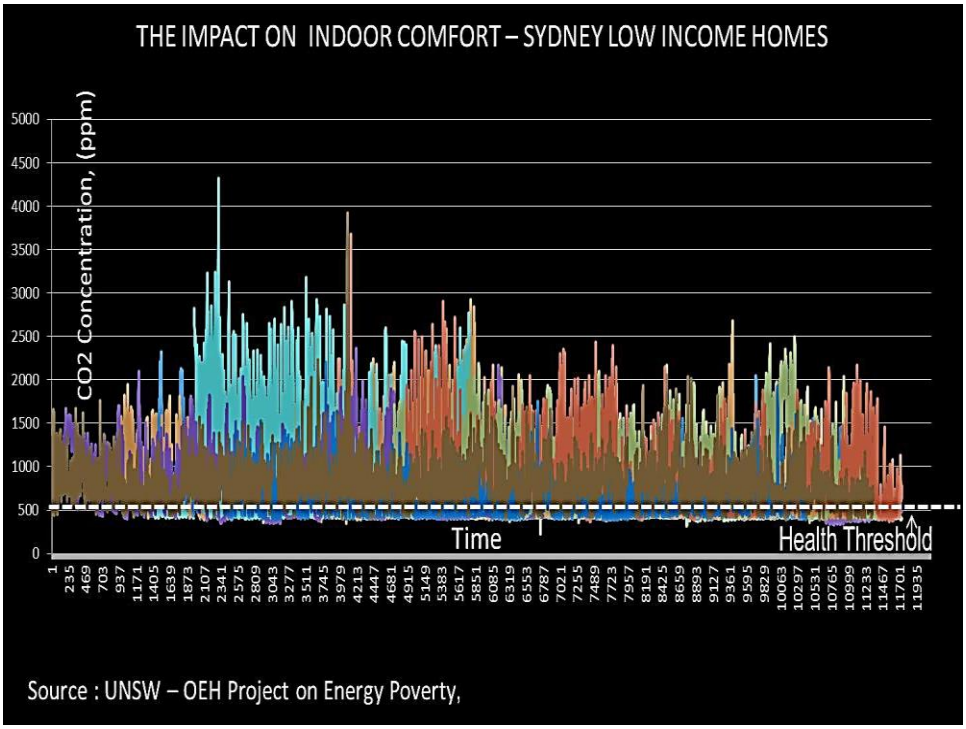
10


Impact of Overeating on Vulnerable Population
Low income lives in deprived urban zones with high overheating. Results in high mortality, Energy cost and discomfort
High Indoor Pollution
Overheating
Vulnerability
Vulnerability
Energy
Mortality
Indoor Temperatures up to 40 C
Increase A/C cost up to 100 %
Cover just 3 % of cooling needs
1
2
3
Urban Overheating increases the Vulnerability of Low Income Population
LOW INCOME HOUSEHOLDS
First Victims of Urban Overheating

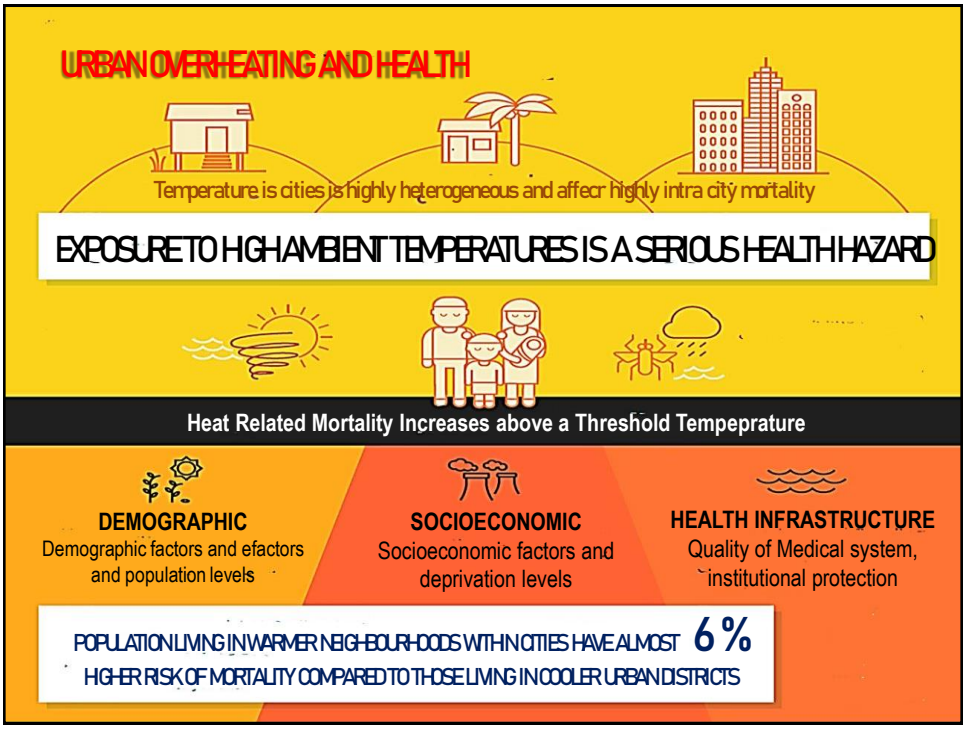
11


THE IMPACT ON INDOOR COMFORT – SYDNEY LOW INCOME HOMES
45
40
35
30
25
20
15
10
5
0
31/08/2018
7/09/2018
14/09/2018
21/09/2018
28/09/2018
5/10/2018
12/10/2018
19/10/2018
26/10/2018
2/11/2018
9/11/2018
16/11/2018
23/11/2018
30/11/2018
7/12/2018
14/12/2018
21/12/2018
28/12/2018
4/01/2019
11/01/2019
18/01/2019
25/01/2019
1/02/2019
8/02/2019
Source : UNSW – OEH Project on Energy Poverty,

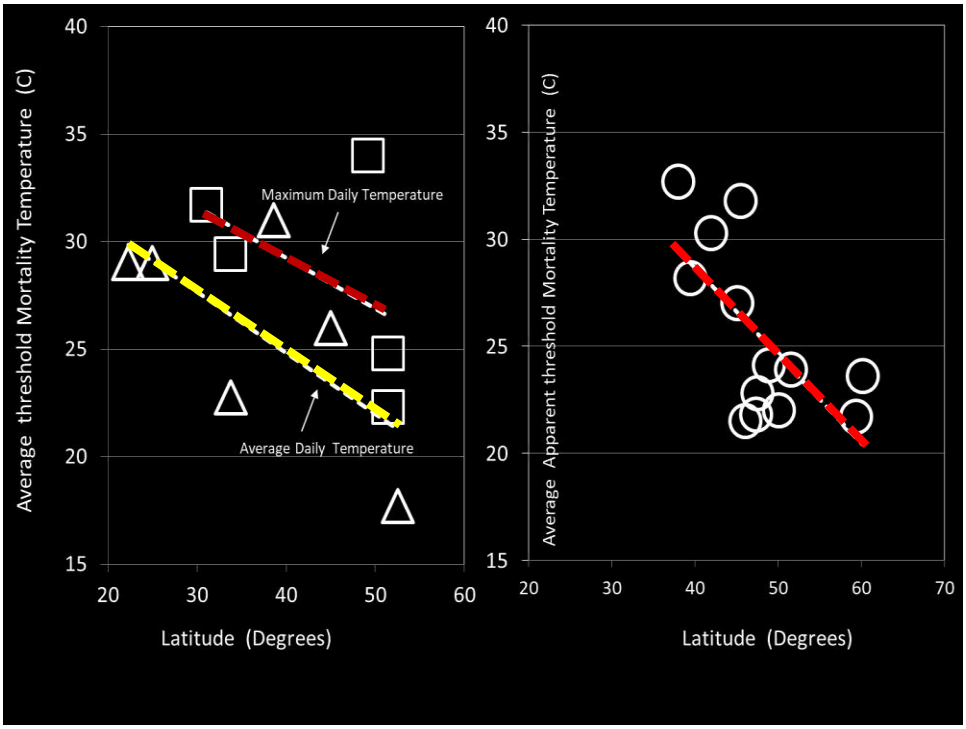
12


THE IMPACT ON INDOOR COMFORT – SYDNEY LOW INCOME HOMES
CO2 Concentration, (ppm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Time
Health Threshold
Source : UNSW – OEH Project on Energy Poverty,

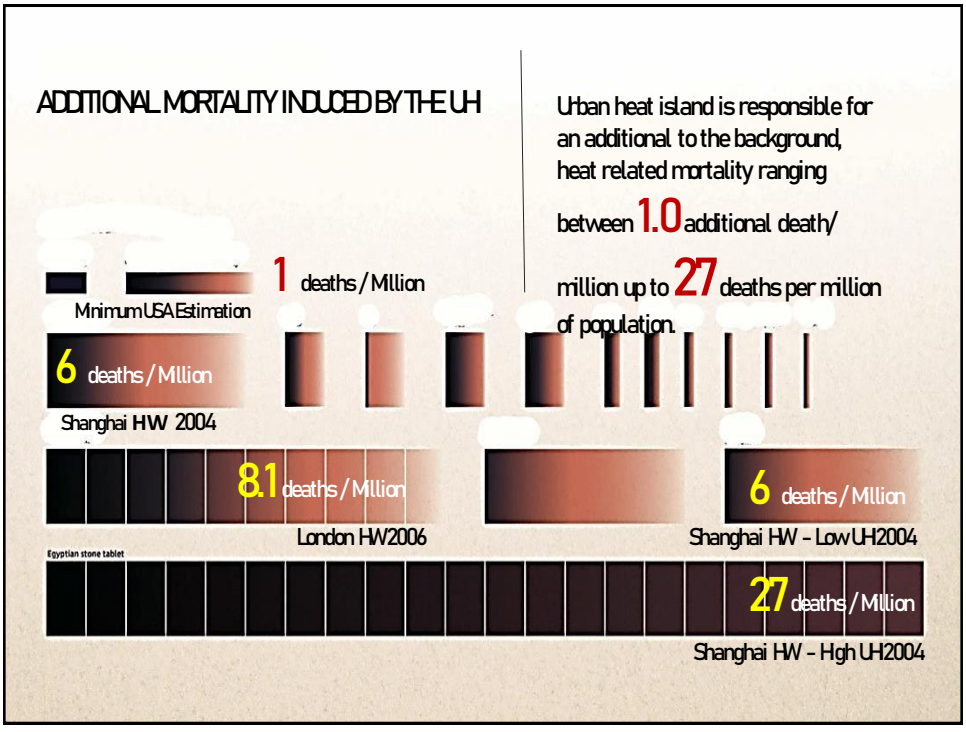
13


URBAN OVERHEATING AND HEALTH
Temperature is cities is highly heterogeneous and affecr highly intra city mortality
EXPOSURE TO HIGH AMBIENT TEMPERATURES IS A SERIOUS HEALTH HAZARD
Heat Related Mortality Increases above a Threshold Tempeprature
DEMOGRAPHIC
Demographic factors and efactors and population levels
SOCIOECONOMIC
Socioeconomic factors and deprivation levels
HEALTH INFRASTRUCTURE
Quality of Medical system, institutional protection
POPULATION LIVING IN WARMER NEIGHBOURHOODS WITHIN CITIES HAVE ALMOST 6 % HIGHER RISK OF MORTALITY COMPARED TO THOSE LIVING IN COOLER URBAN DISTRICTS

14


Average threshold Mortality Temperature (C)
40
35
30
25
20
15
Maximum Daily Temperature
Average Daily Temperature
20
30
40
50
60
Latitude (Degrees)
Average Apparent threshold Mortality Temperature (C)
40
35
30
25
20
15
20
30
40
50
60
70
Latitude (Degrees)

15


ADDITIONAL MORTALITY INDUCED BY THE UH
Urban heat island is responsible for an additional to the background, heat related mortality ranging between 1.0 additional death/ million up to 27 deaths per million of population.
1 deaths / Million
Minimum USA Estimation
6 deaths / Million
Shanghai HW 2004
8.1 deaths / Million
London HW2006
6 deaths / Million
Shanghai HW - Low UH2004
Egyptian stone tablet
27 deaths / Million
Shanghai HW - High UH2004

16

INTRA – URBAN VARIABILITY OF HEAT RELATED MORTALITY

Significant association between the mortality risk and the intensity of UH

Warmer neighbourhoods present a relatively higher mortality risk than the cooler ones. In addition, community attributes are correlated with demographic and socioeconomic factors, and differences between the various neighbourhoods affect highly the levels of mortality risk





Sao Paolo, HRM **30** % higher in urban zones with 2-4 C higher temperature

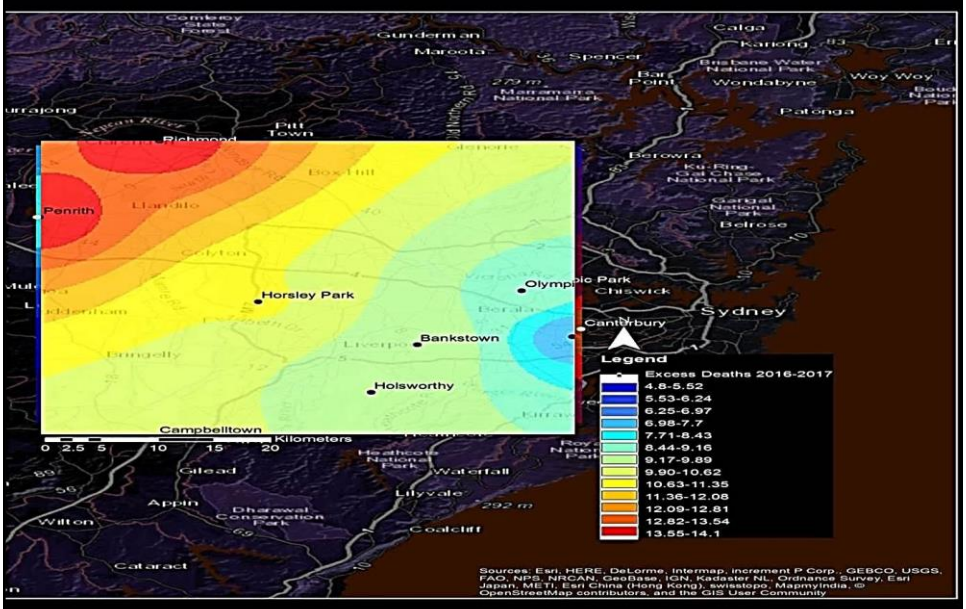
In HK, the additional mortality in the zones with a high and low UH was **4.1** % and **0.7** %

In Taiwan, the additional mortality in the warmer and cooler zones, was **4.2** % and **0.3** %

In Texas, the RR in the zones with high and low UH was **1.12** and **0.0** respectively

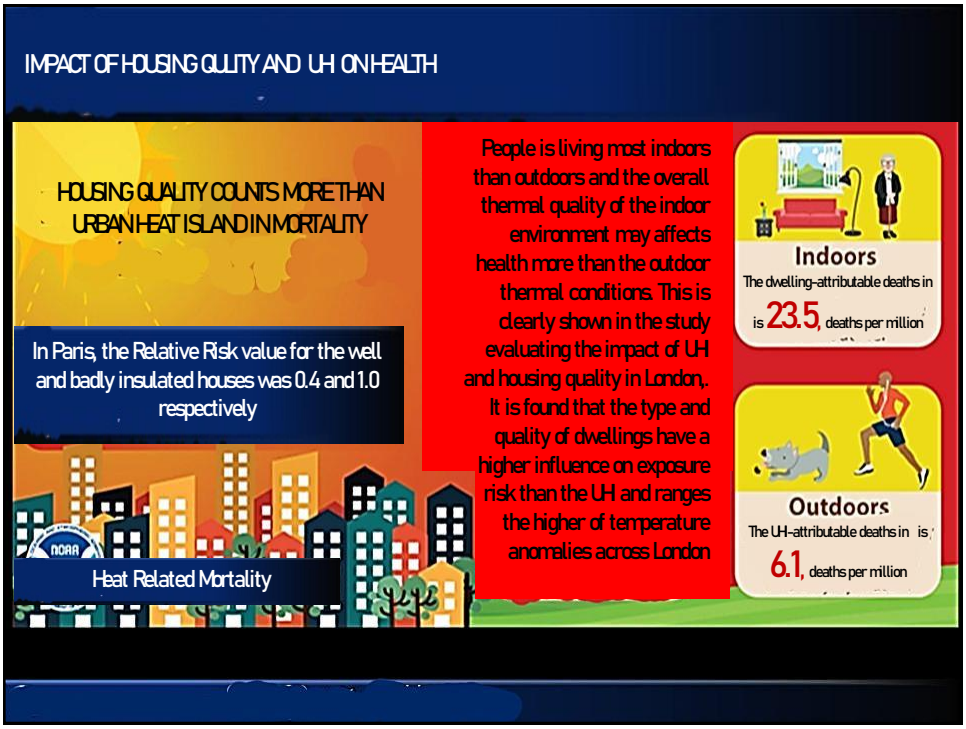
17

EXCESS DEADTHS PER 100000 INHABITANTS DURING THE SUMMER 2016-2017

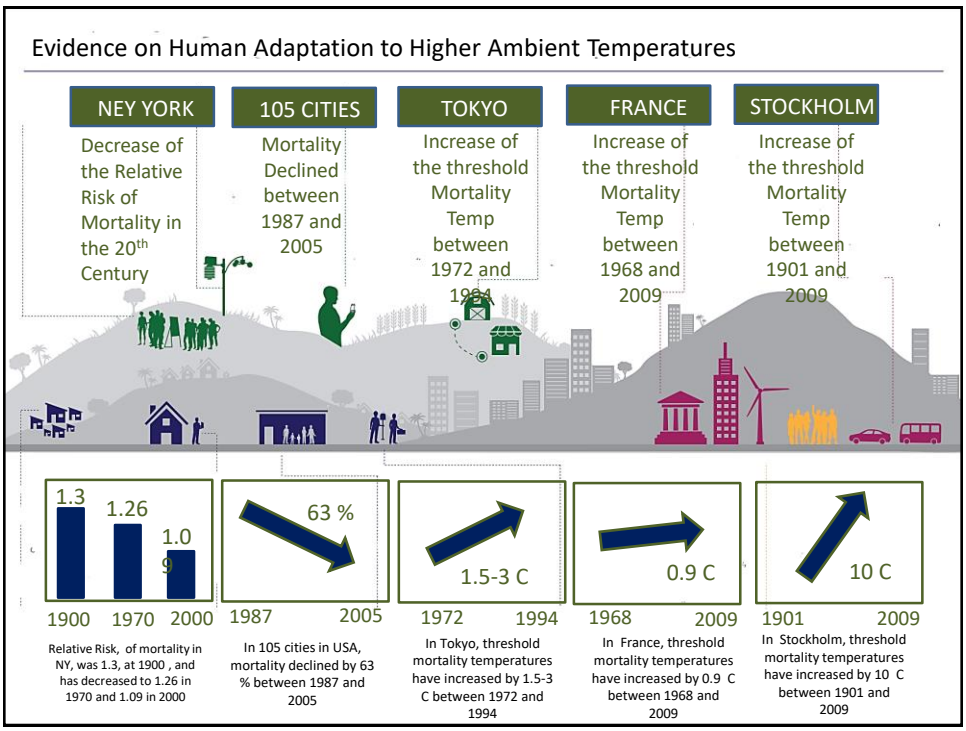


: CRC LCL : Heat Mitigation Study Western Sydney. Sydney Water, 2017

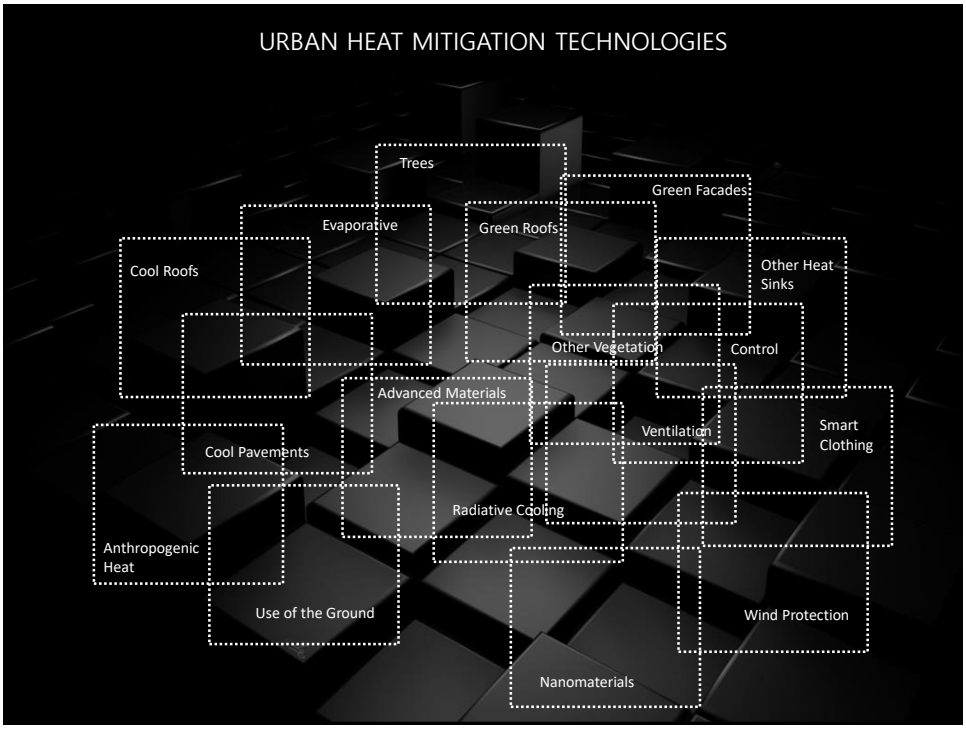
18


IMPACT OF HOUSING QULITY AND UHI ON HEALTH
HOUSING QUALITY COUNTS MORE THAN URBAN HEAT ISLAND IN MORTALITY
In Paris, the Relative Risk value for the well and badly insulated houses was 0.4 and 1.0 respectively
Heat Related Mortality
People is living most indoors than outdoors and the overall thermal quality of the indoor environment may affects health more than the outdoor thermal conditions. This is clearly shown in the study evaluating the impact of UHI and housing quality in London. It is found that the type and quality of dwellings have a higher influence on exposure risk than the UHI and ranges the higher of temperature anomalies across London
Indoors
The dwelling-attributable deaths in is 23.5, deaths per million
Outdoors
The UHI-attributable deaths in is 6.1, deaths per million

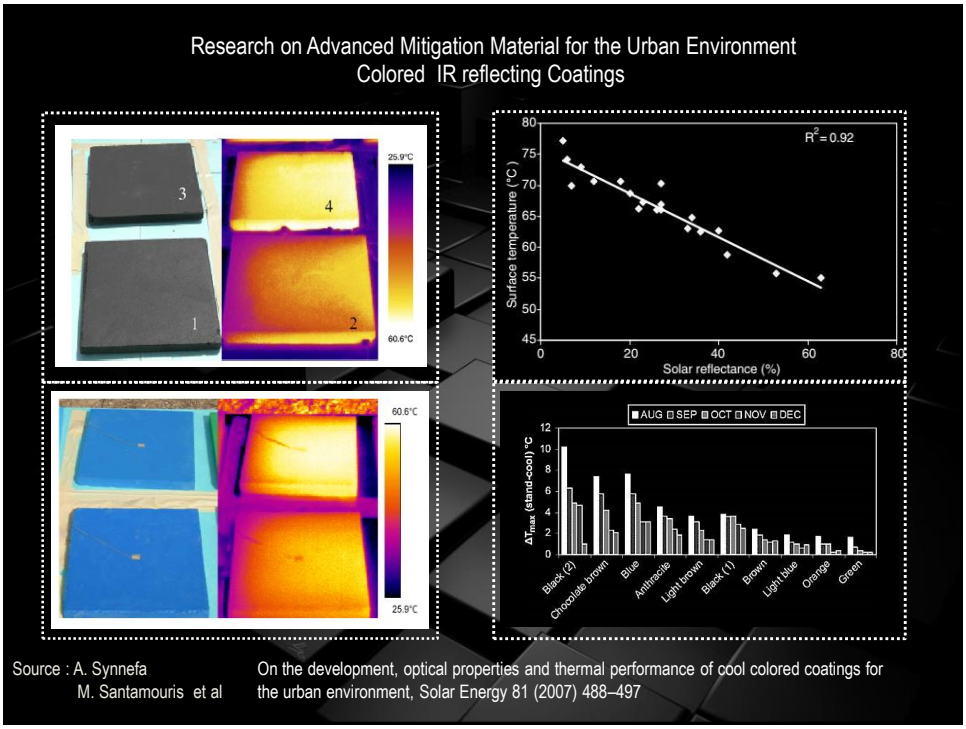
19


Evidence on Human Adaptation to Higher Ambient Temperatures
NEY YORK
Decrease of the Relative Risk of Mortality in the 20th Century
105 CITIES
Mortality Declined between 1987 and 2005
TOKYO
Increase of the threshold Mortality Temp between 1972 and 1994
FRANCE
Increase of the threshold Mortality Temp between 1968 and 2009
STOCKHOLM
Increase of the threshold Mortality Temp between 1901 and 2009
1.3
1.26
1.0
9
1900 1970 2000
Relative Risk, of mortality in NY, was 1.3, at 1900 , and has decreased to 1.26 in 1970 and 1.09 in 2000
63 %
1987 2005
In 105 cities in USA, mortality declined by 63 % between 1987 and 2005
1.5-3 C
1972 1994
In Tokyo, threshold mortality temperatures have increased by 1.5-3 C between 1972 and 1994
0.9 C
1968 2009
In France, threshold mortality temperatures have increased by 0.9 C between 1968 and 2009
10 C
1901 2009
In Stockholm, threshold mortality temperatures have increased by 10 C between 1901 and 2009

20


URBAN HEAT MITIGATION TECHNOLOGIES
Trees
Green Facades
Evaporative
Green Roofs
Cool Roofs
Other Heat Sinks
Other Vegetation
Control
Advanced Materials
Ventilation
Smart Clothing
Cool Pavements
Radiative Cooling
Anthropogenic Heat
Use of the Ground
Wind Protection
Nanomaterials

21


Research on Advanced Mitigation Material for the Urban Environment
Colored IR reflecting Coatings
25.9°C
60.6°C
3
4
1
2
60.6°C
25.9°C
Surface temperature (°C)
Solar reflectance (%)
R² = 0.92
AUG SEP OCT NOV DEC
ΔTmax (stand-cool) °C
Black (2)
Chocolate brown
Blue
Anthracite
Light brown
Black (1)
Brown
Light blue
Orange
Green
Source : A. Synnefa
M. Santamouris et al
On the development, optical properties and thermal performance of cool colored coatings for the urban environment, Solar Energy 81 (2007) 488–497

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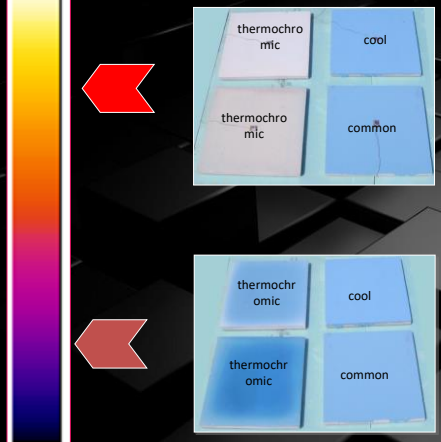
Research on Advanced Mitigation Material for the Urban Environment
Thermochromic Coatings



Thermochromic coatings change color as a function of the ambient temperature.

For low outdoor temperatures (winter), the coatings may be dark presenting a high absorptivity. For higher ambient temperatures (summer), the coating becomes white presenting a high reflectivity. Thus, when applied on roofs or walls they may present the best performance all year round.

Source : T. Karlessi, M. Santamouris· K. Apostolakis, A.Synnefa I. Livada : Development and Testing of Thermochromic coatings for Buildings and Urban Structures, Solar Energy, 2008

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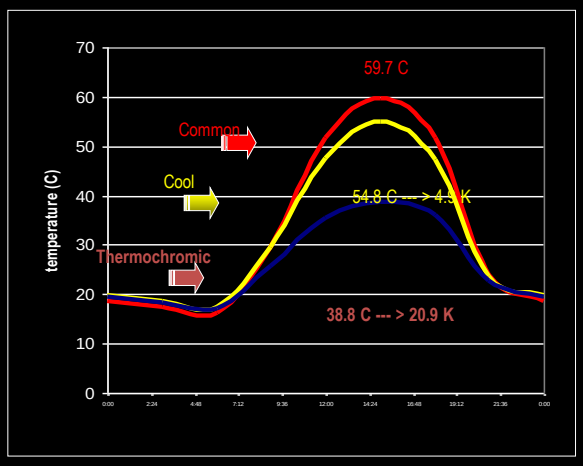
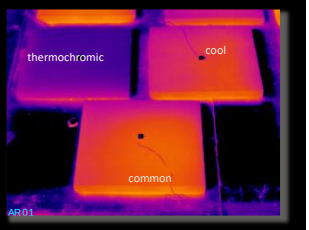
Research on Advanced Mitigation Material for the Urban Environment
Thermochromic Coatings



Black

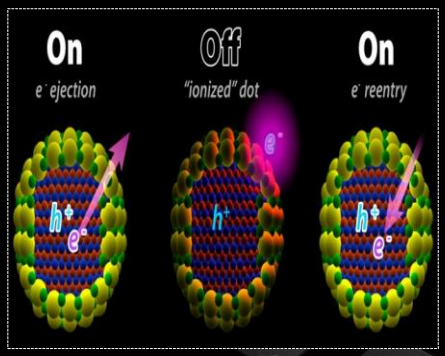


Source : T. Karlessi, M. Santamouris· K. Apostolakis, A.Synnefa I. Livada : Development and Testing of Thermochromic coatings for Buildings and Urban Structures, Solar Energy, 2008

24

Research on Advanced Mitigation Material for the Urban Environment
Use of Quantum Dots for Mitigation ?

Quantum dots (**QD**) are very small semiconductor particles, only several nanometers in size, so small that their optical and electronic properties differ from those of larger particles. They are a central theme in nanotechnology. Many types of quantum dot will emit light of specific frequencies if electricity or light is applied to them, and these frequencies can be precisely tuned by changing the dots' size, shape and material, giving rise to many applications.

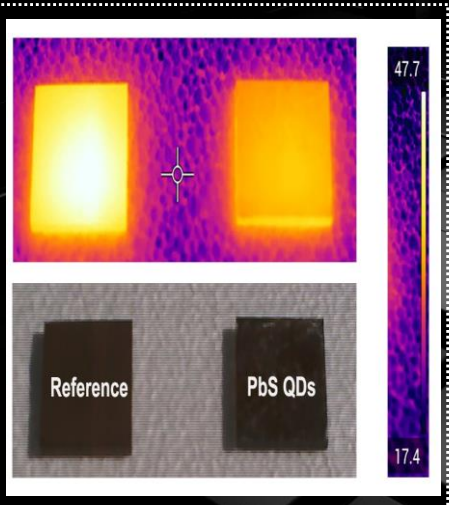


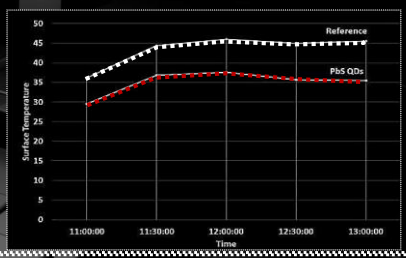


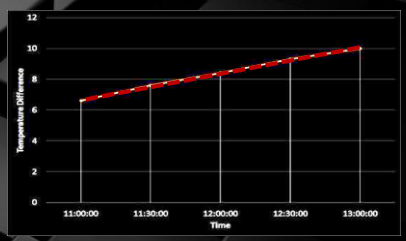
M. Santamouris and S. Garshasbi : Innovative New Generation Mitigation Technologies, SET 2018

25

Research on Advanced Mitigation Material for the Urban Environment
Use of Quantum Dots for Mitigation ?

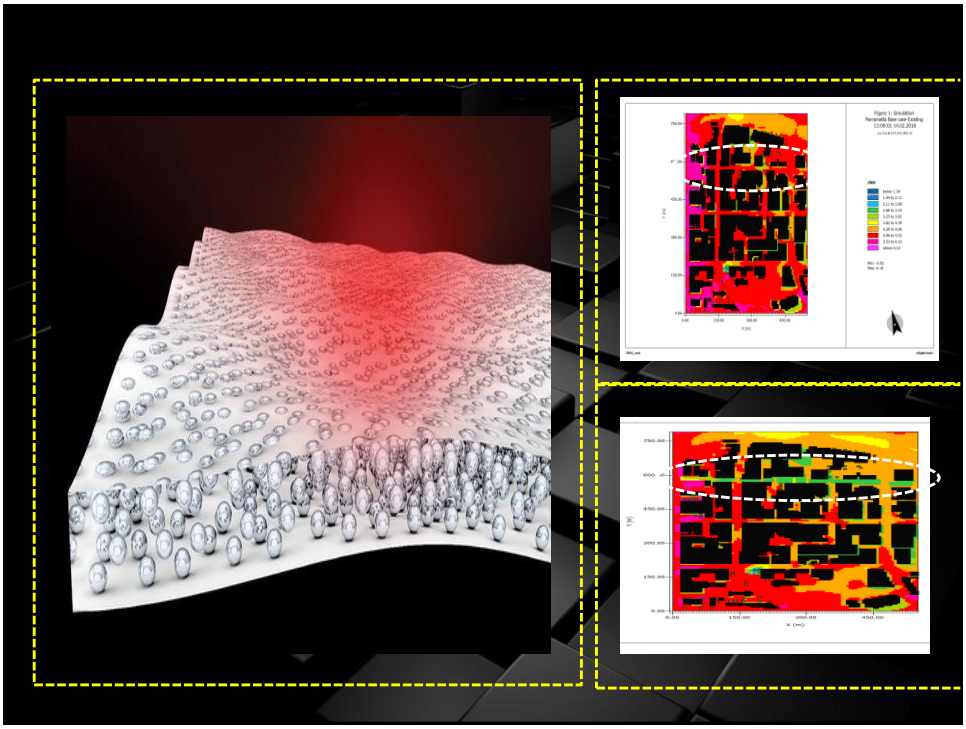




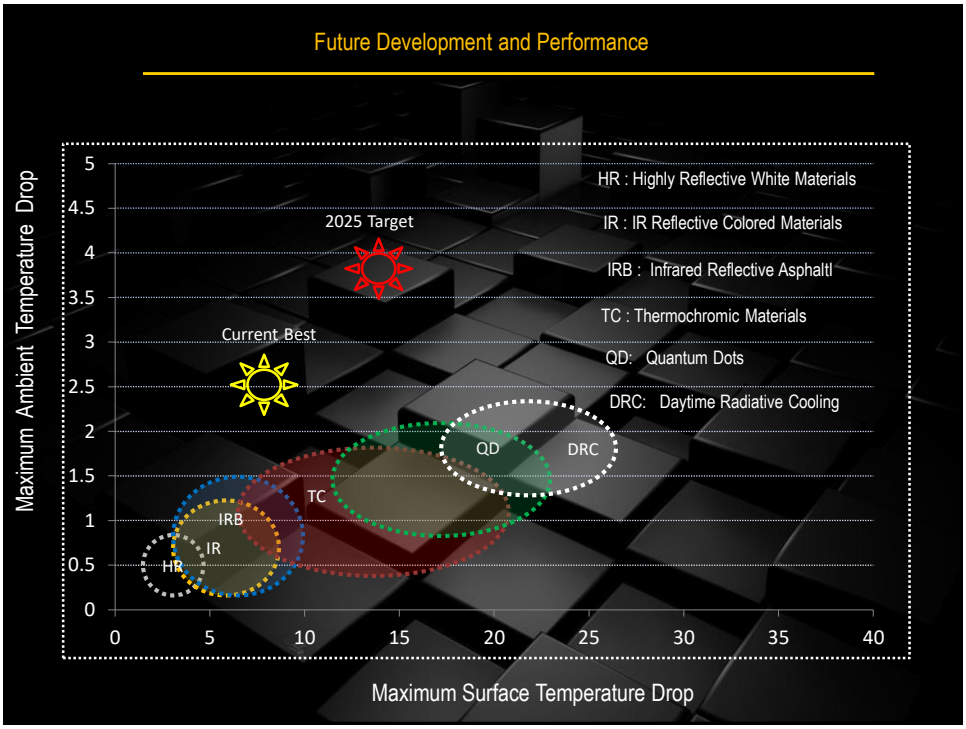


M. Santamouris and S. Garshasbi : Innovative New Generation Mitigation Technologies, SET 2018

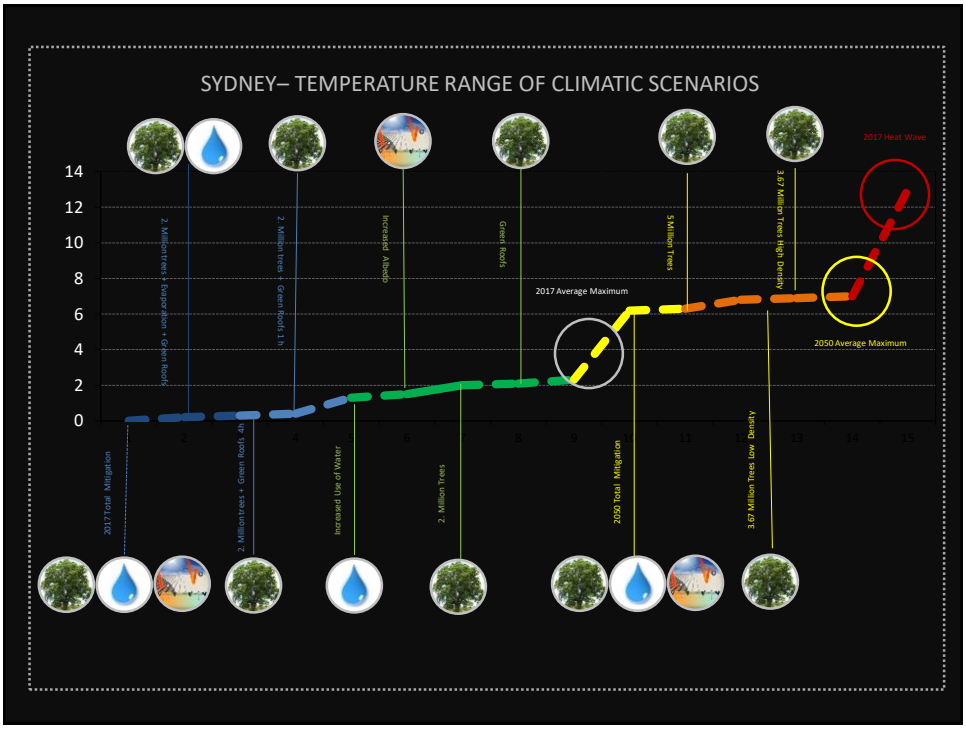
26



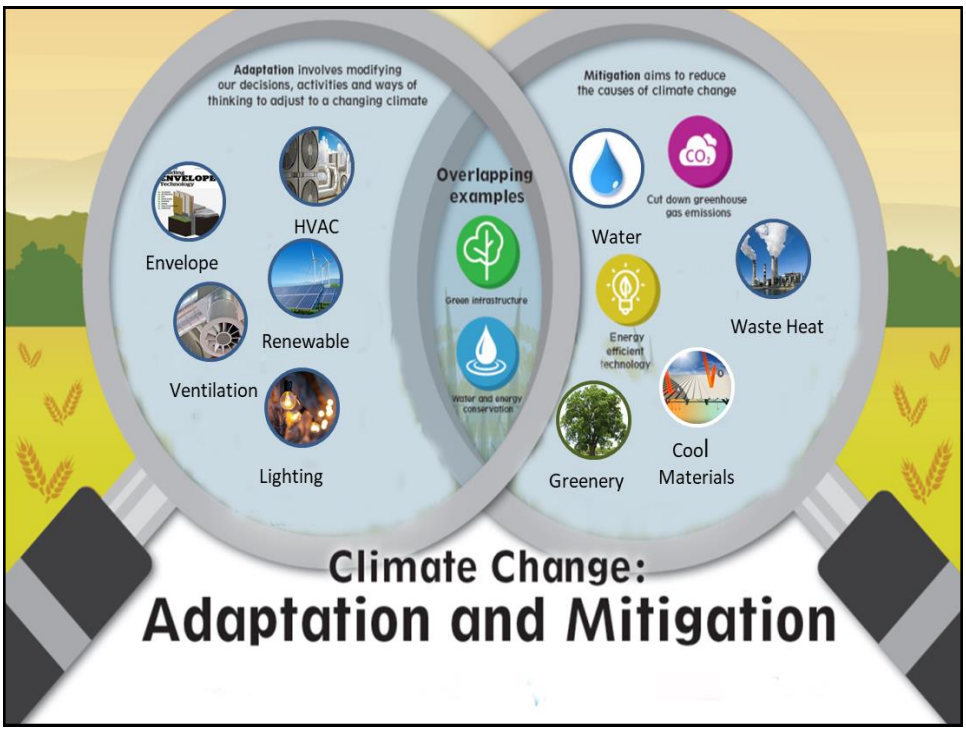
27


Future Development and Performance
Maximum Ambient Temperature Drop
Maximum Surface Temperature Drop
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
5
10
15
20
25
30
35
40
2025 Target
Current Best
HR
IR
IRB
TC
QD
DRC
HR : Highly Reflective White Materials
IR : IR Reflective Colored Materials
IRB : Infrared Reflective Asphaltl
TC : Thermochromic Materials
QD: Quantum Dots
DRC: Daytime Radiative Cooling

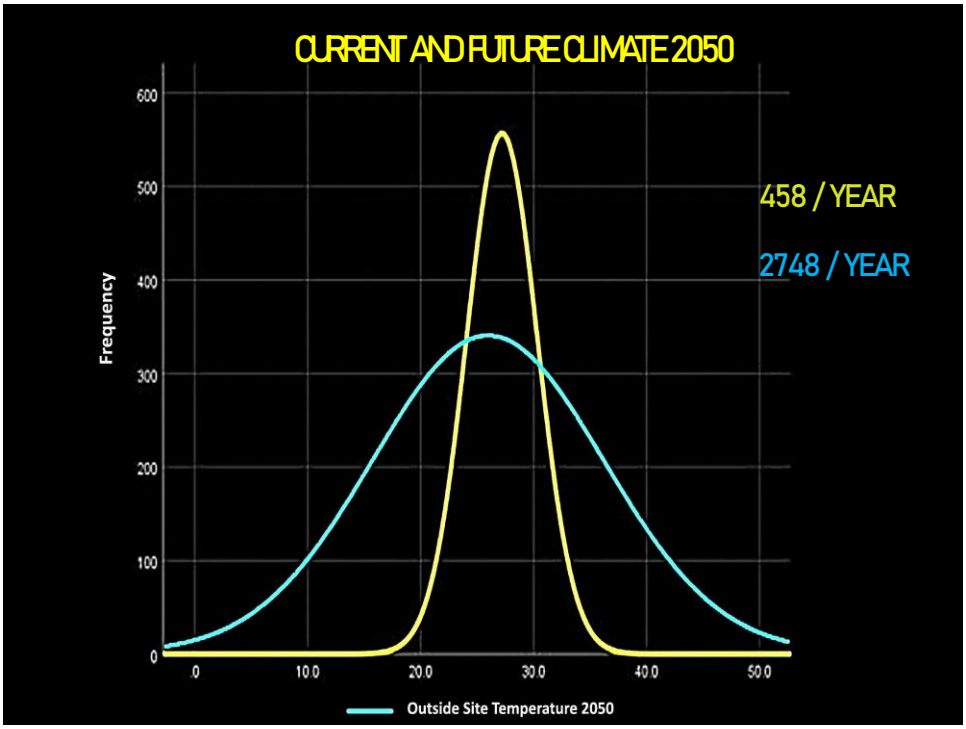
28


SYDNEY– TEMPERATURE RANGE OF CLIMATIC SCENARIOS
14
12
10
8
6
4
2
0
2017 Heat Wave
2017 Average Maximum
2050 Average Maximum
2. Million trees + Evaporation + Green Roofs
2. Million trees + Green Roofs 1 in
Increased Albedo
Green Roofs
5 Million Trees
3.67 Million Trees High Density
2017 Total Mitigation
2. Million trees + Green Roofs 4in
Increased Use of Water
2. Million Trees
2050 Total Mitigation
3.67 Million Trees Low Density

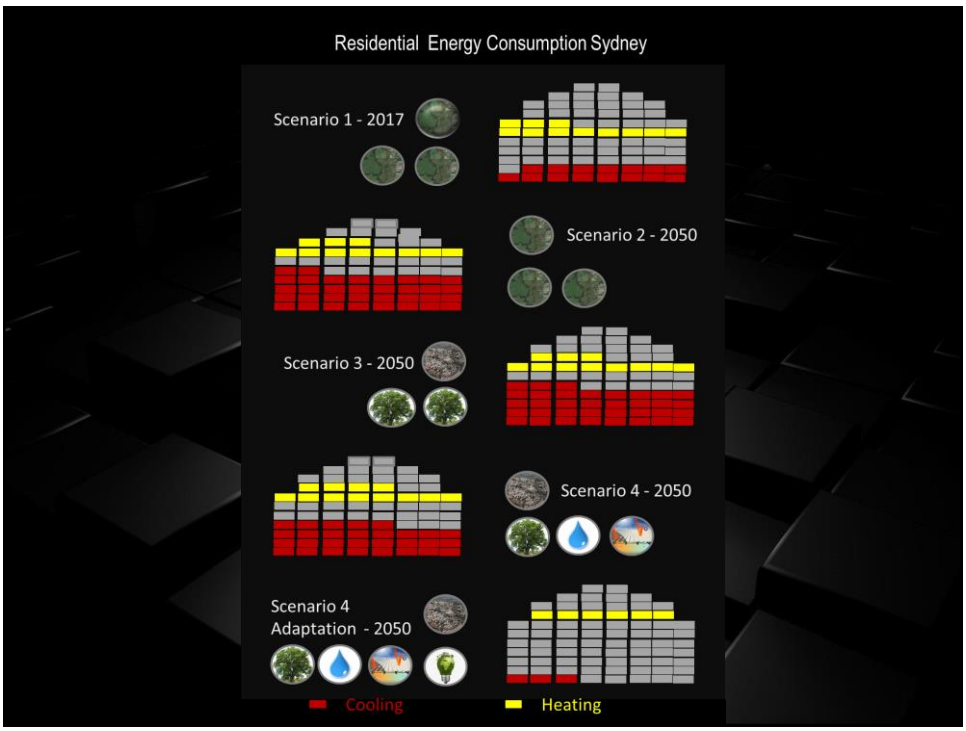
29


Adaptation involves modifying our decisions, activities and ways of thinking to adjust to a changing climate
Mitigation aims to reduce the causes of climate change
Overlapping examples
Envelope
HVAC
Renewable
Ventilation
Lighting
Green infrastructure
Water and energy conservation
Water
Cut down greenhouse gas emissions
Waste Heat
Energy efficient technology
Cool Materials
Greenery
Climate Change:
Adaptation and Mitigation

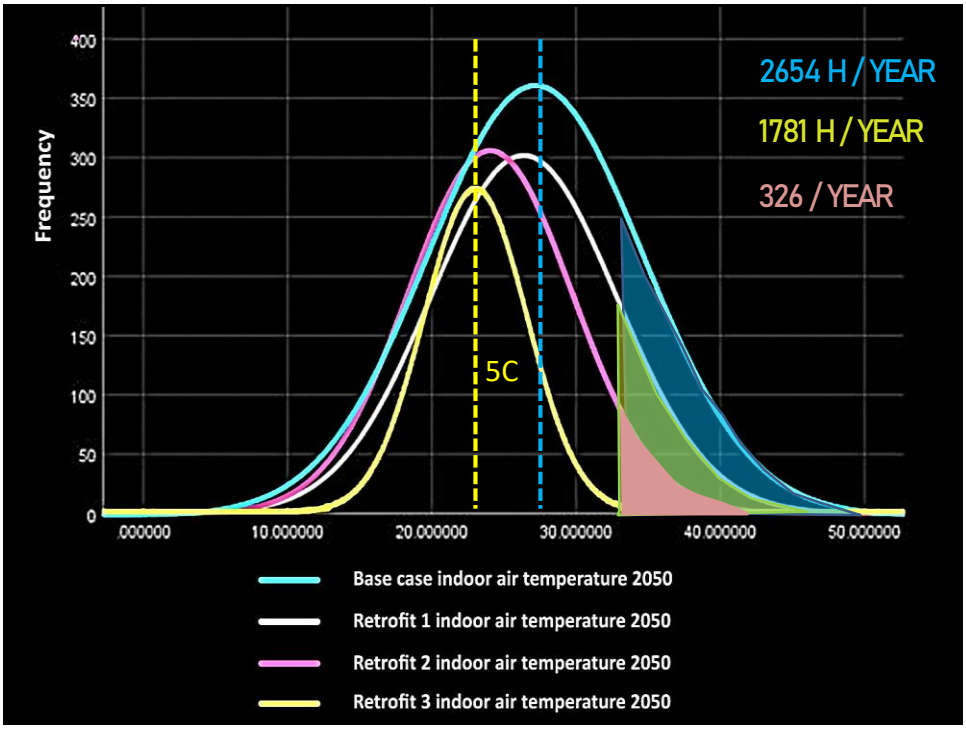
30


CURRENT AND FUTURE CLIMATE 2050
Frequency
600
500
400
300
200
100
0
.0
10.0
20.0
30.0
40.0
50.0
458 / YEAR
2748 / YEAR
Outside Site Temperature 2050

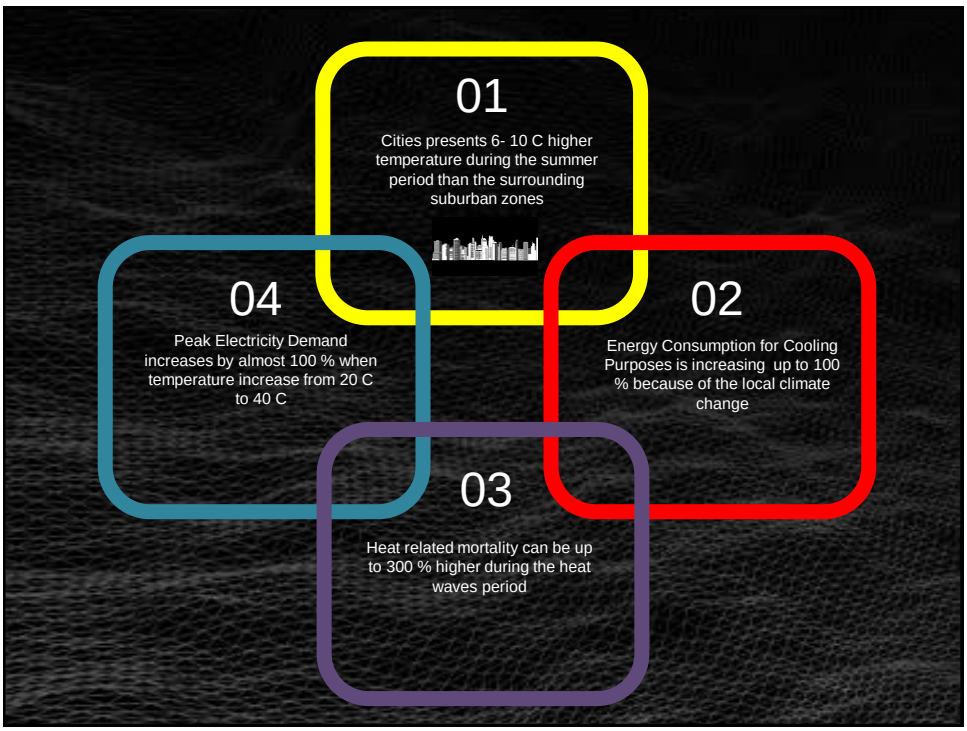
31


Residential Energy Consumption Sydney
Scenario 1 - 2017
Scenario 2 - 2050
Scenario 3 - 2050
Scenario 4 - 2050
Scenario 4
Adaptation - 2050
Cooling
Heating

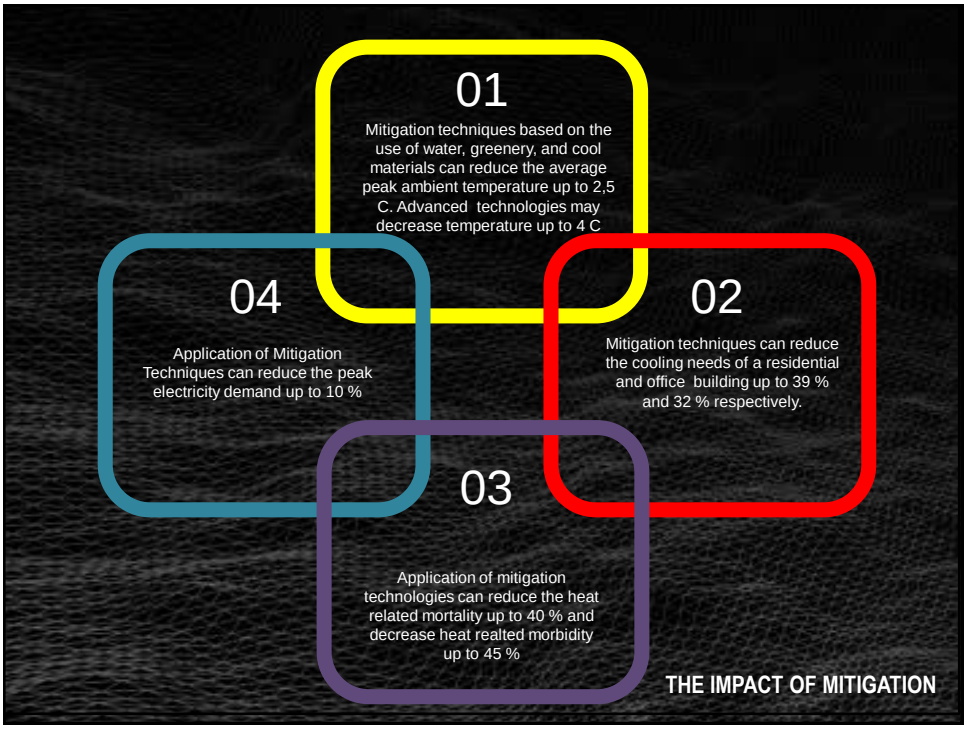
32


Frequency
400
350
300
250
200
150
100
50
0
.000000
10.000000
20.000000
30.000000
40.000000
50.000000
2654 H / YEAR
1781 H / YEAR
326 / YEAR
5C
Base case indoor air temperature 2050
Retrofit 1 indoor air temperature 2050
Retrofit 2 indoor air temperature 2050
Retrofit 3 indoor air temperature 2050

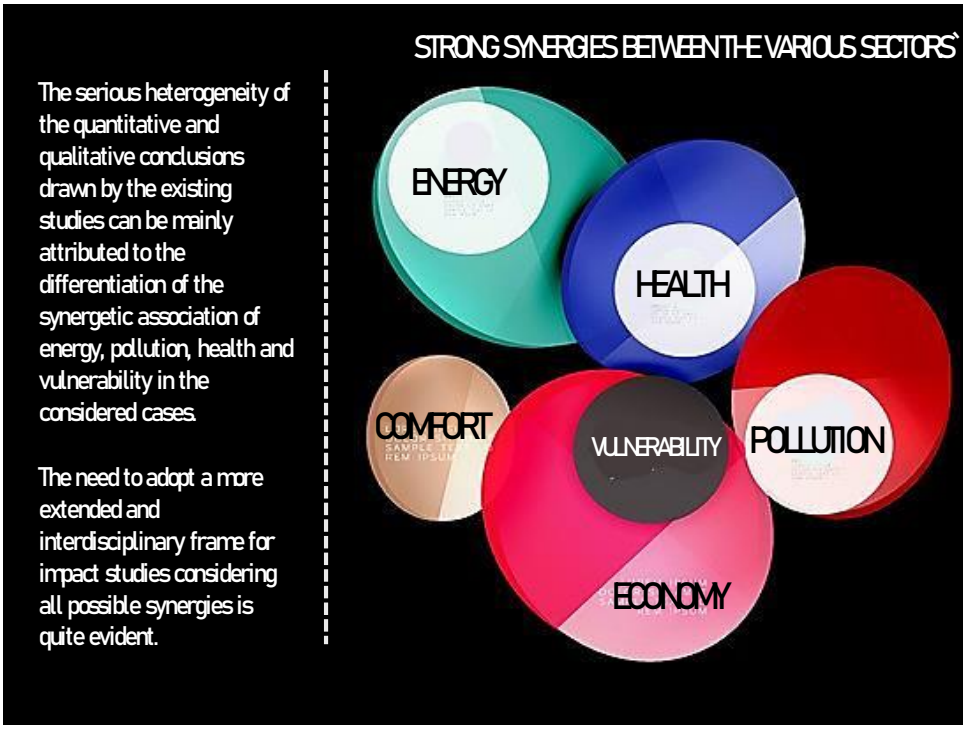
33


01
Cities presents 6- 10 C higher temperature during the summer period than the surrounding suburban zones
02
Energy Consumption for Cooling Purposes is increasing up to 100 % because of the local climate change
03
Heat related mortality can be up to 300 % higher during the heat waves period
04
Peak Electricity Demand increases by almost 100 % when temperature increase from 20 C to 40 C

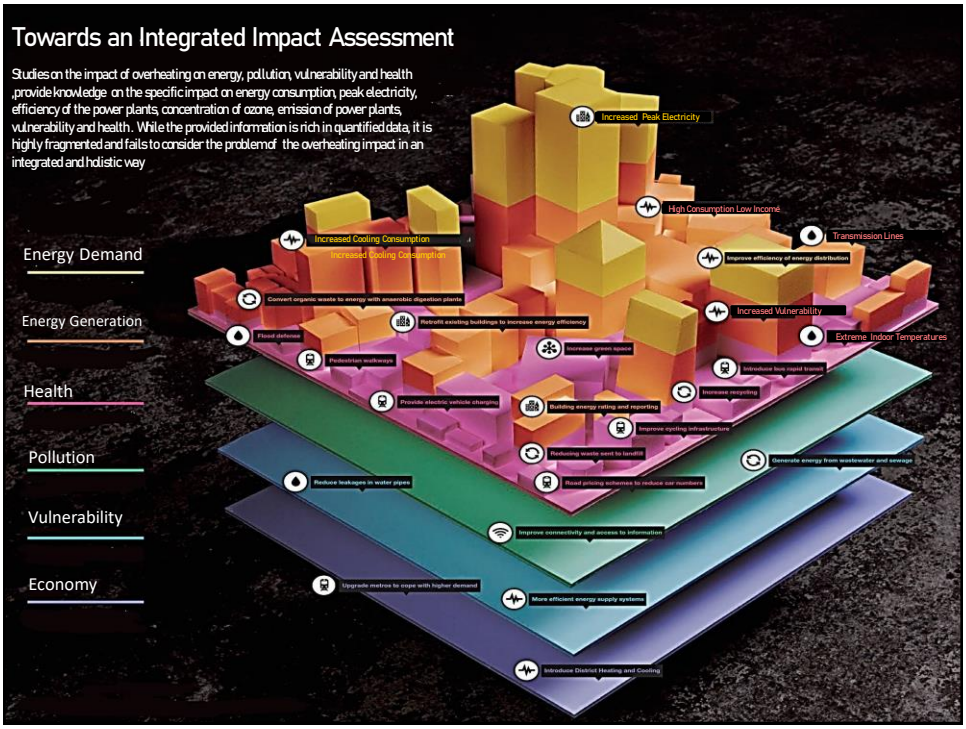
34


01
Mitigation techniques based on the use of water, greenery, and cool materials can reduce the average peak ambient temperature up to 2,5 C. Advanced technologies may decrease temperature up to 4 C
02
Mitigation techniques can reduce the cooling needs of a residential and office building up to 39 % and 32 % respectively.
03
Application of mitigation technologies can reduce the heat related mortality up to 40 % and decrease heat realted morbidity up to 45 %
04
Application of Mitigation Techniques can reduce the peak electricity demand up to 10 %
THE IMPACT OF MITIGATION

35


STRONG SYNERGIES BETWEEN THE VARIOUS SECTORS`
The serious heterogeneity of the quantitative and qualitative conclusions drawn by the existing studies can be mainly attributed to the differentiation of the synergetic association of energy, pollution, health and vulnerability in the considered cases.
The need to adopt a more extended and interdisciplinary frame for impact studies considering all possible synergies is quite evident.
ENERGY
HEALTH
COMFORT
VULNERABILITY
POLLUTION
ECONOMY

36


Towards an Integrated Impact Assessment
Studies on the impact of overheating on energy, pollution, vulnerability and health ,provide knowledge on the specific impact on energy consumption, peak electricity, efficiency of the power plants, concentration of ozone, emission of power plants, vulnerability and health. While the provided information is rich in quantified data, it is highly fragmented and fails to consider the problem of the overheating impact in an integrated and holistic way
Energy Demand
Energy Generation
Health
Pollution
Vulnerability
Economy
Increased Peak Electricity
High Consumption Low Income
Transmission Lines
Increased Cooling Consumption
Improve efficiency of energy distribution
Convert organic waste to energy with anaerobic digestion plants
Increased Vulnerability
Retrofit existing buildings to increase energy efficiency
Extreme Indoor Temperatures
Flood defense
Increase green space
Pedestrian walkways
Introduce bus rapid transit
Increase recycling
Provide electric vehicle charging
Building energy rating and reporting
Improve cycling infrastructure
Reducing waste sent to landfill
Generate energy from wastewater and sewage
Reduce leakages in water pipes
Road pricing schemes to reduce car numbers
Improve connectivity and access to information
Upgrade metros to cope with higher demand
More efficient energy supply systems
Introduce District Heating and Cooling

CURIEUZE NEUZEN

Curious Noses

Sam De Craemer - University of Antwerp

Universiteit Antwerpen

dS De Standaard

VLAAMSE MILIEUMAATSCHAPPIJ

Vlaanderen is milieu

KU LEUVEN HIVA RESEARCH INSTITUTE FOR WORK AND SOCIETY

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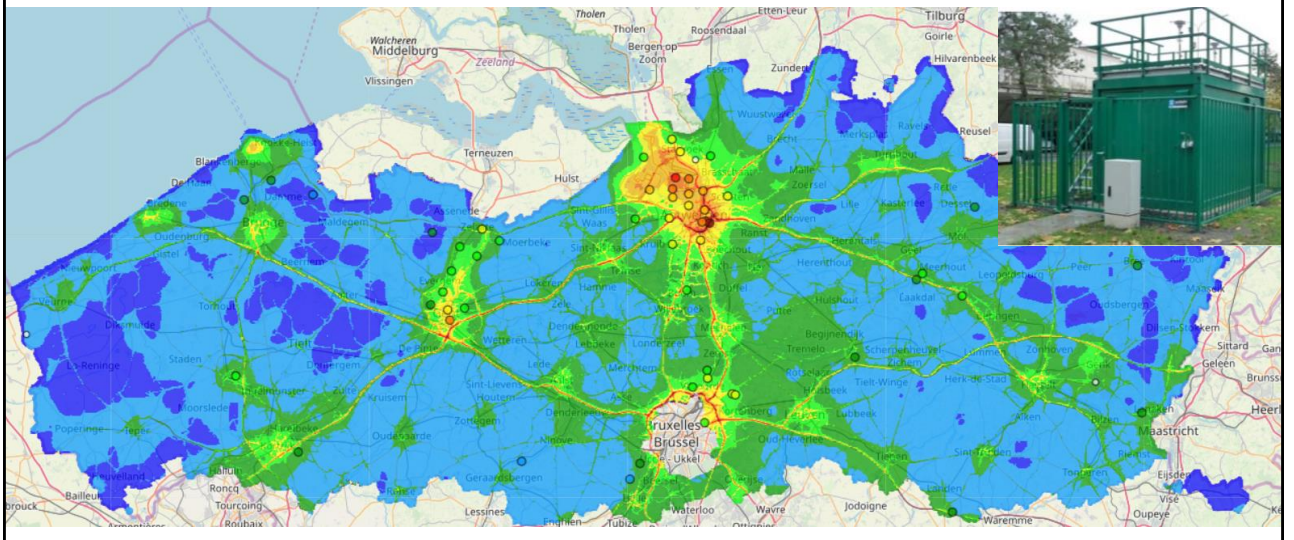
1

Problem 1: Ambient air quality monitoring in Flanders



VMM measurements + VITO's ATMO Street model

2

Measurement data



Meteo data



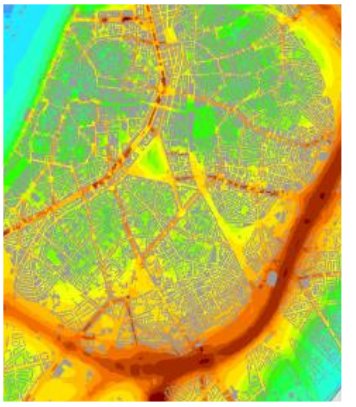
Traffic data



Computer model



Computer air quality map



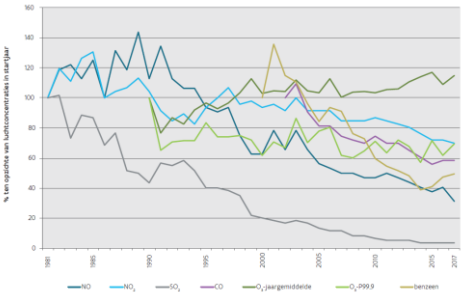
How reliable are these maps for Flanders?
How to gather dense dataset?

3

Problem 2) Meanwhile: fatalism at the bar counter…

Air pollution is getting worse





All pollution comes from industry

4

CurieuzeNeuzen: 20,000 citizens measure air quality





Citizen
Outreach
Inform
Sensibilize

Science
Dense, quality data
Model validation

5

5

Why traffic? Why NO2?

European Environment Agency

Highest impact pollutants

Nitrogen dioxide

61 %	18 %	7 %
VERKEER	INDUSTRIE	LAND- EN TUINBOUW

Particulate matter

57 %	21 %	15 %
HUISHOUDENS	VERKEER	INDUSTRIE

Ozone

39 %	25 %	11 %
VERKEER	INDUSTRIE	LAND- EN TUINBOUW

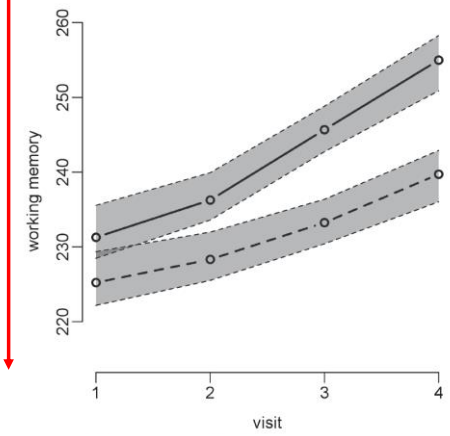
6

6

Why NO2? NO2 and health

Long term elevated exposure

Reduced memory



NO_2 µg/m^3

40.5
Low concentration schools

56.1
High concentration schools

Sunyer et al. PLOS Med 2015

Short term, smog event



Argacha et al. (2016) Int J Cardiology



Casas et al. (2016) Environ Int

Why NO2: measurement

Sensors: PM, NO2



Not simple => everybody should be able to do it
Cheap OR robust

Diffusive Palmes sampler: NO2



Simple, cheap and robust method

Measurement setup: standardized and easy to use



And Extra outreach

Recruitment: multi-mediacampagne



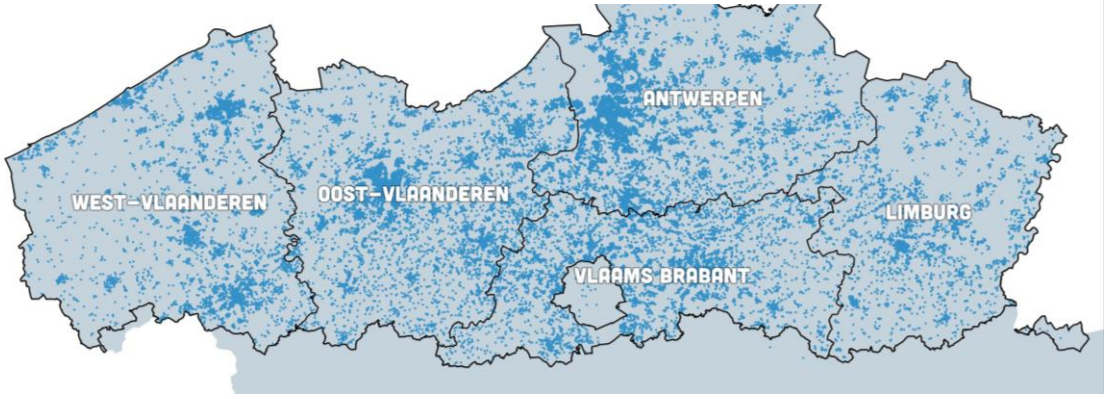
- Print media
- Film theaters
- Nationale Radio
- Nationale TV
- Publiek domein (bussen…)
- Sociale media

Recruiting message
- Curiosity: How healthy air in your street?
- Community: Participate the largest CS AQ project
- Simplicity: It is simple

CURIEUZE NEUZEN VLAANDEREN

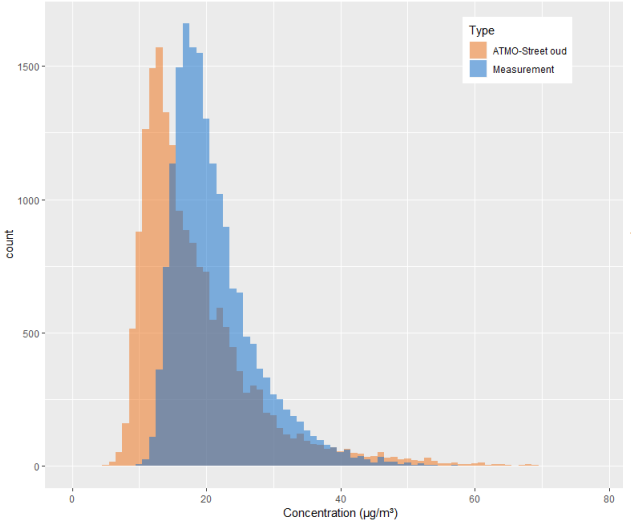


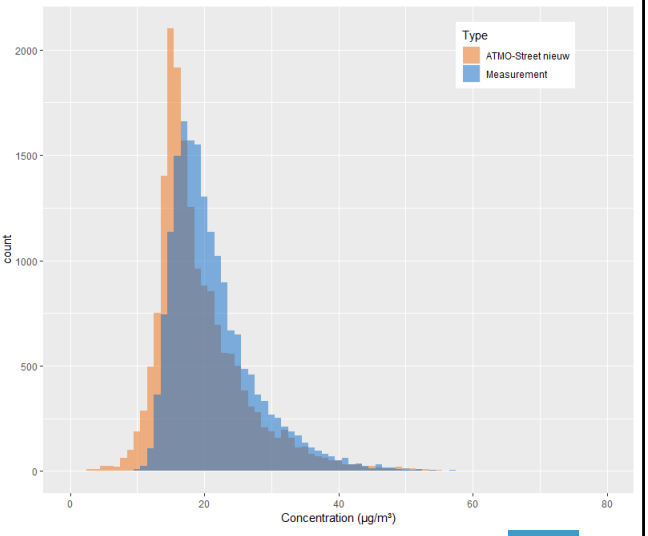
967 schools
597 government
920 companies and organisations
49.778 families



11

Results: the model



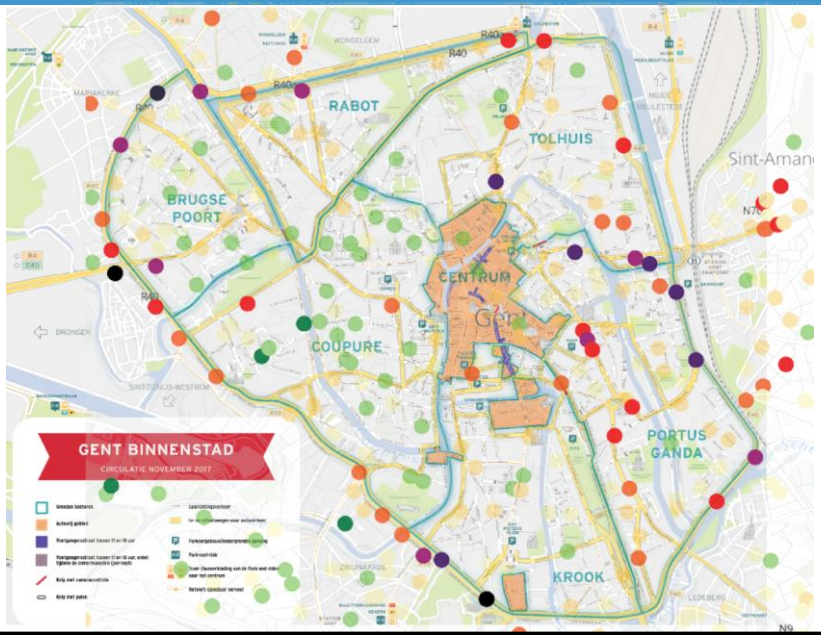


Model performed well and was improved: https://www.vmm.be/data/luchtkwaliteit-in-je-eigen-omgeving

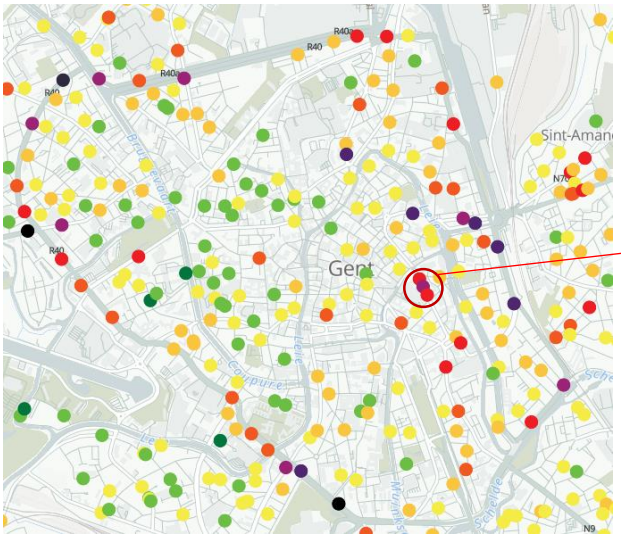
12

12

Impact of traffic: circulation plan



Impact of traffic: street canyons





Tips for ventilation



Avoid taking in outside pollution

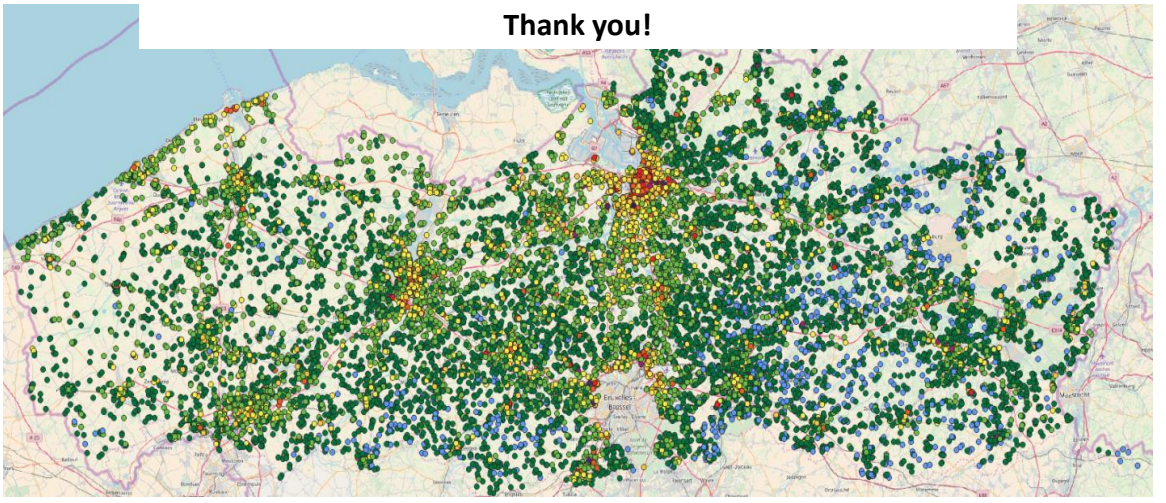
- Do not ventilate on street side (or near other likely pollution sources). Especially in busy roads or canyons
- Avoid ventilating during rush hours
- Avoid ventilating during smog events

Better indoor air quality =>
living in cities more attractive
Stronger urban cores => less distance
=> Less air pollution

15

15

Thank you!



Universiteit Antwerpen

dS De Standaard

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Vlaanderen is milieu

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16

16

Industry views
on the future of ventilation

1

EVIA Members

Companies

AERECO, aldes, atlantic, Airea, BELIMO, BOSCH Invented for life, BRINK, camfil, core, DAIKIN, ebmpapst, Elektrovent, eg ELTA GROUP, filtech, FIME, FläktWoods, Helios air technology, Honeywell, Hoval, itho daalderop, MAICO, MULTI-WING, MITSUBISHI ELECTRIC, NICOTRA Gebhardt, punker, RENSON, rosenberg, ruck, SIG AIR HANDLING, Soler&Palau, STIEBEL ELTRON, systemair, torin-sifan, TROX TECHNIK, Venture Industries, VORTICE, VOSTERMANS VENTILATION, WITT&SOHN, WOLF, zehnder, ZIEHL-ABEGG

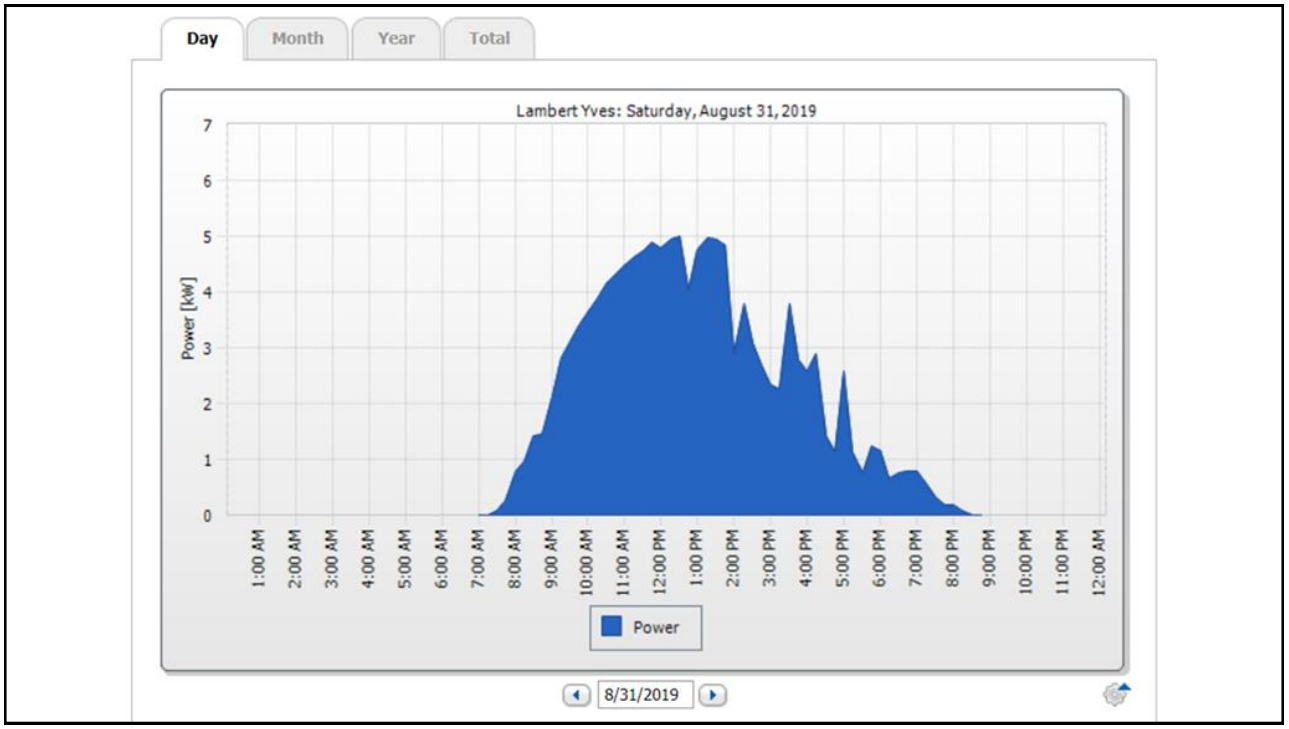
Associations

beama, FGK, FETA, RLT, Stowarzyszenie Polska Wentylacja, Uniclima

2

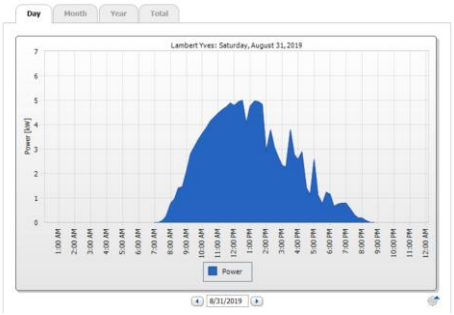

Why do I believe in solar panels ?

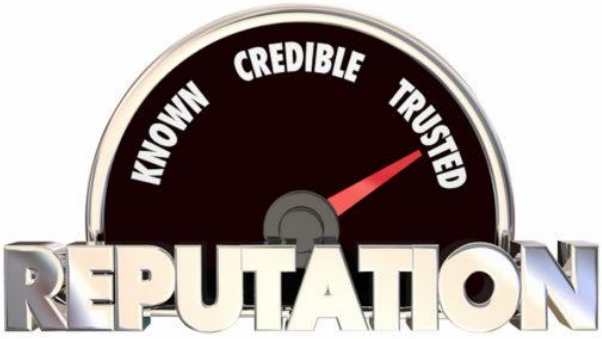
3


Day
Month
Year
Total
Lambert Yves: Saturday, August 31, 2019
Power [kW]
0
1
2
3
4
5
6
7
1:00 AM
2:00 AM
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
10:00 AM
11:00 AM
12:00 PM
1:00 PM
2:00 PM
3:00 PM
4:00 PM
5:00 PM
6:00 PM
7:00 PM
8:00 PM
9:00 PM
10:00 PM
11:00 PM
12:00 AM
Power
8/31/2019

4

Live monitoring & historical data





- Direct link to the system
- Live monitoring
- Proves that it works (because you cannot see it work)
- Shows the actual performance
- Gives confidence in the technology



5

Ventilation = credible/trusted ?



6



7



8

Provide Factual Proof

Facts eliminate objections and protests

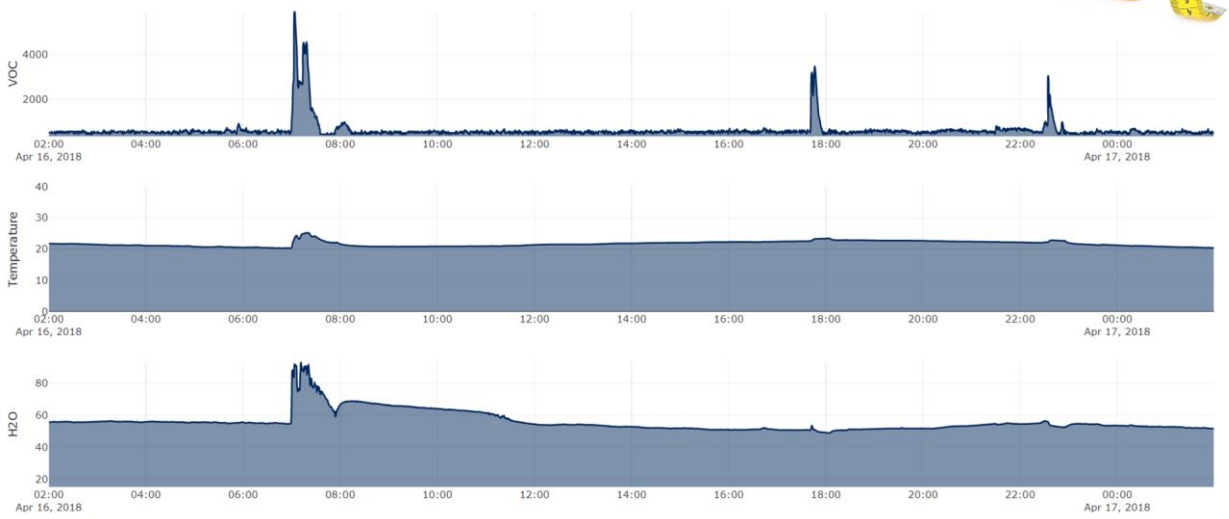
9



10

Live IAQ monitoring & historical data





11

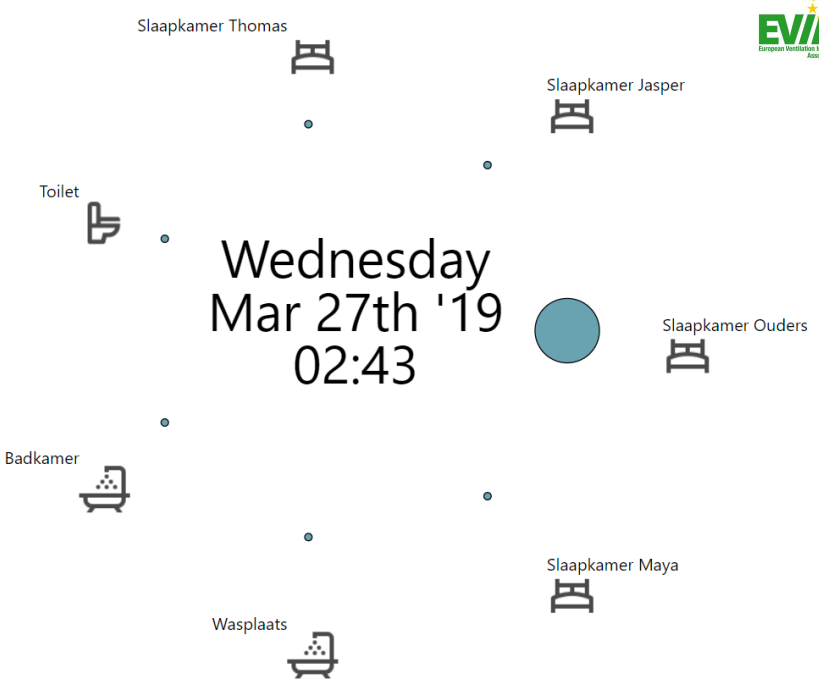
Live energy performance monitoring & historical data



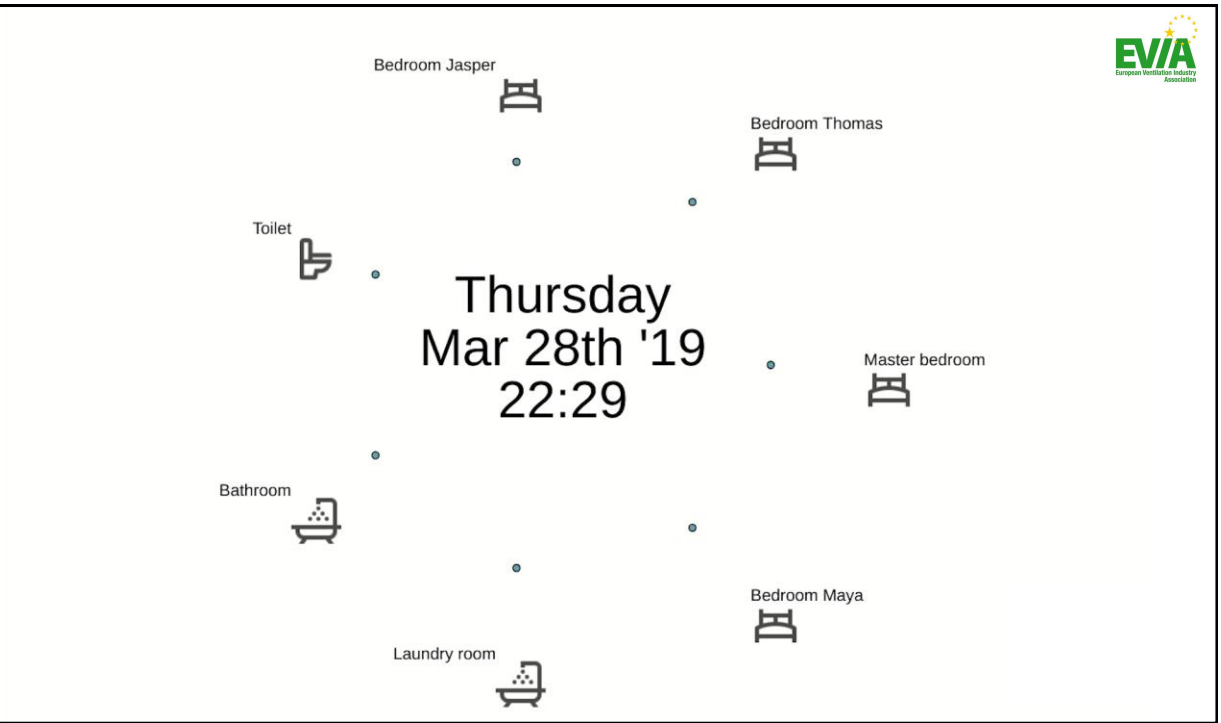
12

Beyond IAQ/energy



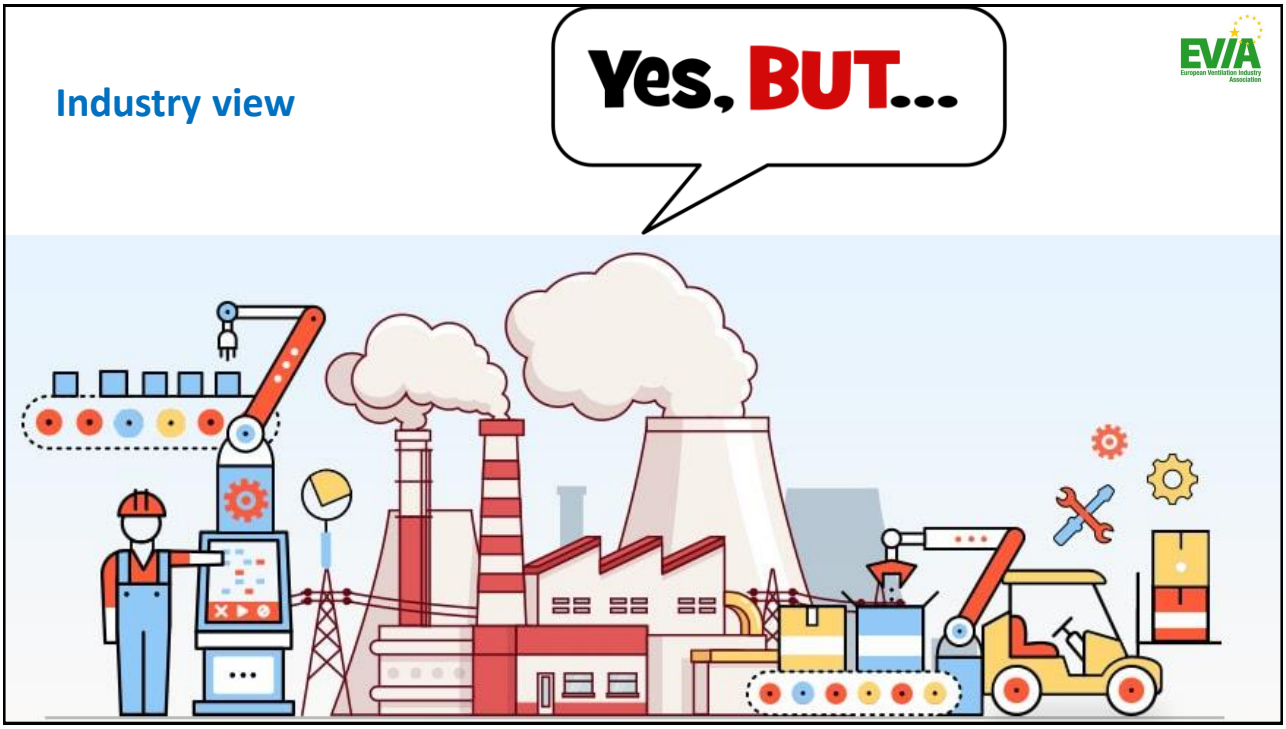


13



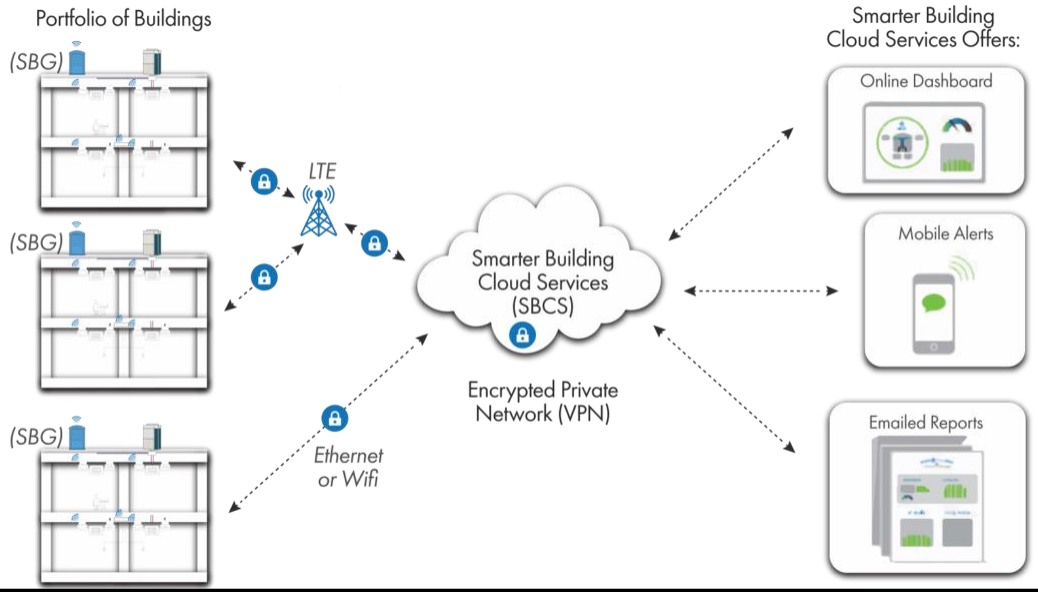
14

Industry view



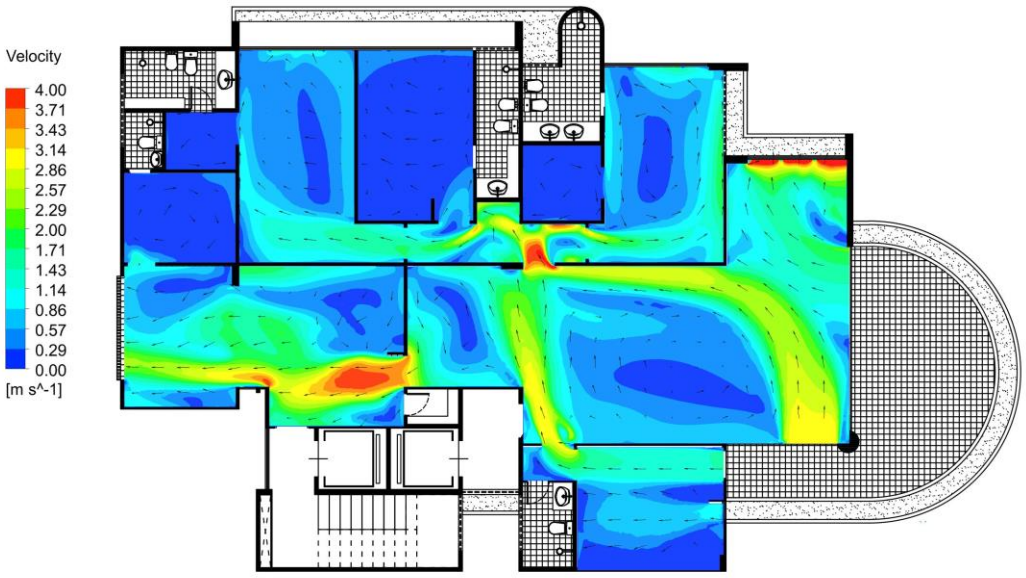
15

Serious efforts in time & investment required



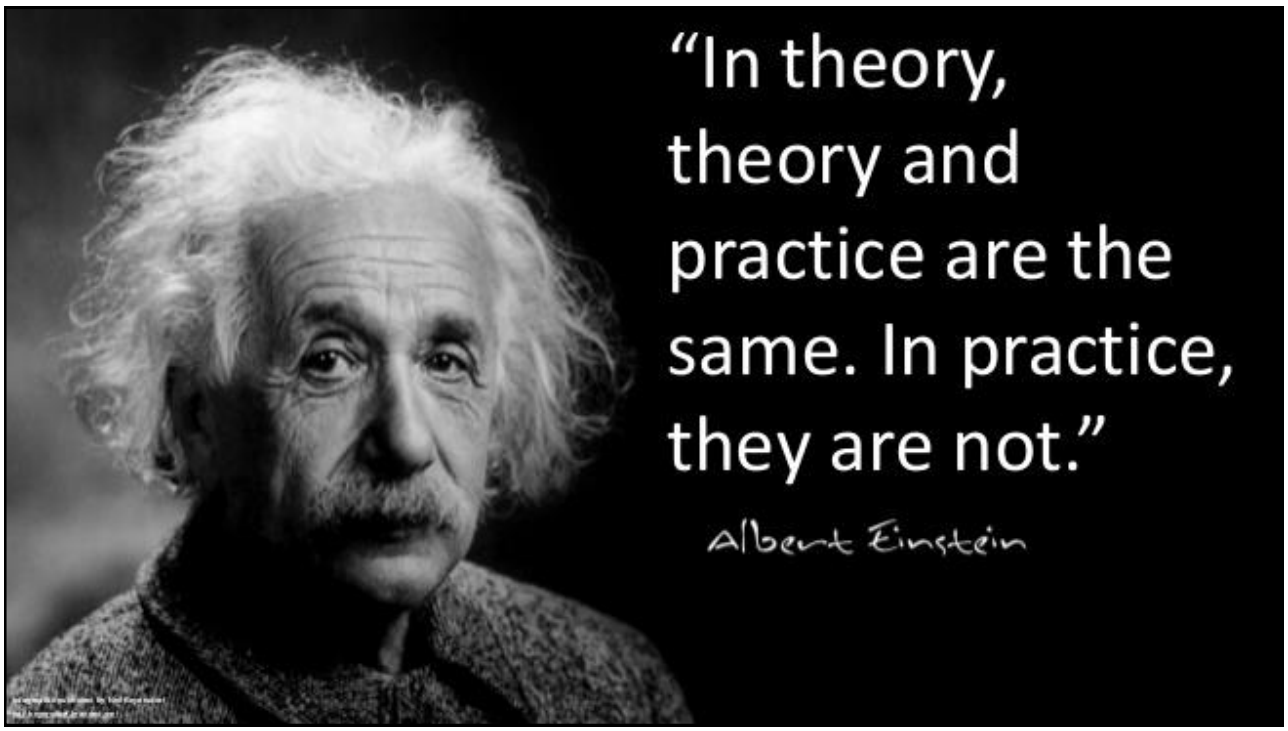
16

Validation in energy- and IAQ-calculations



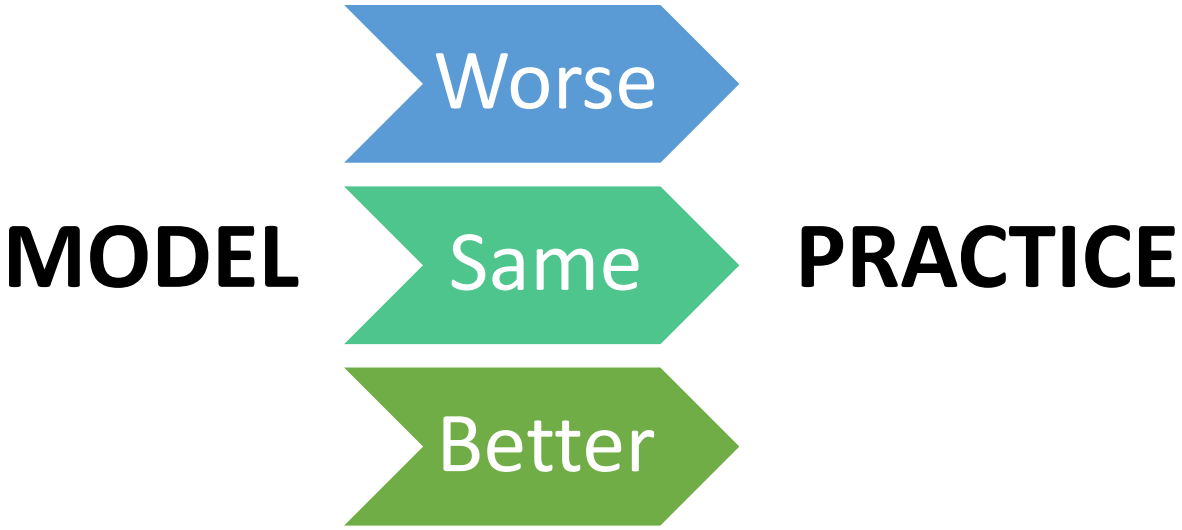


17



18

Performance evaluation



Limits of the model reached ?

There are many factors in real life operations of ventilation systems that can cause differences in the average assumed performance of a specific ventilation system:

- other occupation patterns than on average assumed,
- different number of people than assumed,
- other than on average assumed operation of the ventilation system,
- other than average assumed airtightness,
- other than average assumed wind pressures,
- opening of windows (not included in model),
- other than average assumed use of internal doors,
- etc.
- etc.

Future procedure ?



- Simulation model
- Calculation software
- IAQ + Energy performance

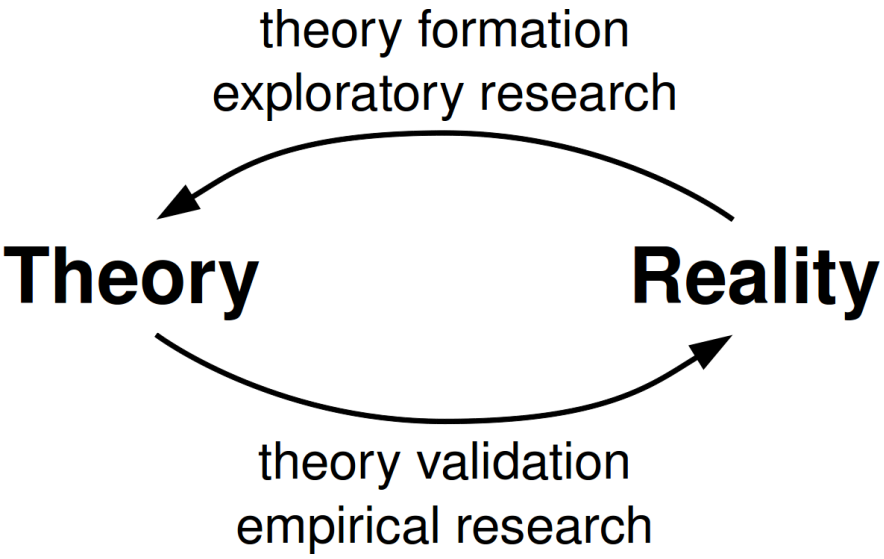
Based on assumptions

=

- Connected device
- Live + historic monitoring data of IAQ & Energy performance

Practice-based evidence

Next steps





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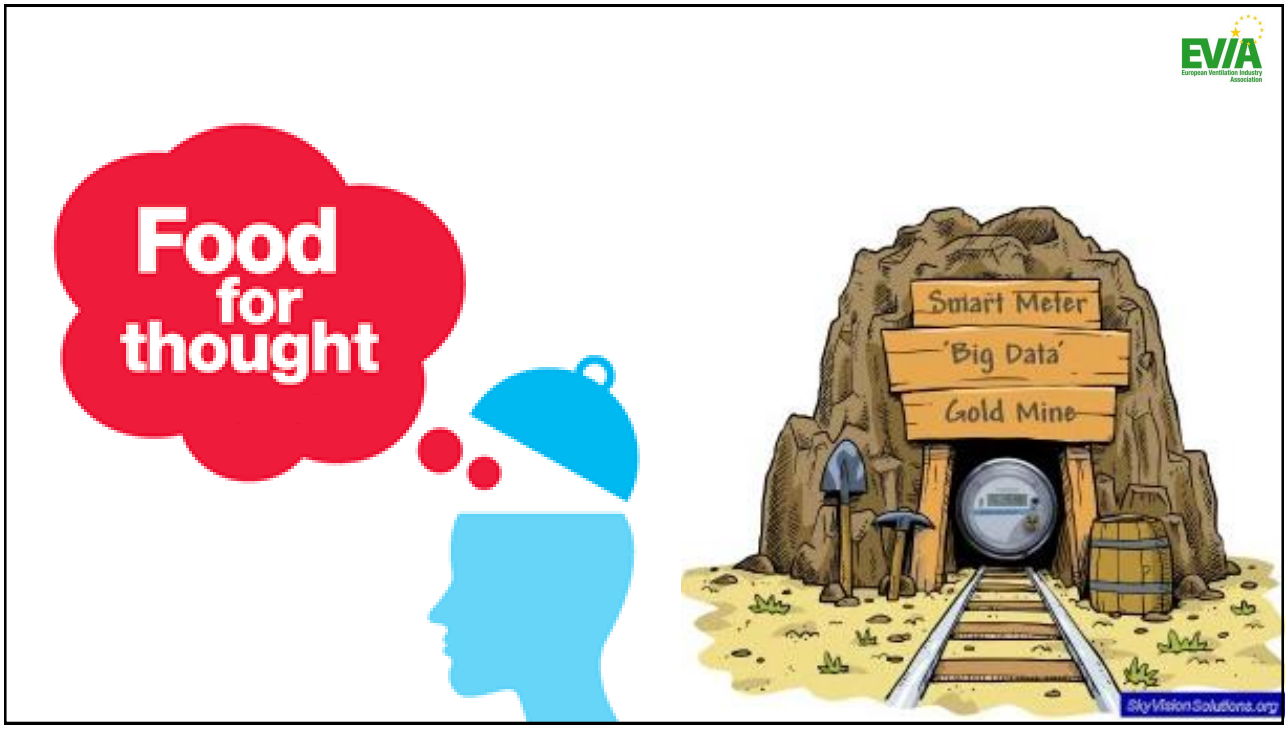

Food for thought
Smart Meter
'Big Data'
Gold Mine
SkyVisionSolutions.org

24

Why performance-based assessment methods? Overview of the needs and the possibilities

Gaëlle Guyot, PhD
BPE Research team, Cerema, France
Research fellow at Univ. Savoie Mont Blanc, LOCIE

1

Outline

- Definitions and context
- Presentation of a performance-based approach for single-family dwellings
- Application on a case study
- Remaining scientific barriers and perspectives

2

Definitions

- **Ventilation: prescriptive vs. performance-based approaches**

"Turn left at the next traffic lights, then take the fourth street to the right, go right ahead at the first roundabout, turn to the right at the second roundabout and keep the left lane, then turn ……."



Spekkink, D. 2005. Key note presentation on PeBBu, CIB Conference, Helsinki, 2005

"To the airport!"



Spekkink, D. 2005. Key note presentation on PeBBu, CIB Conference, Helsinki, 2005

- **Energy-performance calculation methods**
  - C_{ep} en $kW_{ep}/(m^2.an)$
  - Etc.

3

Definitions

- **Ventilation: prescriptive vs. performance-based approaches**

"Turn left at the next traffic lights, then take the fourth street to the right, go right ahead at the first roundabout, turn to the right at the second roundabout and keep the left lane, then turn ……."



Spekkink, D. 2005. Key note presentation on PeBBu, CIB Conference, Helsinki, 2005

Residential ventilation

- Exhausted Airflows / Air change rates
- Trickle ventilators
- Doors undercut, etc…

"To the airport!"



Spekkink, D. 2005. Key note presentation on PeBBu, CIB Conference, Helsinki, 2005

- **Energy-performance calculation methods**
  - C_{ep} en $kW_{ep}/(m^2.an)$
  - Etc.

4

Definitions

- **Ventilation: prescriptive vs. performance-based approaches**

50 kWhep/year/m² !

No condensation !

An healthy indoor air !



Spekkink, D. 2005. Key note presentation on PeBBu, CIB Conference, Helsinki, 2005

- **Tomorrow : A global performance ?**
  - Energy + IAQ indicators

5

Definitions

- **Different ways of defining the ventilation performance**
  - At the design stage, as a design method (modelling)
  - Later at the end of design stage, during the regulatory compliance stage, to assess the design. It could be called a design assessment method (modelling/calculation as EP calculation)
  - At initial commissioning, or later once the building is occupied, as an in-situ performance assessment method (measurement)
- **Performance could be compared**
  - To absolute thresholds
  - To relative ones obtained with "reference" systems/buildings
- **At the design stage, different scales**
  - Ventilation system scale
  - Building scale

6

Presentation of a performance-based approach
3 steps



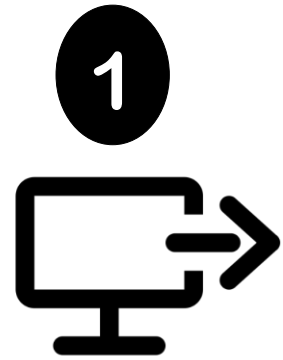
Input data:
Scenarios

Modelling

Output data :
IAQ performance indicators

7

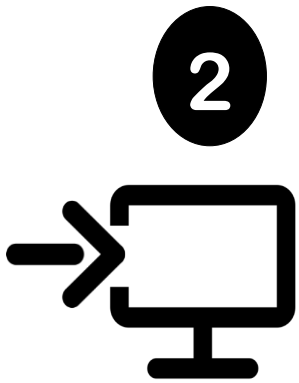
3 scientific barriers



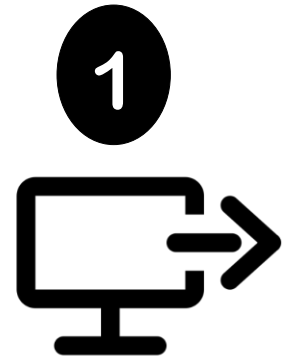
A little set of IAQ performance indicators ?

8

3 scientific barriers



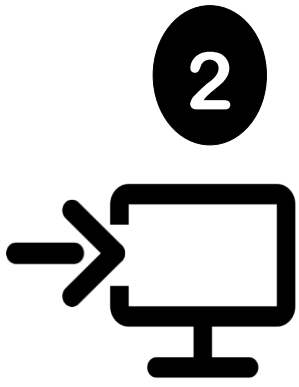
What are the scenarios ?



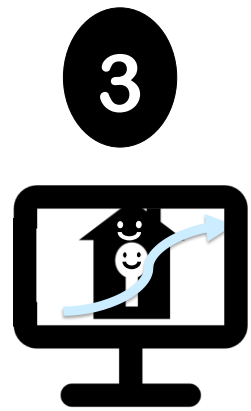
A little set of IAQ performance indicators ?

9

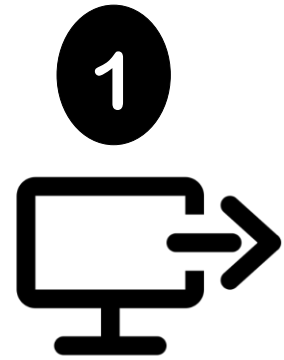
3 scientific barriers



What are the scenarios ?



Level of detail ?



A little set of IAQ performance indicators ?

10

Working steps

Review[1,2]
Literature + Standards + Regulations



What are the scenarios ?

Level of detail ?

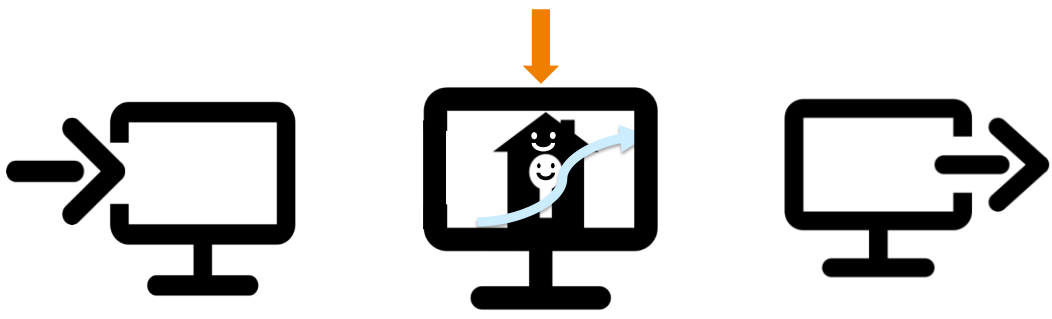
A little set of IAQ performance indicators ?

[1]Guyot, G., Walker, I.S., Sherman, M.H., 2018. Performance based approaches in standards and regulations for smart ventilation in residential buildings: a summary review. International Journal of Ventilation 0, 1–17.
[2]Guyot, G., Sherman, M.H., Walker, I.S., 2018. Smart ventilation energy and indoor air quality performance in residential buildings: A review. Energy and Buildings 165, 416–430.

Working steps

Multizone model

Exploratory study
Impact of airleakage distributions*



What are the scenarios ?

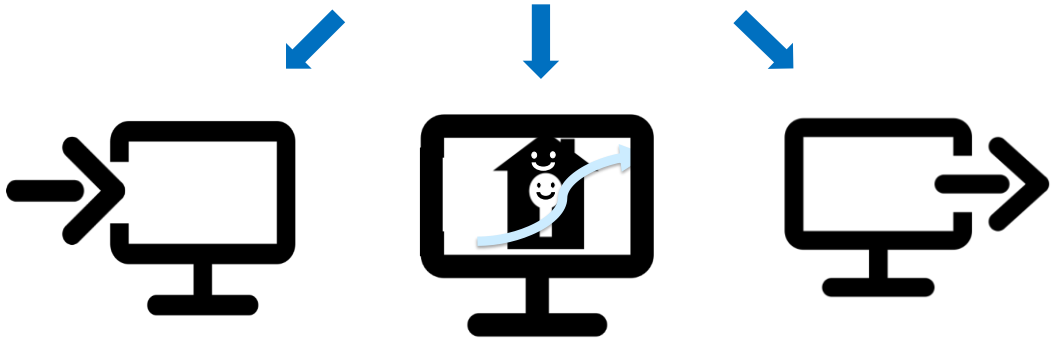
Level of detail ?

A little set of IAQ performance indicators ?

*Guyot, Gaëlle, Hugo Geoffroy, Michel Ondarts, Léna Migne, Mallory Bobee, Evelyne Gonze, and Monika Woloszyn. 2019. "Modelling the Impact of Multizone Airleakage on Ventilation Performance and Indoor Air Quality in Low-Energy Homes." Building Simulation, June. doi:10.1007/s12273-019-0557-x.

Working steps

Comparison with study cases (modelling)



What are the scenarios ?

Level of detail ?

A little set of IAQ performance indicators ?

Proposal of a performance-based method

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Scientific barriers

2

3

1



What are the scenarios ?

Level of detail ?

A little set of IAQ performance indicators ?

14

Conclusions from the review*



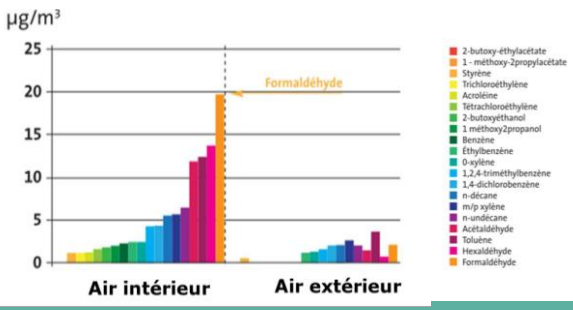
Created by Erin Standley
from Noun Project

- **Multizone**
- **Performance indicators**
  - Condensation risk
  - Average concentration or cumulative exposure above a CO_2 threshold
- **Scenarios**
  - Occupation, humidity, CO_2

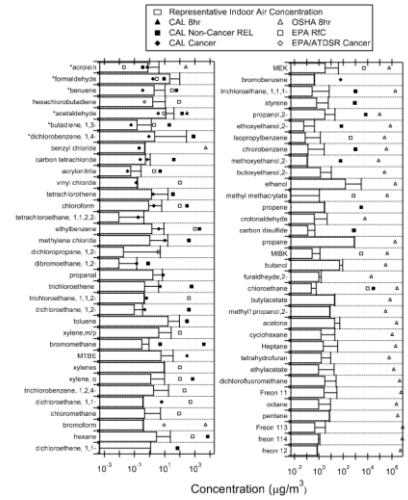
*Guyot, G., Walker, I.S., Sherman, M.H., 2018. Performance based approaches in standards and regulations for smart ventilation in residential buildings: a summary review. International Journal of Ventilation 0, 1–17.

⇒ **What about other polluants identified in measurement campaigns ?**

- ⇒ Identify the most relevant
- ⇒ Identify the indicators
- ⇒ Identify the availability of emission scenarios to calculate them



Source : OQAI, 2010



68 polluants dans review de Logue, et al. 2011.

Relevance of indoor pollutants

1. **RH : building damage + health**
2. **CO_2 : bioeffluents marker***
3. **Fines particules matters ($PM_{2,5}$)**
   - Emitted outdoor and indoor
   - Health impact : 1st place**
4. **Formaldehyde (HCHO)**
   - Measured in 100% of the french dwellings
   - Health impact : 2e place**

* Zhang, X., Wargocki, P., Lian, Z., 2016. Physiological Responses during Exposure to Carbon Dioxide and Bioeffluents at Levels Typically Occurring Indoors. Indoor Air

** Borsboom, W., De Gids, W., Logue, J., Sherman, M., Wargocki, P., 2016. TN 68: Residential Ventilation and Health, AIVC Technical Note 68.

** Logue, J.M., McKone, T.E., Sherman, M.H., Singer, B.C., 2011a. Hazard assessment of chemical air contaminants measured in residences. Indoor Air 21, 92–109

Indicators based on these pollutants

- **A long list is possible …**
- **Average concentration**
- **Average exceeding concentration**
- **Cumulative exposure above a threshold**
- **Dose**
- **Percentage of time spent in a range or above a threshold**
- **…**
- **Per person or per room or per house …**
- **Over the year, the heating period or occupied periods …**

5 selected relevant indicators

Calculated over the heating period (France)

IAQ performance indicators	Threshold	Used reference
Maximal cumulative exceeding CO_2 in bedrooms E_{1000} (ppm.h)	1000 X (ppm.h)	(Zhang et al., 2016) **1000 ppm** with bioeffluents (Zeghnoun, Dor, et Grégoire 2010) 9h20 spent in bedrooms
Maximal formaldehyde dose received by occupants HCHO E_{max} (µg.m^{-3}.h)	9 X (µg.m^{-3}.h)	(Cony Renaud Salis et al., 2017) **9 µg.m^{-3}** proposed as ELV for formaldehyde
Maximal $PM_{2,5}$ dose received by occupants $PM_{2,5}$ E_{max} (µg.m^{-3}.h)	10 X (µg.m^{-3}.h)	(Cony Renaud Salis et al., 2017) **10 µg.m^{-3}** proposed as ELV for $PM_{2.5}$
Maximal % time spent with RH>70% among all the rooms (%)	1000/X (%)	(CCFAT, 2015) Conservative approch. **1000h** est la limite donnée pour HR>75% dans les sdb.
Maximal % time spent among all the bedrooms with RH out of the range 30-70% (%)	800/X (%)	(Mansson, 2001) Conservative approch. **900 h** est la limite donnée pour HR<30 %.

X = simulation duration(h)

r ≤ 1

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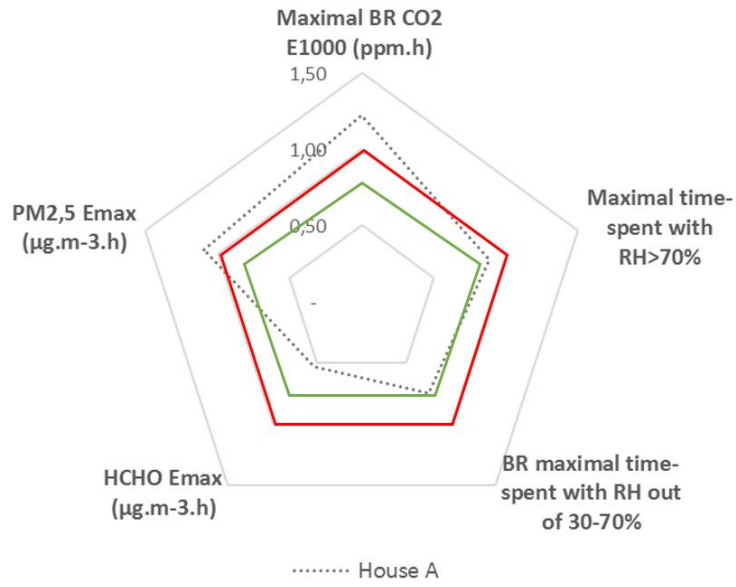
5 selected relevant indicators



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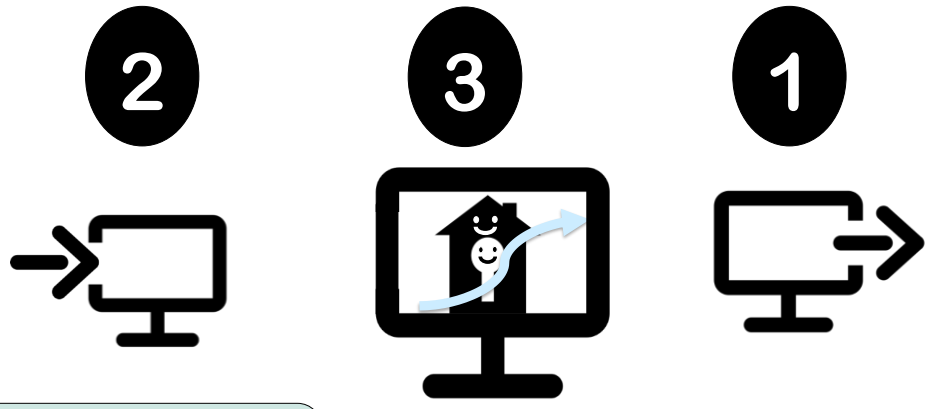
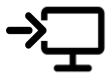
Scientific barriers



What are the scenarios ?

Level of detail ?

A little set of IAQ performance indicators ?



Emission scenarios and occupancy schedules

- **Proposed input data from a review of the available data in 2018**
  - Occupancy : nb of occupants in every room at each time step*
  - Humidity emissions (metabolism + activities)
  - CO_2 emissions
  - No difference between children and adults**
- **Identified barrier: lack of data on pollutants emission rates (HCHO, $PM_{2.5}$, …) at the dwelling scale**

*Zeghnoun, Abdelkrim, Frédéric Dor, et A. Grégoire. 2010. « Description du budget espace-temps et estimation de l'exposition de la population française dans son logement »

**Bienfait, D., Fitzner, K., Lindvall, T., Seppanen, O., Woulliscroft, M., Fanger, P.O., Jantunen, M., Skaret, E., Schwer, J., 1992. Guidelines for Ventilation Requirements in Buildings (No. Report n°11-EUR 14449 EN), European Collaborative Action on Urban Air, Indoor Environment and Human Exposure Reports.

Availability of emission rates in the literature

- **Emissions due to specific activities, building products and materials, obtained in standardized conditions (COV : ISO 16000-9)**
  - Many data, HCHO > $PM_{2.5}$
- **Problems :**
  1. Difficult to extrapolate from standardized conditions -> in situ. Complex physic phenomena (combined effects, re-suspension, etc…).
  2. Difficult to build a robust scenario at the building scale from the materials, products and activities *

⇒ **Simplified method calculating emission rates at the dwelling scale**

*Boulanger, X., Mouradian, L., Pele, C., Pamart, P.Y., Bernard, A.-M., 2012. Lessons learned on ventilation systems from the IAQ calculations on tight energy performant buildings, in: AIVC-Tightvent Conference Proceedings. Copenhagen, pp. 40–43.

Formaldehyde emission rates calculation

- **Mass balance with constant emission assumption**
- **Applied on unpublished data gathered on 10 low-energy houses**
  - *Guyot, G., et al. , 2017. Ventilation performance and indoor air pollutants diagnosis in 21 French low energy homes. International Journal of Ventilation 0, 1–9. (Projet VIA Qualité, ADEME CORTEA 2012)*

House	Floor area [m^2]	Volume [m^3]	Q [$m^3.h^{-1}$]	C [$\mu g.m^{-3}$]	Emission rate g [$\mu g.h^{-1}.m^{-2}$]
1	174	452	110.3	22.9	12.7
2	121	302	73.7	31.1	17.2
3	168	437	308.4	9.0	11.3
4	161	419	209.8	10.3	9.7
5	176	456	286.0	17.4	**23.6**
6	67	174	40.6	17.9	9.1
7	150	375	60.7	24.1	8.6
8	151	378	79.8	35.9	17.4
9	112	314	40.1	15.4	**4.5**
10	80	209	150.0	11.9	16.8

Emission rates assomptions at design stage

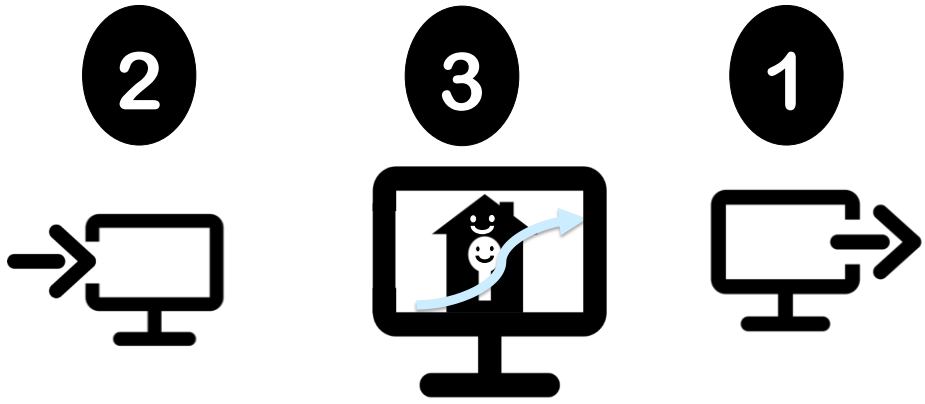
- **Proposal of 3 emission levels**
  - Low: 4.5 $\mu g.h^{-1}.m^{-2}$
  - Middle : 12.0 $\mu g.h^{-1}.m^{-2}$
  - High: 23.6 $\mu g.h^{-1}.m^{-2}$

- **In a calculation at the design stage**
  - Default => high class
  - If use of low-emitting products (A+ label) + occupants awareness = > low class
  - Other cases = > middle class

- ***No useable data in 2018 for $PM_{2,5}$ emission at dwelling scale***
  - *But now : (O'Leary et al. 2019)*

*O'Leary, Catherine, Yvonne de Kluizenaar, Piet Jacobs, Wouter Borsboom, Ian Hall, and Benjamin Jones. 2019. "Investigating Measurements of Fine Particle (PM2.5) Emissions from the Cooking of Meals and Mitigating Exposure Using a Cooker Hood." Indoor Air 29 (3): 423–438. doi:10.1111/ina.12542.

Scientific barriers



What are the scenarios ?

Level of detail ?

A little set of IAQ performance indicators ?



Model : several points to precise in such a method

- **At least …**
- **Physics models and assumptions**
  - Multizone (CONTAM, COMIS, …)
  - Stack effect
  - Wind at the building and pressure coefficients
  - Moisture buffering effect
  - Calculating period adapted to the climate and the habits of the country/region
  - Time step ≤ 10 minutes
- **Building model**
  - Doors : closed (undercut)/ open,
  - Uneven airleakage distributions (enveloppe + internal partition walls)
  - Airflows models used to calculate ventilation flows at every outlet and inlet

Application on a case study



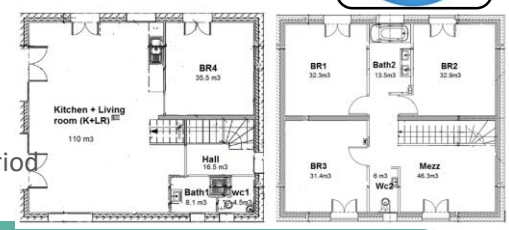
- **We supposed to be at the design stage of a house which must comply with an IAQ performance-based regulation**
- **A low-energy house (50 kWep/year/m²)**
  - 2 stories, 4 bedrooms, …
  - 337 m³ and 135 m²
  - Measured airleakage:
    - Envelope: $n_{50}=1.5\ h^{-1}$
    - Internal partition walls, median value of:

$$q_{50}=0.8\ \ m^3.h^{-1}.m^{-2}$$

- **Multizone modelling**
  - with CONTAM + R
  - Δt=10 minutes, Over the heating period

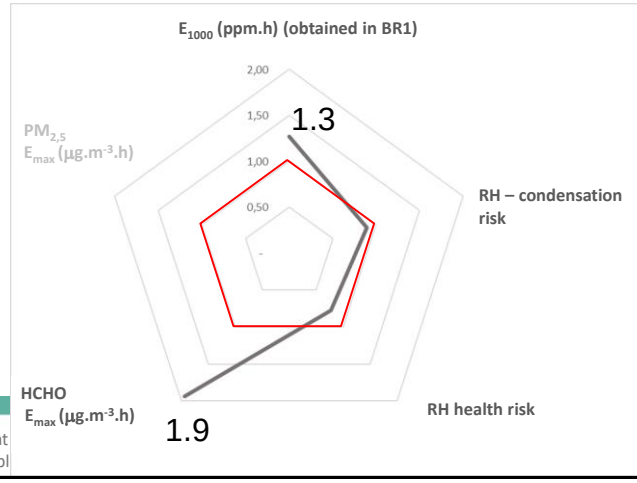






Results

- **If the owner whishes**
  - A wooden frame house (=> airleakage distribution)
  - Equipped with an exhaust-only ventilation system
  - With no awareness about IAQ labelling
    - => use of the high emission level in the calculation



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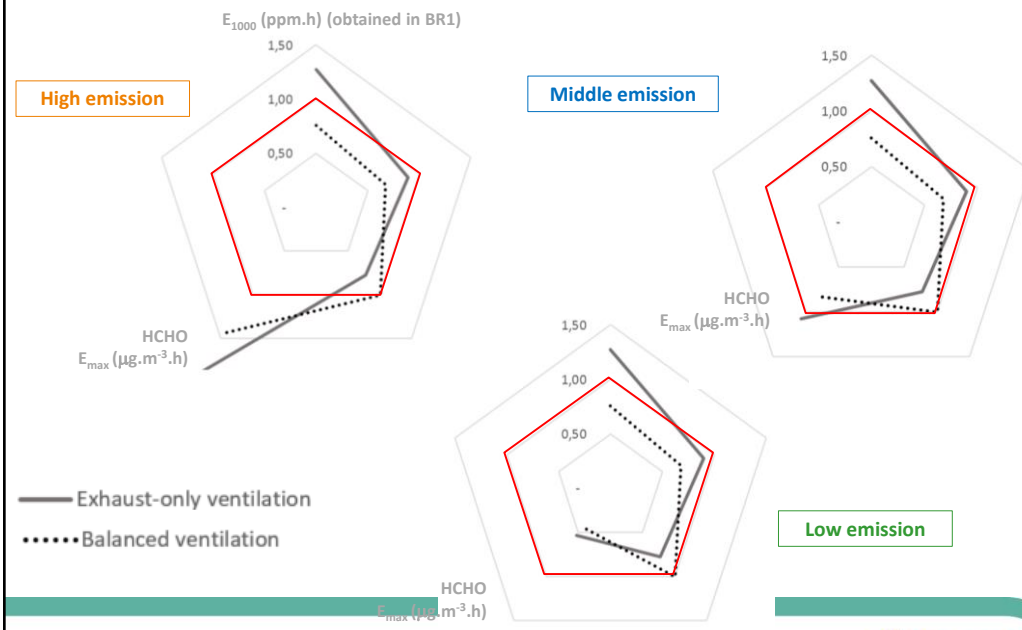
Results

How the method can help in the design choices



30

Conclusion and perspectives

- **Development of a performance-based method answering (partially) to the 3 scientific barriers**
  - The method is applicable and useful at the design stage
- **Several issues should still be adressed**
  - Performance indicators
    - $PM_{2.5}$ + other pollutants ???
    - Robustness / so many possibilities
    - Acute risk should also be assessed
    - Performance to protect against outdoor pollution
  - Input scenarios
    - Robustness / Stochastical approaches ? 75- ou 90-percentile values?
    - Lack of emission data to be used at the design stage
  - Tested on a large variability of ventilation systems

  => Sensivity analysis

Cerema

Thank you for your attention !

Further information in:
Guyot, Gaëlle. 2018. "Towards a Better Integration of Indoor Air Quality and Health Issues in Low-Energy Dwellings: Development of a Performance-Based Approach for Ventilation." PhD Thesis, Le Bourget du lac: Université Savoie Mont Blanc.

Performance-based assessment methods for ventilation systems: Overview of on-going work in France and in Europe

François Parsy, PhD
AERECO SA
& Gaëlle Guyot, PhD
BPE Research team, Cerema, France
Research fellow at Univ. Savoie Mont Blanc, LOCIE

1

Outline

1. **France towards performance-based approaches**
   - Background : Regulations and Technical agreements for DCV systems
   - First outcomes from a national consultative body initiative
   - On-going work toward a general performance-based approach
2. **On-going work in Europe for the revision of EN 15665 and TR 14788**
   - Content of EN 15665
   - Content of CEN TR 14788
   - Revision: On-going work and way forward
3. **Conclusion and perspectives**

2

1. France – *Background : EP and airing regulations*

- **The EP regulation (RT2012) generalizes low energy dwellings (~50 $kWh_{ep}/m^2/y$)**
  - Envelope airtightness requirement for single-family dwellings:
    - $q_{a4} \leq 0.6\ m^3/h/m^2 \cong n_{50} \leq 2.3\ h^{-1}$
    - Justification : measurement or quality management approach
- **Dwellings ventilation is concerned by another 30 year-old regulation (1982-1983)**
  - Compulsory general layouts of ventilation installation : location of inlets and outlets, doors undercut,
  - Required exhausted airflows in each humid room
    - Depending on the number of humid and main rooms of the dwelling
    - => 6 – 9 L/s/pers in a 4 bedroom-dwelling
    - Can be reduced in case of DCV systems
  - No compulsory procedure at commissioning

⇒ **A prescriptive approach except for DCV systems**

3

1. France – *Background : EP and airing regulations*

- **Humidity-based DCV is a reference in France**
  - > 30 years of experience
  - Well rewarded in the EP calculation
  - > 92% of residential buildings built after 2008 (Mélois et al. 2019*)
- **An agreement procedure for each DCV system** (Guyot, Walker, and Sherman 2018**)
  - Asked by the manufacturer
  - Based on a multizone modelling using conventional entry data
    - Weather data, homes geometries, airleakage distribution, occupancy schedules, emission scenarios…
  - Calculated performance indicators :
    - Calculated by room, over the heating period
    - CO_2 cumulative exposure indicator E_{2000} < 400.000 ppm.h
    - Number of hours $T_{RH>75\%}$ < 600 h in kitchen, 1000 h in bathrooms, 100 h in other rooms

$$E_{2000} = \sum_{t=0}^{T} C_{co_2>2000}(t) * t < 400\,000\ ppm.h$$

- **The agreement describes for each system and for each size of dwelling, the configuration (type and number of exhaust devices + trickle ventilators) to be used**
  - > 25 DCV systems with agreements (mostly RH controlled)

* Mélois, Adeline Bailly, Bassam Moujalled, Gaëlle Guyot, and Valérie Leprince. 2019. "Improving Building Envelope Knowledge from Analysis of 219,000 Certified on-Site Air Leakage Measurements in France." *Building and Environment*, May. doi:10.1016/j.buildenv.2019.05.023.
** Guyot, G., I.S. Walker, and M.H. Sherman. 2018. "Performance Based Approaches in Standards and Regulations for Smart Ventilation in Residential Buildings: A Summary Review." International Journal of Ventilation 0 (0): 1–17. doi:10.1080/14733315.2018.1435025.

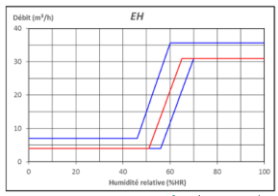
4

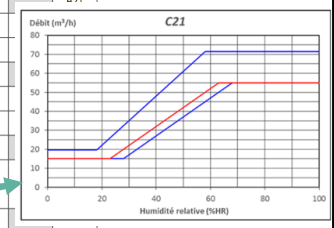
1. France – *Background : EP and airing regulations*

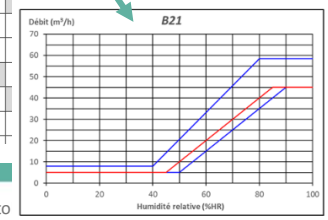
ANNEXE B.3 – Système « BAHIA solution individuelle » en Hygro B

Tableau 2 – Configurations du système « BAHIA solution individuelle » en Hygro B

Configuration de base												Pièces techniques supplémentaires			
Logement	Pièces humides	Type ou module d'entrée d'air (1)			Bouches d'extraction										
		Séjour	Par chambre	Cuisine	SdB1	SdB2	SdB/ WC1	SdB/ WC2	WC	Salle d'eau	Autre SdB	Autre SdB/ WC	Autre WC	Autre Salle d'eau
F1 (2)	1 SdB/WC	2*EH ou 45		C32			BW21				B21	BW21		
	dB/WC	2*EH ou 45		C32			BW21					BW21		
	SdB . WC	2*EH ou 45		C32	B21				W13		B21	BW21		
	dB/WC	EH	EH	C36			BW21				B21	BW21		
	dB/WC	EH	EH	C36			BW21					BW21		
	SdB . WC	EH	EH	C36	B21				W13		B21	BW21		
	dB/WC	EH	EH	C21			BW21				B21	BW21		
	dB/WC	EH	EH	C21			BW21					BW21		
	SdB . WC	EH	EH	C21	B21				W13		B21	BW21		
F4	1 SdB/WC	EH	EH	C21			BW21				B21	BW21		
F4	1 SdB/WC	EH	EH	C21			BW21					BW21	W13	B21
F4	1 SdB 1 WC	EH	EH	C21	B21				W13		B21	BW21	W13	B21
F5	1 SdB/WC	EH	EH	C21			BW21				B21	BW21		
F5	1 SdB/WC	EH	EH	C21			BW21					BW21		
F5	1 SdB 1 WC	EH	EH	C21	B21				W13		B21	BW21		
F6	1 SdB + 1WC + 1SdE	EH	EH	C21	B21				W13	B23				
F6	2 SdB/WC	EH	EH	C21			BW22	BW22			B21	BW22		
F6	2 SdB/WC	EH	EH	C21			BW22	BW22				BW22		







5

1. France - *First outcomes from a national consultative body initiative*

- **A national consultative body called "Club Ventilation" built in 2015 by the French ministry in charge of construction** (Jobert et al. 2018*)
- **All major actors of the ventilation field (45 participants)**
- **Plenary meetings: 4 to 5 times a year + working groups**

- **A working group called "GT Critères"**
  - Comprised of external and independent scientists
  - Aimed to extend the actual agreement procedure for innovative systems, characterizing the ventilation performance with changing airflows as the availability of:
    - Maintain pollutant indoor concentrations in order to be sure that they are not dangerous for health
    - Avoid condensation except for short periods.
  - Consulted regularly the national consultative body members

=> Final proposal

* Jobert, Romuald, Andrès Litvak, Gaelle Guyot, and Laurent Deleersnyder. 2018. "Presentation of a National Consultative Body on Ventilation Issues: Actors, Working Groups and Projects Overview." In Smart Ventilation for Buildings. Juan les Pins, France.

6

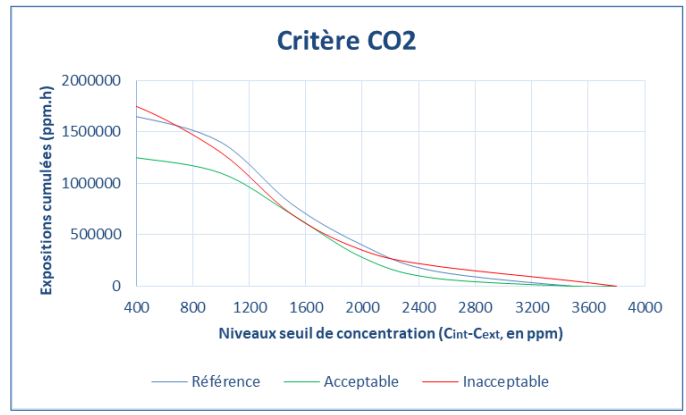
1. France - *First outcomes from a national consultative body initiative* – Final proposal

- **Equivalence principle**
  - A new agreement can be obtained after the analysis of a folder showing that the new system is equivalent to at least a reference system
  - Performances must be at least as good than a reference system
  - Reference systems : complying with the regulations (Arrêté 1982, NF DTU68.3), having an agreement
- **Two performance indicators**
- **Calculated using multizone modelling with conventional scenarios**
  - As the actual agreement procedure
  - + Robustness calculation (weather, dwelling geometry, occupation)

* Jobert, Romuald, Andrès Litvak, Gaelle Guyot, and Laurent Deleersnyder. 2018. "Presentation of a National Consultative Body on Ventilation Issues: Actors, Working Groups and Projects Overview." In Smart Ventilation for Buildings. Juan les Pins, France.

Criteria n°1 : based on CO_2 concentration

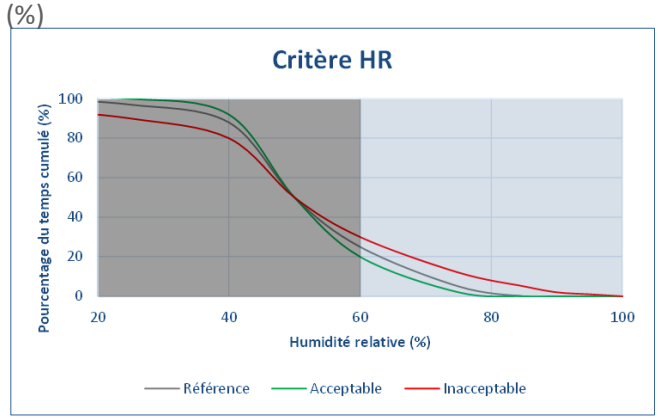
- **Criteria**
  - Curve : CO_2 cumulative exposure (ppm.heures) as a function of CO_2 concentration (ppm)



- **Validation**
  - Must be lower that the curve produced for the reference system
    - For any concentration higher than Coutdoor + 400ppm
    - AND for every living and bedroom

Criteria n°2 : based on Humidity

- **Criteria**
  - Curve : Cumulative exceeding time percentage (%) as a function of relative humidity threshold (%)



- **Validation**
  - Must be lower that the curve produced for the reference system
    - For any relative humidity higher than 60%
    - AND in all the rooms

9

1. France - *On-going work toward a general performance-based approach*

- **Recent ESSOC law voted in 2018**

⇒ **The whole building code should be rewritten in a performance-based way**

- **For ventilation, the presented work is being used as a starting point**
  - Must be adapted to the building scale
  - Equivalence principle
  - + A performance criteria on background pollutants dilution
  - + A performance criteria on acute risk
  - Both based on a fictive pollutant (Cf ASHRAE 62.2)

* Jobert, Romuald, Andrès Litvak, Gaelle Guyot, and Laurent Deleersnyder. 2018. "Presentation of a National Consultative Body on Ventilation Issues: Actors, Working Groups and Projects Overview." In Smart Ventilation for Buildings. Juan les Pins, France.

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Outline

1. **France towards performance-based approaches**
   - Background : Regulations and Technical agreements for DCV systems
   - First outcomes from a national consultative body initiative
   - On-going work toward a general performance-based approach

2. **On-going work in Europe for the revision of EN 15665 and TR 14788**
   - Content of EN 15665
   - Content of CEN TR 14788
   - Revision: On-going work and way forward

3. **Conclusion and perspectives**

REVISION OF EN15665 AND CEN TR14788

Ventilation requirements in European standards

Expectations of ventilation*

- Dilution and removal of pollutants
- Provision for respiration of occupants
- Control of internal humidity

* ref: CEN TR14788:2006

National standards normalize this in two ways

- Prescriptive approach
- Performance-based approach
  - ➢ Or a combination of both

Prescriptive	Performance-based
Germany, Ireland, …	France (DCV), Belgium, Spain, …
Setting the mean	Setting the goal
Requirements on airflows / openings	Requirements on IAQ indices
30 m^3/h in each bathroom	Maximum 1000 hrs/year over 75%RH in bathrooms

Introduced in European standards via EN 15665 in 2009

1

REVISION OF EN15665 AND CEN TR14788

Outline

- Performance-based approach in European standards
- Content of EN15665
- Content of CEN TR14788
- Revision: On-going work and way forward

2

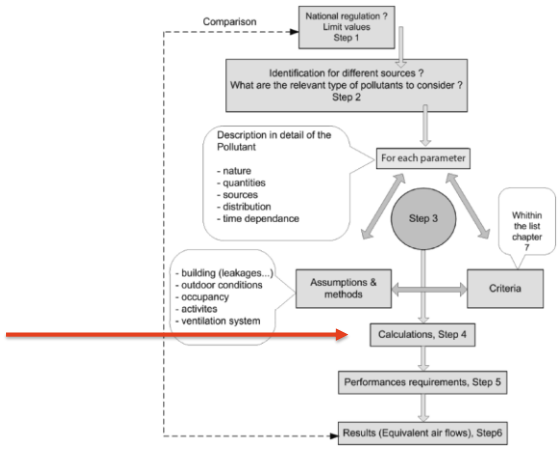
Content of EN15665 – Determining performance criteria for residential ventilation systems

Context

- Status: normative document
- Target group: regulators
- Scope: give procedure and criteria to set ventilation requirements in national regulations

Procedure

- Covers both prescriptive and performance-based
- Performance: options for calculation levels
  - ➢ Blank tables to communicate requirements to designers in each case



3

Content of EN15665 – Determining performance criteria for residential ventilation systems

Context

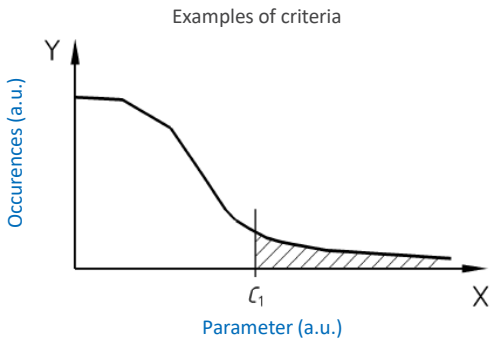
- Status: normative document
- Target group: regulators
- Scope: give procedure and criteria to set ventilation requirements in national regulations

Criteria

"standard of judgment; rule for evaluating something"

~ List of possibilities to analyze time-evolution of pollutants

+ Recommended use of these criteria



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Outline

- Performance-based approach in European standards
- Content of EN15665
- Content of CEN TR14788
- Revision: On-going work and way forward

5

Content CEN TR14788 – Design and dimensioning of residential ventilation systems

Context

Target group: Designers of ventilation systems

Status: Technical Report

- No standard, only information and guidelines, very detailed

Key content: 5-step methodology for design

1. Make design assumptions
   - Building geometry, weather, pollution levels, …
2. Determine performance requirements
   - Flowrates: direction, effect of weather, minimal, …
   - Noise, heat losses, maintenance, durability, …
3. Select ventilation strategy
   - Mechanical / natural
   - Constant airflows / demand-controlled ventilation
4. Plan the layout
   - Location of terminals
5. Dimensioning of terminals

Additional information in annexes: standard emission rates, water vapor absorption effect and many examples

Performance-based approach is not explicitly supported,

- despite being in use in several countries

6

Outline

- Performance-based approach in European standards
- Content of EN15665
- Content of CEN TR14788
- Revision: On-going work and way forward

7

On-going work and way forward

Main goals

- Merge the two documents: "Design and performance of residential ventilation systems"
  - Coherence from regulation to design
  - Target group: Mostly designers, regulators
- Introduce ventilation performance at the design stage
  - Backing national regulation of several countries
  - Opening the way to innovative systems
- Develop natural and hybrid ventilation in the text

CEN Status

- Will soon be registered as CEN PWI (2019)

Work status

- Scope, writing rules, definitions
  - i.e. No quantitative requirements
- Main structure of the document
  - Articulation performance-based / prescriptive
  - Text/graphics for clauses on criteria, noise, principles

Way ahead

- Selection of elements from TR14788 to include
- Text production

Publication… realistically, 2022 / 2023?

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THANK YOU FOR YOUR ATTENTION



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40th AIVC - 8th TightVent & 6th venticool Conference

From energy crisis to sustainable indoor climate 40 years of AIVC



PERFORMANCE-BASED SPANISH REGULATIONS RELATING TO INDOOR AIR QUALITY

Pilar Linares-Alemparte. IETcc-CSIC
Sonia García-Ortega. IETcc-CSIC

1

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Introduction

Previously

2006

Old Spanish IAQ regulation: DB HS3

Scope: dwellings

CTE
CÓDIGO TÉCNICO DE LA EDIFICACIÓN

Minimum ventilation rates

	Ventilation flow q_v l/s	
	Per occupant	Per usable m^2
Bedrooms	5	
Living and dining rooms	3	
Bathrooms and WC		15 per room
Kitchens	2	50 per room (1)
Storage rooms		0,7
Car parks		120 per parking space
Waste bins store rooms		10

(1) Extractor fan for hob

2

Introduction

Previously

2006

Old Spanish IAQ regulation: DB HS3

Scope: dwellings



First time IAQ was regulated

Good IAQ

The only directly accepted ventilation system: CAV-systems

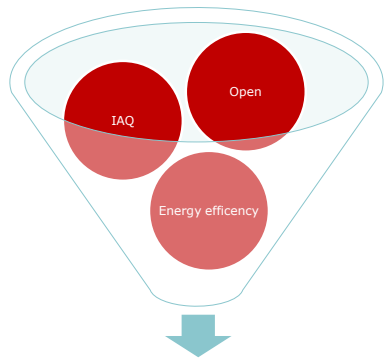
Efficient ventilation systems: DCV-systems

- Not included as accepted solution
- Accepted through specific Technical Approval Document

3

Introduction

Goals



2017

New Spanish IAQ regulation: DB HS3

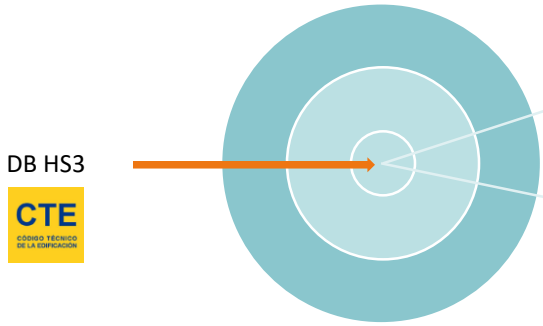
Scope: dwellings

4

Introduction

Target groups





DB HS3

General technitians

Simplified method

Specialists

Expert method



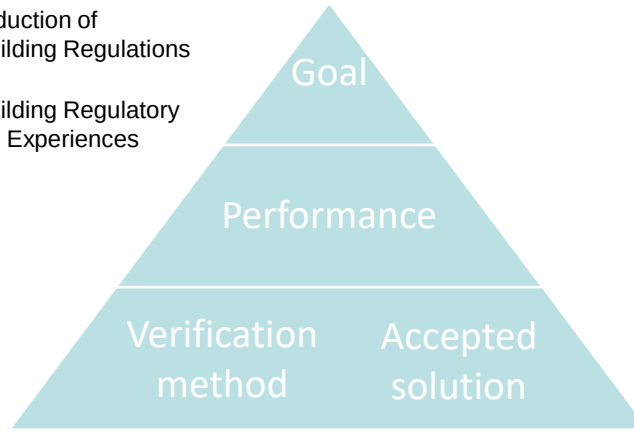
5

Introduction

Structure

Guidelines for the Introduction of Performance-Based Building Regulations

Performance-Based Building Regulatory Systems:Principles and Experiences



6

New DB HS

Goal

"Buildings shall be provided with means so that their enclosures can be suitably ventilated, and contaminants that are commonly produced during their normal use can be removed. A sufficient flow of external air shall therefore be provided and air polluted with contaminants extracted"

New DB HS

Performance

Pollutants

Human activity

Building materials

CO_2 Accumulated value

CO_2 Average concentration

Minimum ventilation flow

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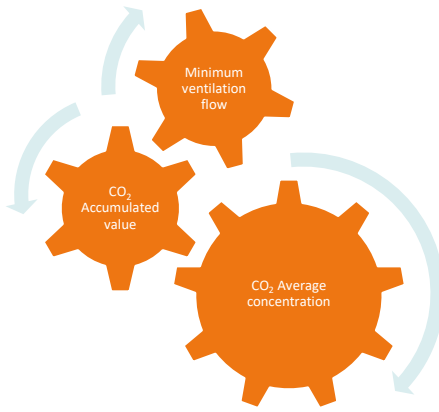
New DB HS

Performance



Design values

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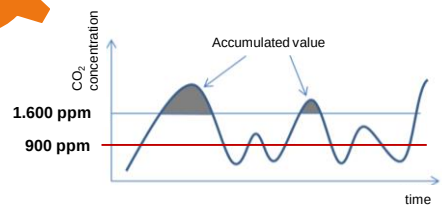
New DB HS

Performance

CO_2 Average concentration — 900 ppm maximum yearly average

CO_2 Accumulated value — 500000 ppm per hour maximum yearly accumulated above 1600 ppm



Open

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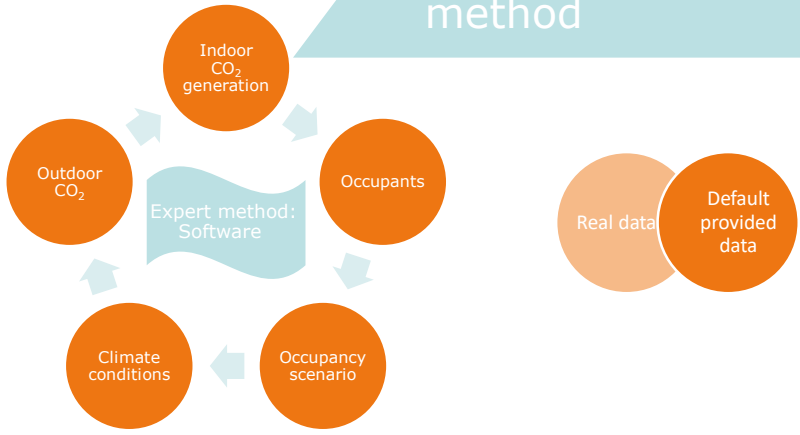
New DB HS

Verification method



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New DB HS

Accepted solution

Type of dwelling	Minimum ventilation flow [l/s]				
	Dry rooms			Wet rooms	
	Master bedroom	Bedrooms	Dining and living room (1)	Global minimum	Minimum per room
0 or 1 bedrooms	8	-	6	12	6
2 bedrooms	8	4	8	24	7
≥ 3 bedrooms	8	4	10	33	8

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New DB HS

Dwelling case study	Continuous ventilation rate (1) (l/s)	Total whole dwelling continuous ventilation rate (l/s)	Yearly average CO_2 concentration (2) (ppm)	Yearly accumulated over 1.600 ppm (2) (ppm·h)
1	6	12	816	0
2	8	24	812	145860
3	11	33	789	150020
4	11	33	848	247000
5	8	24	826	105560

(1) In kitchen and each bathroom.
(2) The highest value per room in each dwelling.



IAQ

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New DB HS

Dwelling case study	Climatic zone	Orientation	Energy demand					
			Current IAQ requirements [Kw-h/m²·year]		Proposed IAQ r[2006] nts [Kwh/m²·year]		I...[2017]... (%)	
			Heating	Cooling	Heating	Cooling	Heating	Cooling
1	D3	North	64.66	12.43	30.62	11.26	53	9
		South	39.25	15.25	9.78	14.4	75	6
	A3	North	14.8	12.42	3.95	11.43	73	8
		South	0.93	15.13	0	14.49	100	4
2	D3	North	68.2	10.6	50.95	9.88	25	7
		South	49.49	13.43	33.09	12.82	33	5
	A3	North	18.14	10.59	11.8	9.92	35	6
		South	4.39	13.27	1.37	12.71	69	4
3	D3	North	54.94	12.87	43.39	12.47	21	3
		South	33.73	18.25	23.51	18.01	30	1
	A3	North	11.89	12.86	8.17	12.49	31	3
		South	1.09	18.18	0.15	17.97	86	1
4	D3	North	51.32	11.07	31.77	10.35	38	7
		South	41.87	13.95	23.22	13.33	45	4
	A3	North	11.36	11.08	5.21	10.45	54	6
		South	4.8	13.93	1.07	13.36	78	4
5	D3	North	53.03	13.8	23.6	12.83	55	7
		South	47.2	15.08	19.01	14.18	60	6
	A3	North	7.34	13.57	0.83	12.65	89	7
		South	4.58	14.79	0.13	13.97	97	6

Energy efficency

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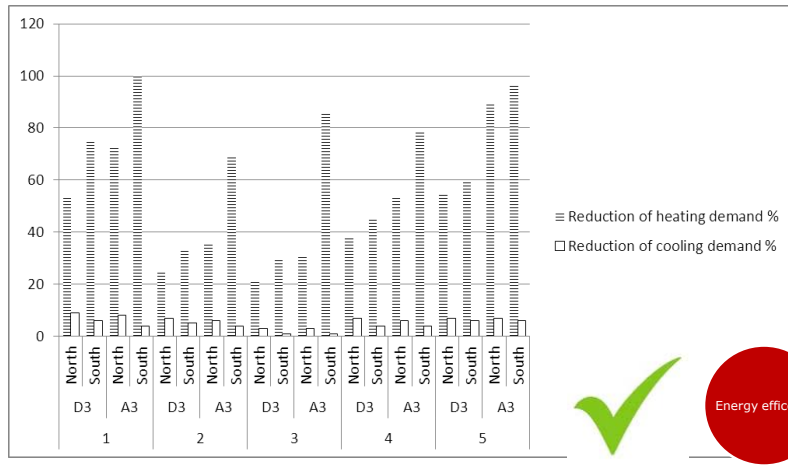
New DB HS



Energy efficency

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Thanks for your attention



16

Challenges and limitations of performance-based approaches: the Belgian experience

Samuel Caillou, Sébastien Pecceu
BBRI – Belgian Building Research Institute, Belgium

1

Performance based approach has been used in Belgium in EP regulation from 2008 to 2015

- Aim
  - Evaluate the energy savings of Demand Controlled Ventilation (DCV) systems
  - Because DCV was not included in the Energy Performance (EP) calculation method at that time
- More than 35 DCV systems have been evaluated
- The assessment method has evolved several times

→ Large experience about challenges and limitations

2

The performance-based method used in Belgium was based on simulations using CONTAM software



- Hypotheses & evolution
  - Dwelling: 2-storeys at the beginning, single floor in the latest evolution
  - Airtightness of the building envelope
  - Typical Reference Year data (Uccle, Belgium)
  - Monte Carlo approach for occupancy
- INPUT:
  - Ventilation system to be tested & control logic
- OUTPUT
  - CO_2 exposure to the occupants → IAQ criteria
  - Average flow rate of outdoor air → Energy evaluation

The DCV to be tested has to fulfill 3 IAQ criteria

- CO_2 exposure
  - Exposure (total for all occupants) above 1000 ppm CO_2
  - Must be equal or better than for reference system A (natural one)
- Tracer for odors
  - Exposure to a tracer (released in the toilets)
  - Must be equal of better than for reference system A
- Humidity
  - Average local relative humidity on a specific thermal bridge < 80%

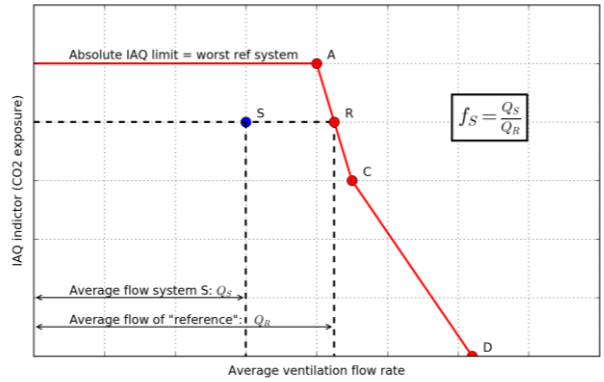
In the 2d version of the method, the energy saving of DCV system was calculated using a trade-off against reference systems

Reference systems:

- A: natural supply and exhaust
- C: natural supply, mechanical exhaust (MEV)
- D: mechanical supply and exhaust

Other systems:

- S: system to be evaluated
- R: virtual reference with same IAQ as S, interpolated from A, C and D references



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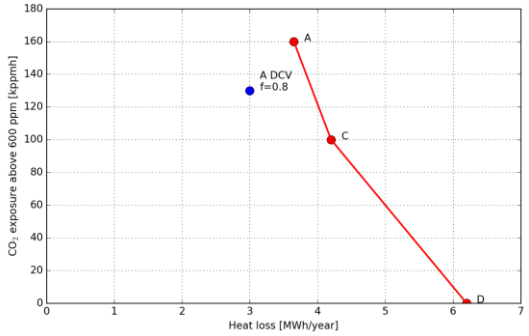
4 examples of challenges and limitations

- Natural ventilation system with DCV
- Mechanical exhaust ventilation (MEV) with DCV based on RH in service spaces
- Mechanical exhaust ventilation (MEV) with CO_2 controllable air inlets in the day zone
- MEV system with air inlets on roof pane

6

Natural ventilation system (A) provides apparently better IAQ when the flow rate is reduced

- Natural ventilation system (A) with DCV
  - Natural supply (grids in windows) and exhaust (grids and chimneys)
  - Exhaust grids regulated on relative humidity (RH)

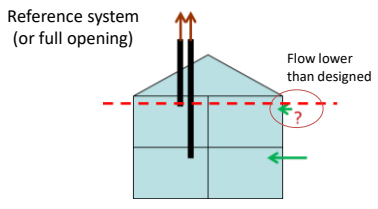


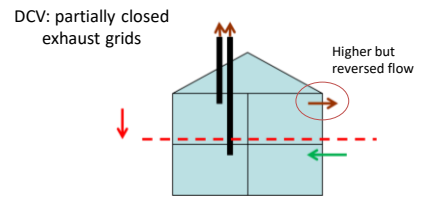
Results:
- Better IAQ than reference A
- Lower flow rate: reduction factor 0,8

7

First, the reference system A provides bad IAQ
Second, in the DCV system, the flow paths are not as foreseen

- Reference system A
  - Lower flow rate (than designed) at 1st floor due to stack effect → low IAQ for ref A system
- DCV system
  - Exhaust grids partially closed → lower flowrate via exhaust chimneys but higher (reversed!) flowrate via inlets at 1st floor → better IAQ
  - Origin of the incoming air on the first floor ? No criteria in the method…





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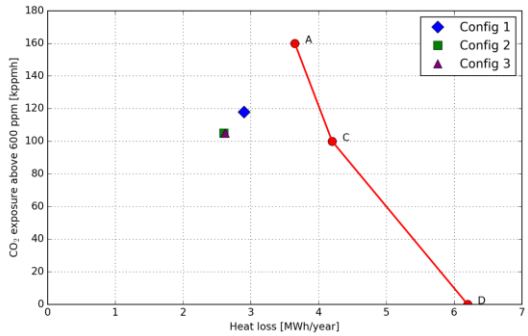
MEV with RH regulation in service spaces leads to reduced flow rate but provides degraded IAQ compared to reference MEV

- MEV system (C system) with DCV
  - Natural supply (grids in windows) and mechanical exhaust
  - Exhaust regulated on relative humidity (RH) in service spaces only

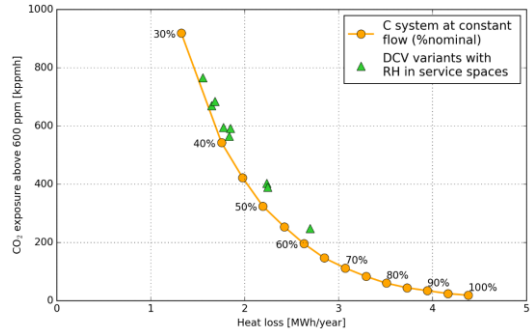


Results:

- Lower flow rate: reduction factor ~ 0,73
- Degraded IAQ compared to reference MEV (C)

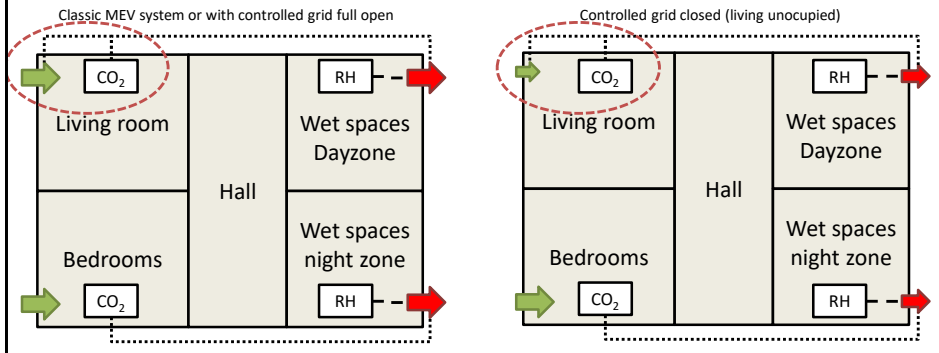
The evaluation method changed in 2015

- New reference curve introduced: reference system with constant flow from 10 to 100% (and other changes: ref building, etc.)
- With the new method, all systems with RH regulation in service spaces only are less performant than reference curve
- Because RH in service spaces are not reliable for IAQ in living spaces (CO_2)



CO_2 controlled air inlets in living room with 2 zones system

- Control logic of extractions: max of RH in wet space or CO_2 in dry space of the same zone

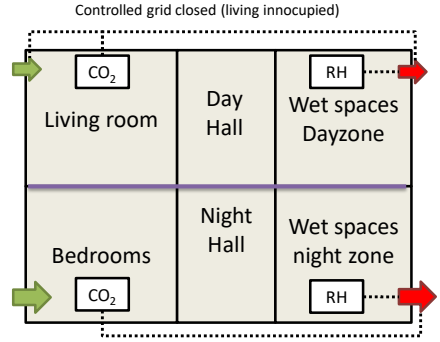


- Closing living air inlet → increasing natural supply in bedrooms → allow decreasing the total extraction flow

Issue #1: what if day and night zones are split and airtight ?

- Night zone:
  - Bedrooms ventilation insured only by night zone extraction
  - No contribution from day zone extraction
- Day zone:
  - Low CO_2 → extraction flow may be driven by RH of wet space
  - Supply in day zone will be balanced event if inlet partially closed

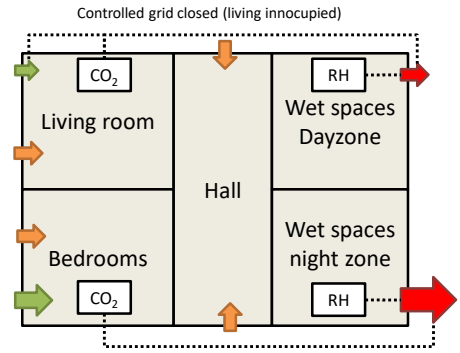
→ Total flow higher than in 1st case



Issue #2: envelope airtightness

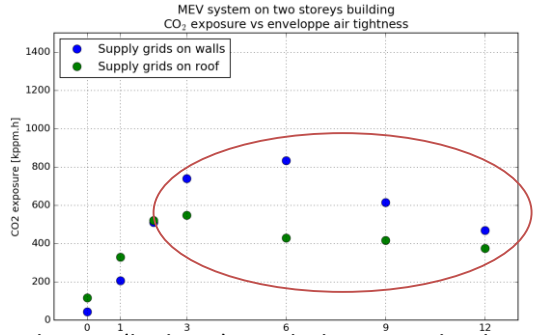
- Closing of the controlled air inlets
  - Higher flow through leaks
  - Limited increase of supply in bedrooms
  - Extraction flow decreases only slightly

→ Total flow higher than in 1st case



IAQ seems to improve with air inlets on roof rather than wall…

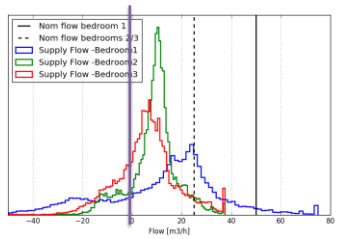
- 2 storeys residential building with 3 bedrooms on 1st floor
- Impact of the air inlet location: façade or roof (e.g. converted attic)



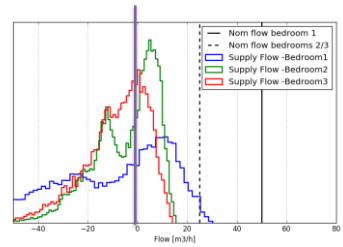
- For low airtightness (high v_{50}), works better with inlets on roof according to CO_2 criteria!

Flow rate distribution at air inlet for dry spaces

Wall air inlets



Roof air inlets



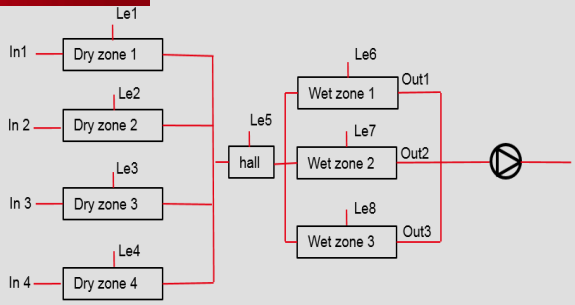
- Flow mostly positive for wall mounted inlets
- Flow mostly negative for roof mounted inlets → works mostly as exhausts. Is that wishable ?

Conclusions

- Summary of encountered issues in the 4 examples
  - Apparent improvements of performance sometimes due to system not working as designed (e.g. air inlets working as exhausts)
  - Absence of absolute IAQ criteria and impact of the reference when using comparative/relative approaches
  - Impact of the calculation hypotheses or parameters (building floor plan, airtightness, …)
- Possible solutions
  - Use of multiple criteria and conditions
  - Work on undisputable reference for comparative approaches ?
  - More elaborated approaches to handle the variability (e.g. Monte Carlo, decision trees, etc.)

Thank you for your attention

Samuel Caillou, Sébastien Pecceu
BBRI – Belgian Building Research Institute, Belgium



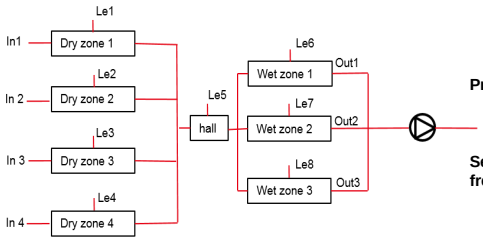
DEMAND CONTROLLED VENTILATION : SENSITIVITY AND ROBUSTNESS OF THE PERFORMANCES

Xavier Faure
PhD – Eng. Project Manager at CEA,

1

HOW DOES VENTILATION SYSTEMS WORK ?

Schematic view of airflow network in dwellings



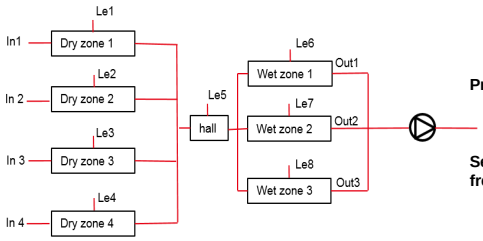
Primary components are : fan, ducts, outlets and inlets
→ guaranteed performances

Secondary components are : envelope local airtightness, free area of internal doors
→ non guaranteed components

2

PERFORMANCE BASED APPROACHES AND REAL LIFE

Schematic view of airflow network in dwellings



Primary components are : fan, ducts, outlets and inlets
→ guaranteed performances

Secondary components are : envelope local airtightness, free area of internal doors
→ non guaranteed components

After being installed, ventilation system have to deal with occupancy and climatic conditions as well.

The question is : In the context of performance based approaches, how sensitive is a DCV system to some parameters ?

Studied parameters are :
Envelope external leakage and it's distribution around the building envelope ;
Wind velocity (keeping the same flow effect around the envelope -> same Cp) ;
Occupancy (from 1 to 6 persons in the same dwelling)

3

SENSITIVITY ANALYSES - METHODS

ANOVA based analyses is realized

Consist in identifying how the variance of a specific output Y is influenced by one or several input(s) Xi.

The first order index is computed through the ratio of the partial variance of Y explained by Xi alone upon the variance of Y :

$$S_i = \frac{V\left[E[Y|X_i]\right]}{V[Y]}$$

Random **B**ased **D**istribution **F**ourier **A**mplitude **S**ensitivity **T**est (RBD-FAST) methods is chosen for sake of simplicity, rapid convergence and for the required assumption :

- No specific assumptions are to be considered on the model
- Inputs parameters are here independent but could be correlated

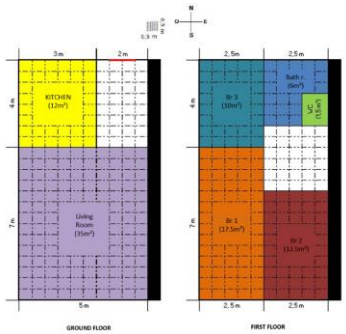
Based on *S. Tarantola, D. Gatelli and T. Mara (2006) "Random Balance Designs for the Estimation of First Order Global Sensitivity Indices", Reliability Engineering and System Safety, 91:6, 717-727*

4

STUDIED CASE – GENERAL PARAMETERS

French performance based design approach :

4 rooms, 2 storey dwelling



Assumptions

Envelope external leakage : global value of 0.6 $m^3/h/m^2$
→ Distribution depending on each zone external surfaces

Fixed Internal humidity buffering effect in each zone

Occupancy : presence and domestic activities defined for each week day and number of persons

Fixed climatic conditions (taken from energy regulation computation assumptions and one specific city)

Simulations are realized on 262 days (from 1/09 up to 31/05) and computation of global outputs after one month to limit the influence of initial conditions (mainly for moisture effect).

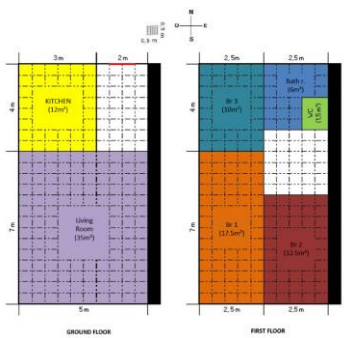
Software : MATHIS (official code for the French protocol) :
https://gitlab.com/CSTB/mathis

5

STUDIED CASE – GENERAL PARAMETERS

French performance based design approach :

4 rooms, 2 storey dwelling :



Global outputs

1- Energy → mean extracted airflow from wet rooms only

2 - IAQ → Exposure index based on cumulative CO2 concentration above 2000ppm

3 - Humidity exposure index based on the number of hours above 75% in each zone

4 - Reversed flow through inlets

Studied ventilation systems :

Hygro A and Hygro B DCV strategies taken from the same official technical data sheet with agreement delivered in summer 2019 and for the next 5 years

6

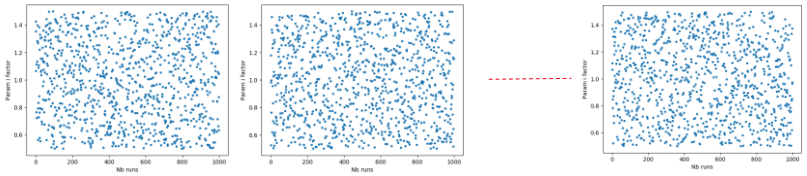
STUDIED CASE – METHOD OF ANALYSES

Sensitivity Analyses :

Considered parameters :
17 external leakages for each external surface on all zone (+/- 50%)
1 pressure coefficient variation (to integrate wind velocity analyses around +/- 20%)
Number of occupant (from 1 to 6)

Outputs :
1st step : SA on global parameters computed from full simulations (262 days)
2nd step : Temporal analyses on local variables (summer/winter case)

1000 runs with Latin hypercube sampling for the 18 parameters

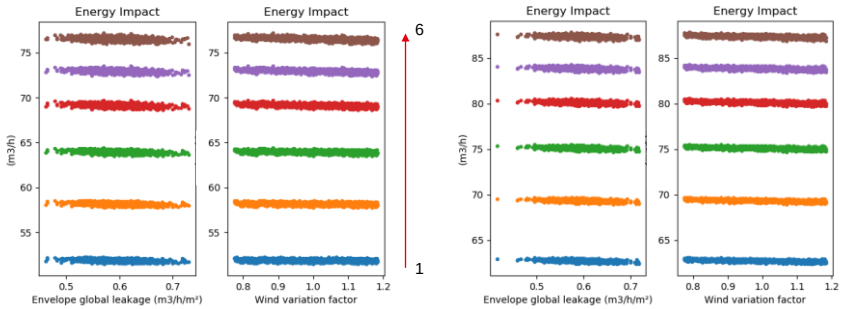


Same samples are kept for each system (hygro A and B) and all cases

RESULTS – GLOBAL OUTPUTS

Global extracted air flow in wet rooms

Hygro B case **Hygro A case**



Local leakage sampling gives 20% of variation around 0.6m³/hr/m² for the global envelope leakage;

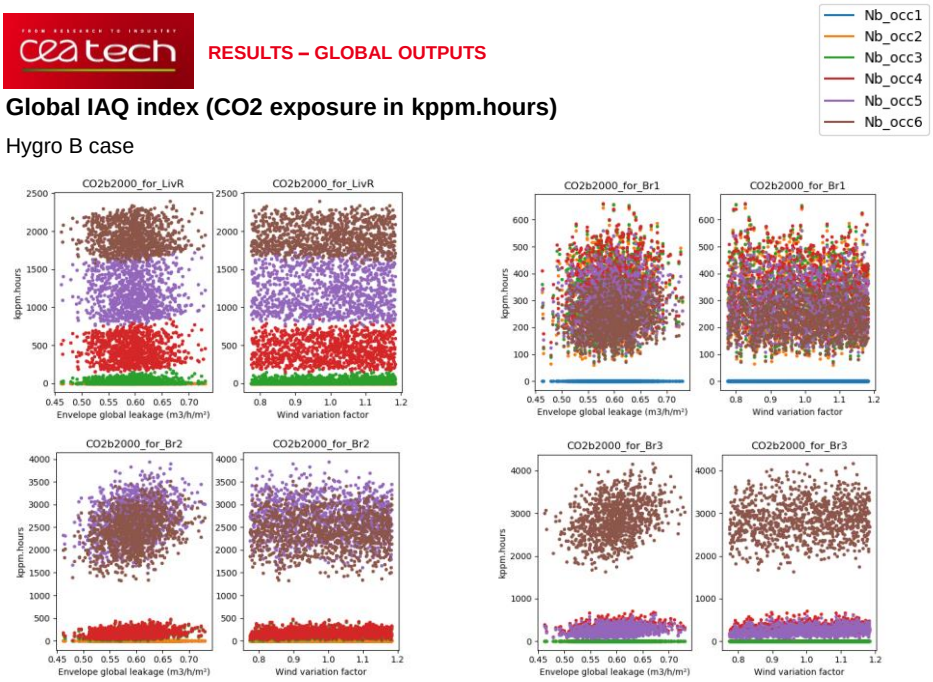
Major influence of the number of occupant → useless to include them in the SA;

Very few variation in each case : extracted airflow are not sensitive to leakage nor wind;

RESULTS – GLOBAL OUTPUTS

Global IAQ index (CO2 exposure in kppm.hours)

Hygro B case



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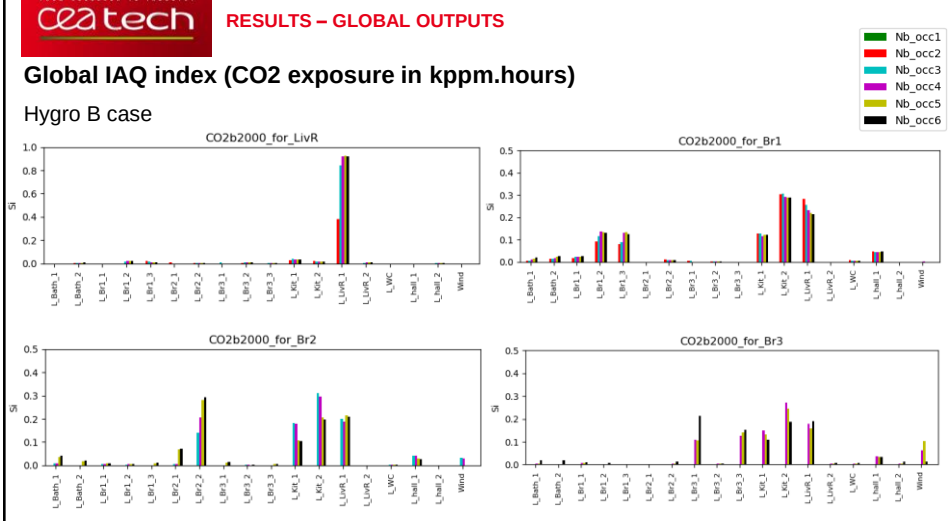
RESULTS – GLOBAL OUTPUTS

Global IAQ index (CO2 exposure in kppm.hours)

Hygro B case

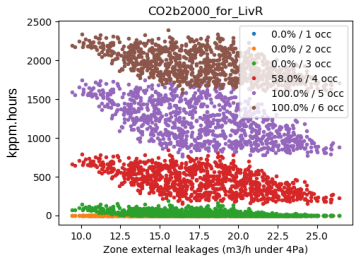


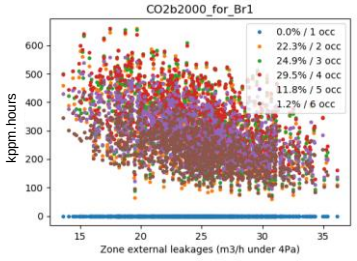
Zone leakages are systematically concerned bot not only : Leakage from kitchen is always important as more than 2/3 of the airflows are extracted from the kitchen.

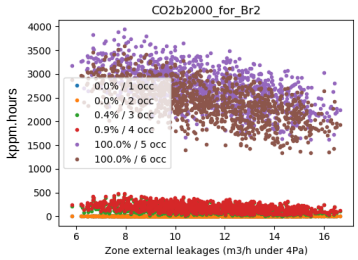
10

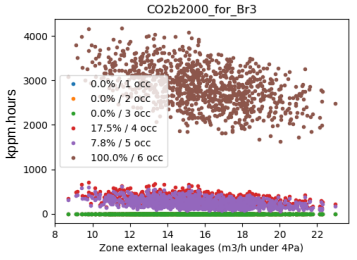
RESULTS – LOCAL OUTPUTS

Local leakage impact – Hygro B





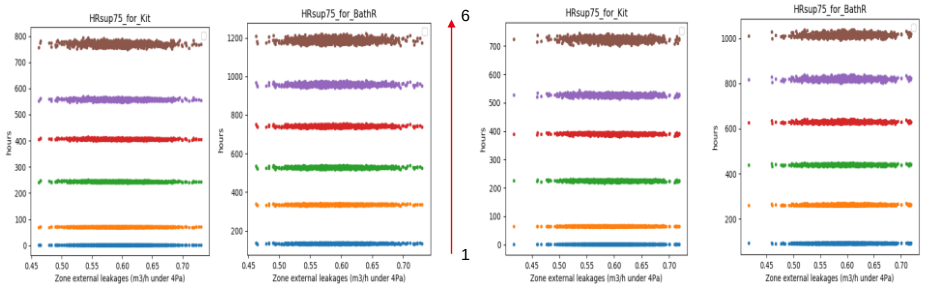




RESULTS – GLOBAL OUTPUTS

Global humidity exposure index (nb hours above 75%)

Hygro B case **Hygro A case**



As for extracted airflow, humidity in wet rooms are quite independent on leakage or wind but highly sensitive to the number of occupant (→ domestic activities !)

But airflow is extracted from these zones and it's values is depending on the humidity ratio in these same zones !

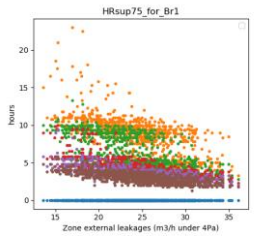
How about the other zones ?

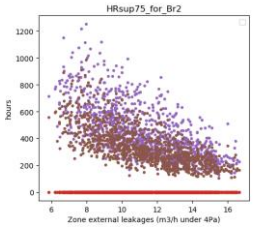
Nb_occ1
Nb_occ2
Nb_occ3
Nb_occ4
Nb_occ5
Nb_occ6

RESULTS – GLOBAL OUTPUTS

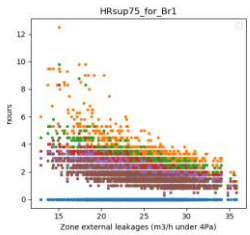
Global humidity exposure index (nb hours above 75%)

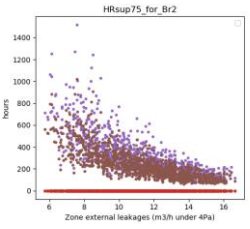
Hygro B case





Hygro A case



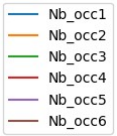


Same effect then for IAQ index

Strong leakage effect

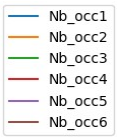
Leakages are considered as inlets.

→ If inlet area is reduced, air change rate will be lower…

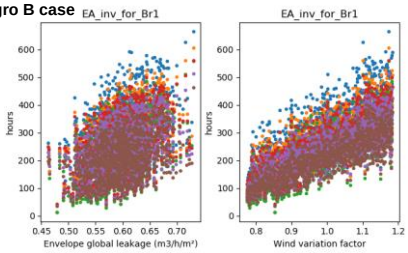


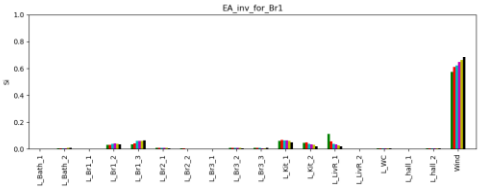
RESULTS – GLOBAL OUTPUTS

Global Reversed flow at inlets (hours), example for the main Br



Hygro B case





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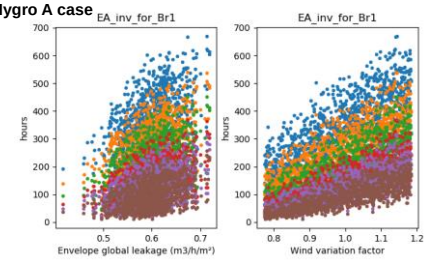

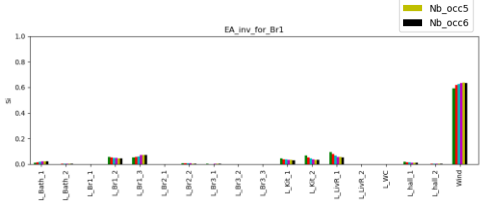

RESULTS – GLOBAL OUTPUTS

Main conclusion on global variables :

Extracted airflows and Humidity Index are very robust in wet rooms.

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For dry rooms… local leakages have important impact.

Each zone is first influence by its leakage equivalent area

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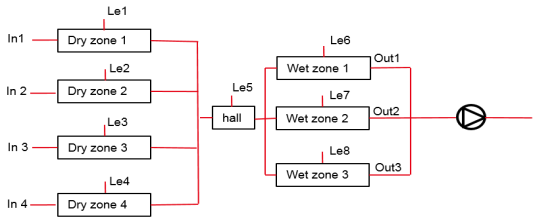
Leakages in wet rooms are always present in all sensitivity analyses → direct influence on the extracted airflow from other rooms.



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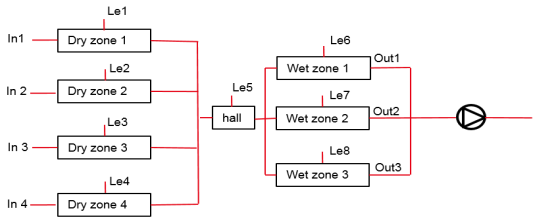


Is this sensitivity time dependent ?

RESULTS – GLOBAL OUTPUTS

Temporal analyses

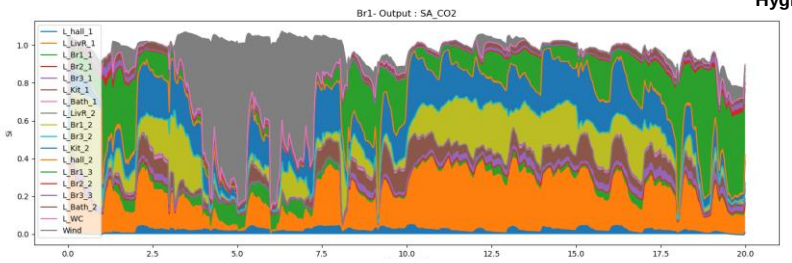
40 days simulations have been realized on two periods: January and August.

SA is realized at each time step to catch whether sensitivity indexes are time dependent (occupancy presence, domestic activities, climatic conditions)

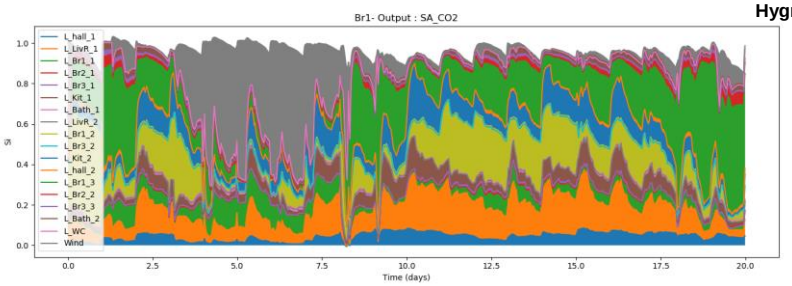
RESULTS – LOCAL OUTPUTS

Dynamic sensitivity analyses (winter) :

Hygro B



Hygro A



RESULTS – LOCAL OUTPUTS

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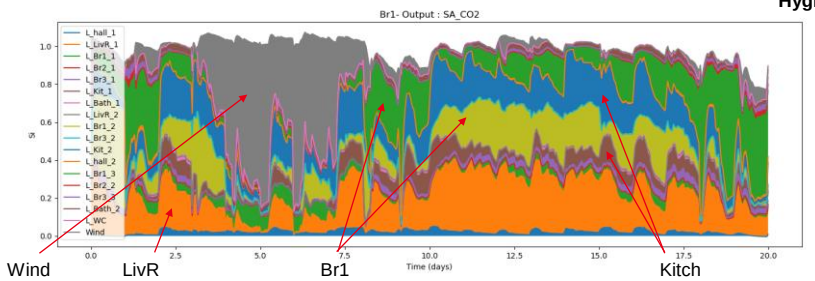
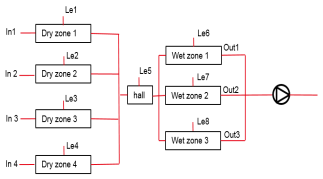


SA indexes are logically dependent on the occupancy (source planning) as well as climate conditions

/!\ Analyses should also consider potential inertial effects on these indexes :
→ an effect of one parameter can still be present even thought this parameter doesn't change any more.

GENERAL CONCLUSIONS



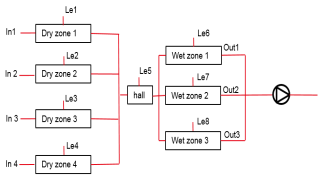
This system seems to be :

Very robust on the extracted airflows (due to simulation assumptions) ;

Very robust on humidity ratio in wet rooms (airflow is extracted in these zones depending on this ratio !) ;

Very sensitive to occupancy (Demand Controlled Ventilation) ;

GENERAL CONCLUSIONS



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Very robust on humidity ratio in wet rooms (airflow is extracted in these zones depending on this ratio !) ;

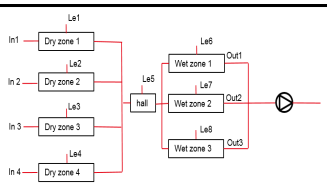
Very sensitive to occupancy (Demand Controlled Ventilation) ;

Quite sensitive to envelope leakage and it's distribution around the building envelope ;

Quite sensitive to external conditions ;

Quite sensitive to occupant locations (better choose the good bedroom !) ;

GENERAL CONCLUSIONS



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Very sensitive to occupancy (Demand Controlled Ventilation) ;

Quite sensitive to envelope leakage and it's distribution around the building envelope ;

Quite sensitive to external conditions ;

Quite sensitive to occupant locations (better choose the good bedroom !) ;

How to enhance robustness :

Leakage are considered as real inlets for the system. It should not !
Too few inlets are present in dry rooms. There will be Energy impact for sure but…..aren't we focused on IAQ ?

Since robustness is obtained from the extraction modulation on one variable in specific rooms. What about multi-variable based DCV with multi-location exhaust points ?

How should/could we control the airflow network ? In order to ensure air change rate at the right place at the right time → autonomous component

Thank you for attention

xavier.faure@cea.fr

Acknowledgments, for precious discussions :
Jeanne Goffart ; Mickael Rabouille ; Aurélie Foucquier

Why performance-based assessment methods?

Conclusions & Perspectives

Samuel Caillou
BBRI – Belgian Building Research Institute, Belgium

1

Performance-based assessment methods can be used

- To evaluate innovative and/or more complex systems
  - DCV systems
  - Natural ventilation systems
- To evaluate / quantify
  - The IAQ performances: check IAQ/ventilation requirements

    Check if the system is able to provide sufficient air change rate to fulfill given IAQ criteria
  - The Energy performances: quantify the energy saving factors

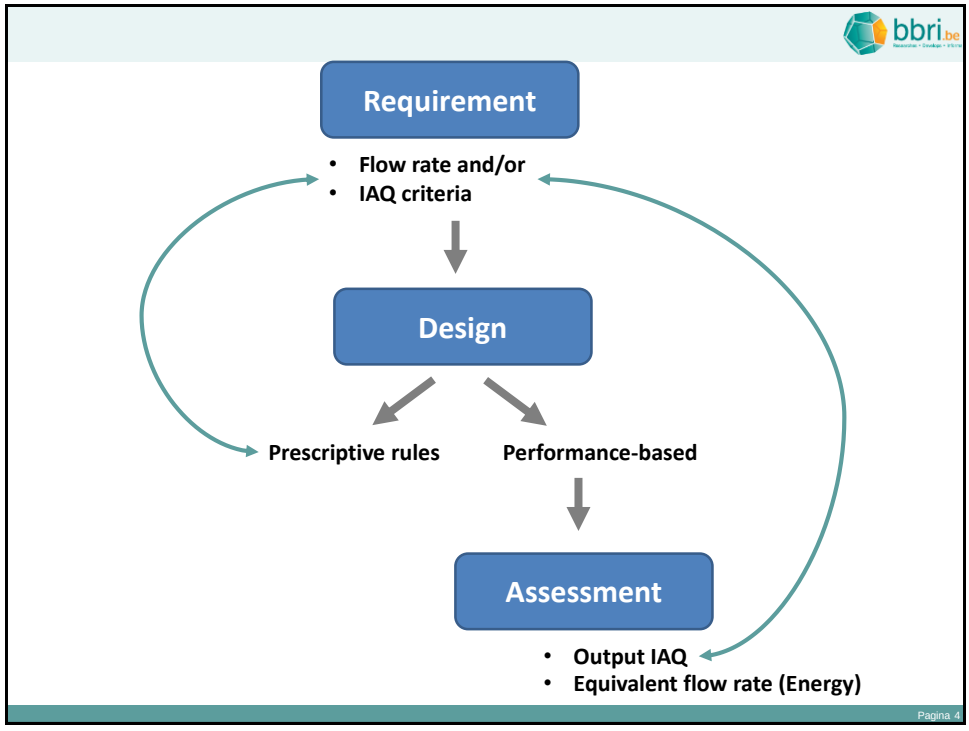
    Calculate the ventilation heat losses for the whole year based on given climate data

2

Performance-based assessment methods and prescriptive ones are complementary

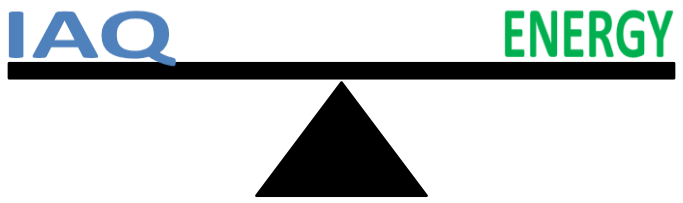
- Prescriptive methods
  - Simple, cheaper
  - For basic design
- Performance-based methods
  - More complex, more expensive
  - But more powerful: to open the possibilities

3



4

Ventialtion is always a balance between IAQ and Energy



Random or arbitrary: Flow rate ↘ ➔ Indoor Air Quality ↘

Intelligent DCV : Flow rate ↘ ➔ Indoor Air Quality =

5

Points of attention (1)

- Equivalency between
  - Prescriptive requirements (flow rates, …)
  - And performance-based criteria (CO_2, RH, VOC, …)
- Use of multiple criteria
  - Bioeffluents
  - Humidity
  - VOC
  - Flow paths?

6

Points of attention (2)

- Building models
  - Number and types of rooms
  - Airtightness of envelope
  - Shape of the building
- Occupant profile
  - Average of different profiles
  - Or specific results for some typical profiles

Points of attention (3)

- Importance of reference systems
  - Best controlled
  - Relative approach or absolute criteria?
- Avoid to use a black-box!
  - Mandatory to explain the cause of the calculated result?
  - More elaborated approaches to handle the variability (e.g. Monte Carlo, decision trees, etc.)

Perspective: common performance-based method?

- Current revision of
  - EN 15665
  - TR 14788

Thank you! Lunch time

Applicability of a simple and new airtightness measuring method and further comparisons with blower door measurements

Timothy Lanooy, Wim Kornaat, Niek-Jan Bink, and Wouter Borsboom

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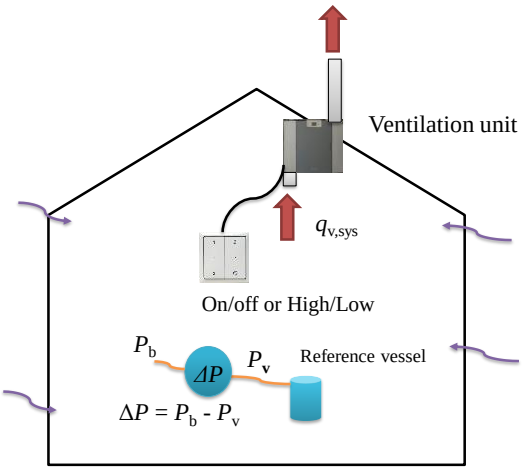



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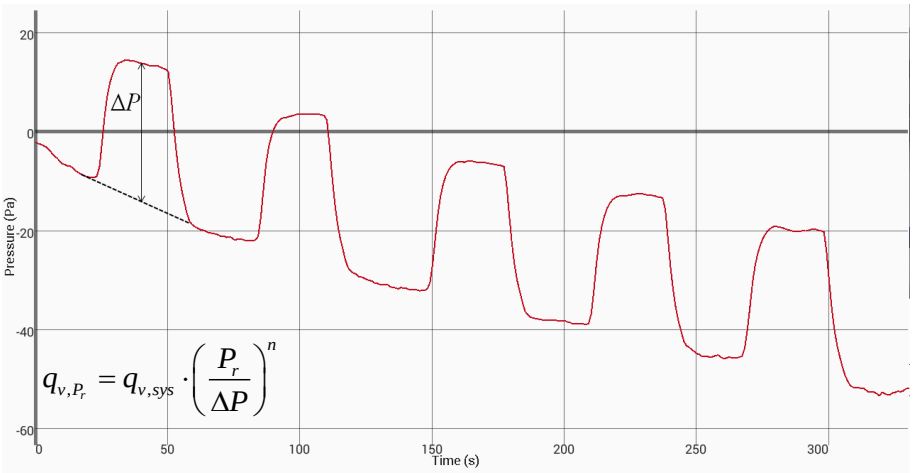
Equation and typical measurement signal



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Uncertainty flow rate

$$\sigma_{q_{v,P_r}} = \sqrt{\left(\frac{\delta q_{v,P_r}}{\delta q_{v,sys}} \right)^2 \cdot \sigma_{q_{v,sys}}{}^2 + \left(\frac{\delta q_{v,P_r}}{\delta \Delta P} \right)^2 \cdot \sigma_{\Delta P}{}^2 + \left(\frac{\delta q_{v,P_r}}{\delta n} \right)^2 \cdot \sigma_n{}^2}$$

- Dependent on measuring device used
- All our measurements are done with a FlowFinder, accuracy ±3%



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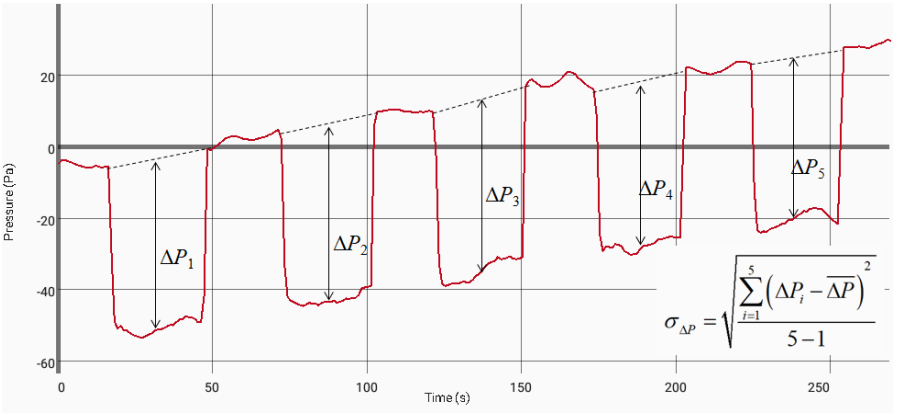
Uncertainty pressure signal

$$\sigma_{q_{v,P_r}} = \sqrt{\left(\frac{\delta q_{v,P_r}}{\delta q_{v,sys}}\right)^2 \cdot \sigma_{q_{v,sys}}{}^2 + \left(\frac{\delta q_{v,P_r}}{\delta \Delta P}\right)^2 \cdot \sigma_{\Delta P}{}^2 + \left(\frac{\delta q_{v,P_r}}{\delta n}\right)^2 \cdot \sigma_n{}^2}$$



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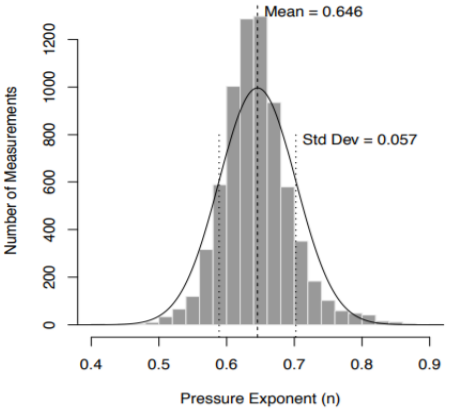
Uncertainty flow exponent

$$\sigma_{q_{v,P_r}} = \sqrt{\left(\frac{\delta q_{v,P_r}}{\delta q_{v,sys}}\right)^2 \cdot \sigma_{q_{v,sys}}{}^2 + \left(\frac{\delta q_{v,P_r}}{\delta \Delta P}\right)^2 \cdot \sigma_{\Delta P}{}^2 + \left(\frac{\delta q_{v,P_r}}{\delta n}\right)^2 \cdot \sigma_n{}^2}$$



- Currently ±0,10 is used on an average flow exponent of 0,66
- Arguably a value of ±0,06 would also be justifiable

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Switching between high and low fan setting

When switching between two airflows, an extra flow has to be introduced in the equation.

$$q_{v,P_r} = \left(q_{v,high}^{\frac{1}{n}} - q_{v,low}^{\frac{1}{n}} \right)^n \cdot \left(\frac{P_r}{\Delta P} \right)^n$$

When $q_{v,low} = 0$, the original equation $q_{v,P_r} = q_{v,sys} \cdot \left(\frac{P_r}{\Delta P} \right)^n$ is regained.

The extra flow also brings an extra uncertainty into the equation

$$\sigma_{q_{v,P_r}} = \sqrt{\left(\frac{\delta q_{v,P_r}}{\delta q_{v,high}} \right)^2 \cdot \sigma_{q_{v,high}}{}^2 + \left(\frac{\delta q_{v,P_r}}{\delta q_{v,low}} \right)^2 \cdot \sigma_{q_{v,low}}{}^2 + \left(\frac{\delta q_{v,P_r}}{\delta \Delta P} \right)^2 \cdot \sigma_{\Delta P}{}^2 + \left(\frac{\delta q_{v,P_r}}{\delta n} \right)^2 \cdot \sigma_n{}^2}$$

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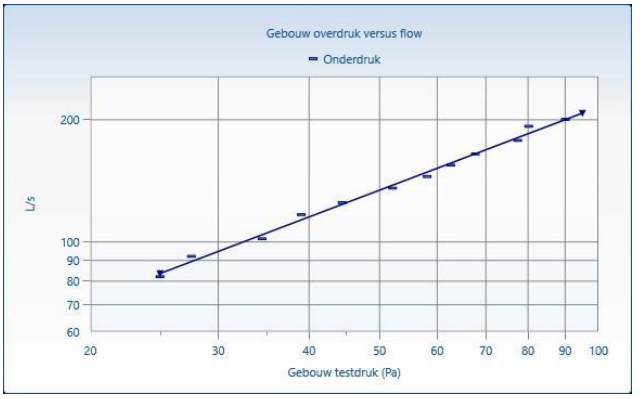
Uncertainty of a blower door test

ISO9972 only gives a recommended procedure for estimating an uncertainty for the flow exponent and the air leakage coefficient. A way to calculate the total uncertainty taking into consideration more variables has been described by Delmotte (2013)*.



*Delmotte, C., (2013). *Airtightness of buildings – Calculation of combined standard uncertainty. Athens, Greece, Proceedings of the 34th AIVC Conference, 25-26 September 2013.*

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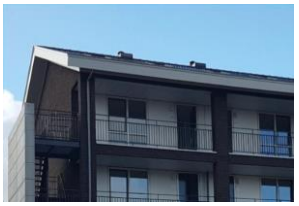
Measured buildings

- Newly built or renovated.
- Both the blower door and ATT measurements are done by the same independent party.





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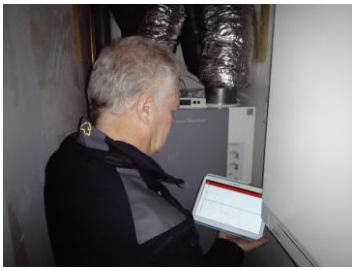
Procedure





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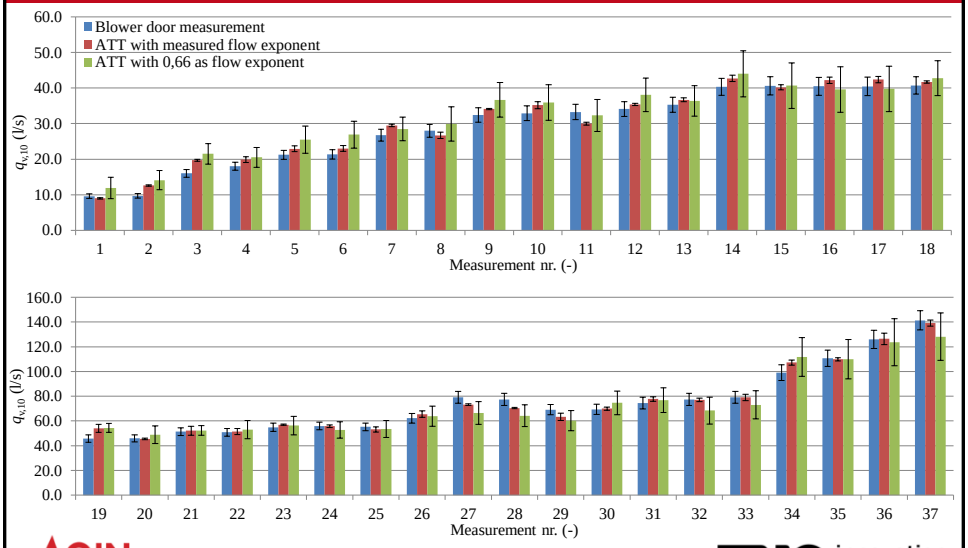
10

On/off vs blower door



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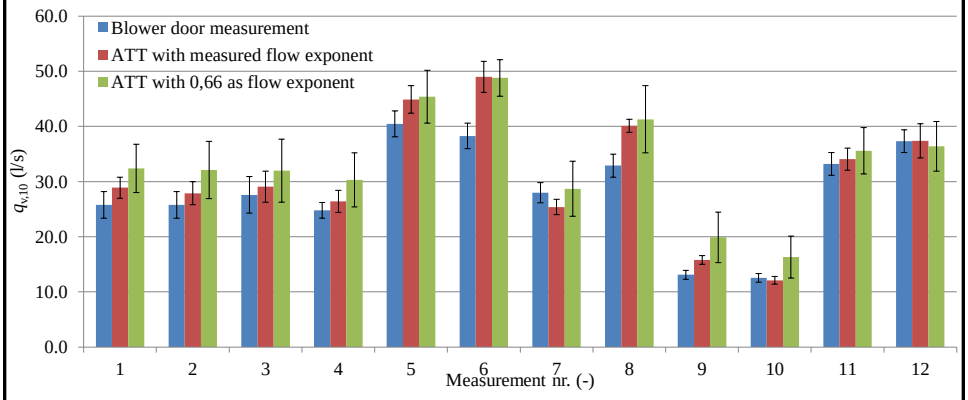
High/low vs blower door



- The air leakage value as measured with ATT with a measured flow exponent is higher in 10 out of 12 cases.
- The ATT and blower door measurements have similar uncertainties when using a measured flow exponent.

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Measurements done on both on/off and high/low

Measurement	$q_{v,10}$ on/off (l/s)	$\Delta P_{on\text{-}off}$ (Pa)	$q_{v,10}$ high/low (l/s)	$\Delta P_{high\text{-}low}$ (Pa)
1	30,9±3,2	27,5	32,4±4,4	22,4
2	28,2±3,5	34,6	32,0±5,7	20,2
3	27,4±2,9	28,7	30,3±4,9	15,9
4	29,9±4,8	48,6	28,7±5,0	25,1
5	30,9±3,2	27,5	32,1±5,2	17,8
6	35,9±5,0	39,5	41,3±6,1	27,5

The closer $\frac{P_r}{\Delta P}$ in the equation is to 1, the smaller the impact of the uncertainty in the flow exponent will be on the total uncertainty, explaining the similar uncertainties in measurement 4.

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In summary

• A method to measure the air leakage through a buildings own ventilation system has been described, measuring the pressure between the building itself and a reference vessel.

• A measurement with the ATT gives a higher value for the air leakage than the blower door:
- in 23 of the 37 measurements when switching between on and off.
- in 10 of the 12 measurements when switching between high and low.

• Switching between high and low is not the preferred method of testing, because of the increase in uncertainty caused by the extra flow in the calculation as well as the lower pressure signal.

• The increase in uncertainty is however not significant to the extent that the measurement becomes unusable as a quick tool to judge whether a building passes its airtightness requirement, as long as the uncertainty is considered in this judgement.

• Switching between a high and low setting should therefore only be used when switching between on and off cannot be done.

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AIVC2019

Refined assessment and comparison of airtightness measurement of indoor chambers using the blower door and Pulse methods

Presenter: Christopher Wood

Authors: Xiaofeng Zheng, Joe Mazzon, Ian Wallis, Christopher J Wood

1

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- Background to Pulse
- Equipment and setup
- Test results
- Conclusions

Buildings, Energy and Environment Research Group
Faculty of Engineering
University of Nottingham, United Kingdom

2

Introduction-Research activities

Research activities

Real houses natural environment	36th AIVC
House-sized chamber sheltered environment	38th AIVC
1. Small chamber natural environment; 2. Impact of steady wind on the pulse test; 3. Pulse → Infiltration (one dwelling); 4. Pulse vs. BD in an extended range.	39th AIVC
1. Refined comparison in a sheltered environment; 2. Experimental verification of DOMVENT3D; 3. Verification of the divide-by-20 rule; 4. Indoor pressure distribution during the Pulse test; 5. Wind impact on the Pulse test in a real house;	40th AIVC

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3

Working Principle of Pulse

The pulse technique is implemented by releasing a measured amount of compressed air from an air tank over short period of time (1.5 s) to the test space and monitor the pressure response in the space.



Tank unit



Control unit

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Working Principle of Pulse

PULSE

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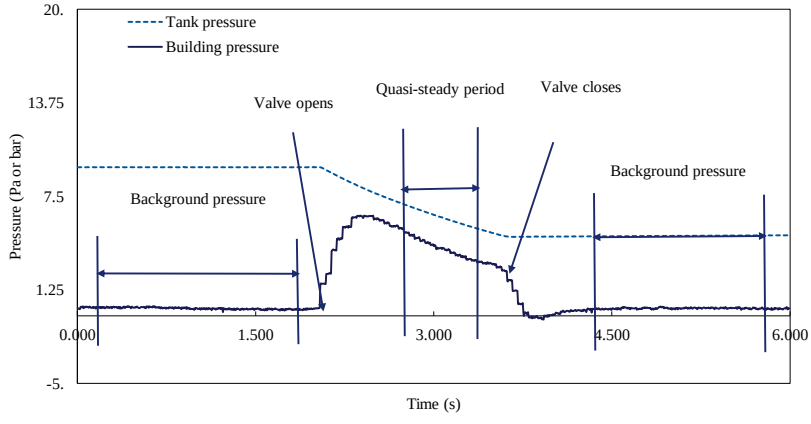
Working Principle of Pulse



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6

Test chambers



Small test chamber



Large test chamber

Chamber	Dimensions (m×m×m)	Volume (m^3)
Small	4.0×2.0×2.0	16
Large	L shaped	269

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7

Test chambers



Sheltering building

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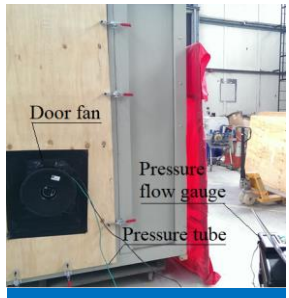
8

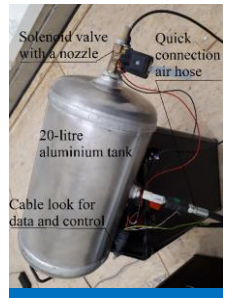
Equipment



PULSE-60



Duct Blaster B



PULSE-20/40

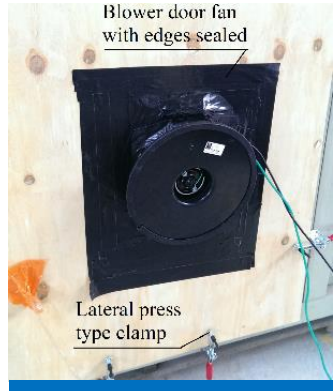
Large chamber tests

Small chamber tests

Small chamber test setup



Setup in small chamber



Installation of DBB

Small chamber testing scenario

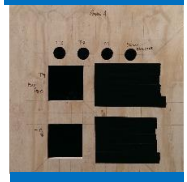

T0


T1


T2


T3


T4


T5


T6


T7

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Large chamber test setup



Petrol driven multiple gear portable fan


Installation of DBB

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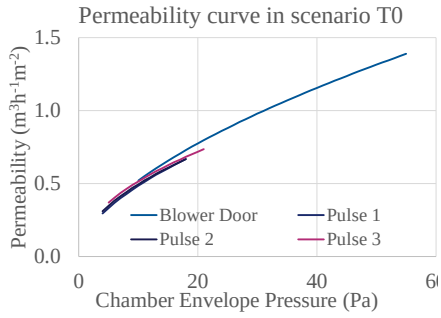
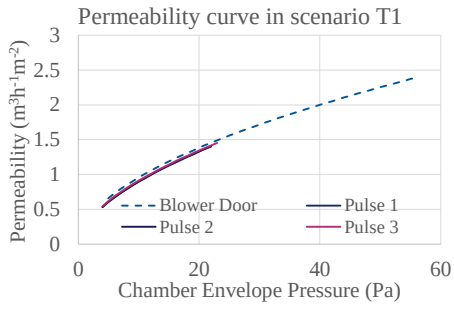
12

Results-Small chamber tests





Scenario	Range of crossover (Pa)	Minimum (%)	Maximum (%)	Average (%)
T0	10-18	4.1%	7.8%	6.4%
T1	5-23	2.5%	7.8%	4.9%
T2	6-16	0.8%	4.1%	1.6%
T3	7-20	0%	2.2%	0.6%
T4	N/A	N/A	N/A	N/A
T5	9-13	6.0%	12.8%	9.6%
T6	16	7.4%	7.4%	7.4%
T7	14-20	3.8%	6.4%	5.5%

Note: N/A means no pressure overlap was achieved.

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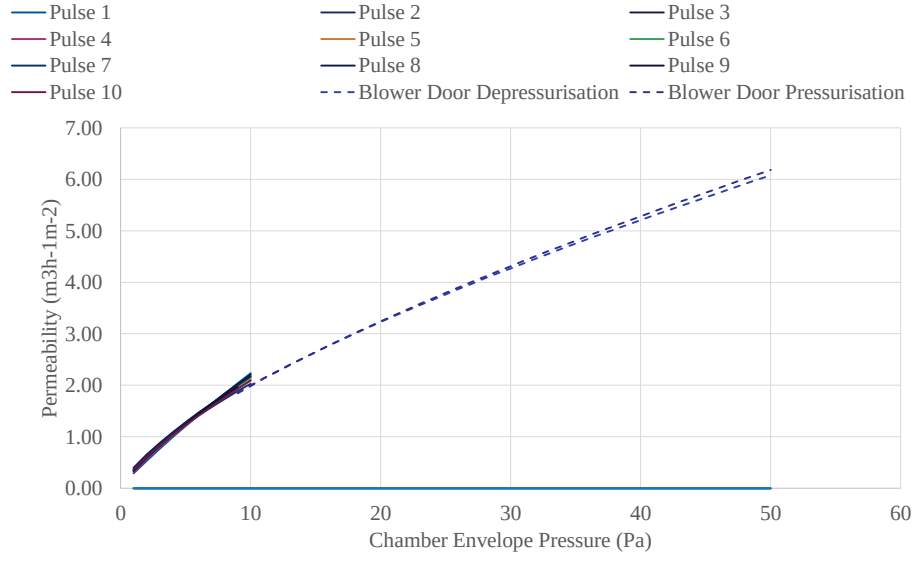
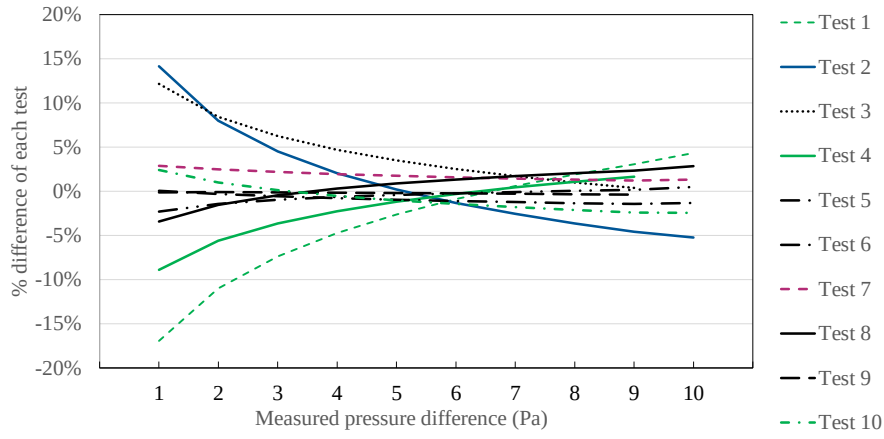
Results-Large chamber test



14

Results-Large chamber test



Measurement Relative % difference (1-10Pa) of 10 repeated tests

15

Conclusions

- Measures were taken to achieve a minimized difference in testing and envelope conditions under various scenarios;
- In most of testing scenarios, a good agreement was obtained in an overlapped pressure range, with a maximum difference of 7.4% in the small chamber. A similar difference was observed in the large chamber.
- This finding was found to be similar with previous comparison, which suggests the blower door installation didn't cause significant difference in the leakage of tested chamber.
- The largest discrepancy was observed in the scenario where the largest opening was present, which might be attributable to uneven pressure distribution around the opening.
- A good repeatability was demonstrated in the repeated tests carried out in the large chamber and the results showed the measurement RPD was within ±5% when the measured pressure level is no smaller than 4 Pa.

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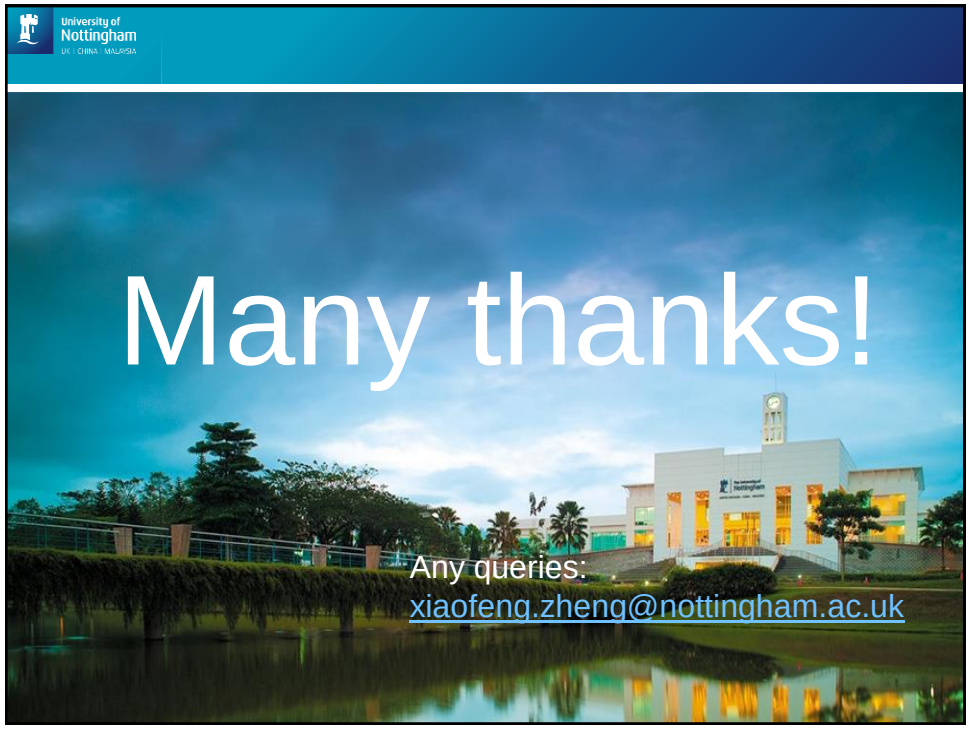
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Many thanks!
Any queries:
xiaofeng.zheng@nottingham.ac.uk

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Evaluation of Indoor Pressure Distributions in a Detached House Using the Pulse Airtightness Measurement Technique

Presenter: Yun-Sheng (Winston) Hsu

Authors: Yun-Sheng Hsu, Xiaofeng Zheng, Edward Cooper, Mark Gillott, Shin-Ku Lee and Christopher J Wood

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Contents

- Research Motivation
- Dwelling and Equipment
- Test Arrangement, Results and Analysis
  1. Indoor Pressure Distribution During Pulse Test And Blower Door Test
  2. Effect Of Pulse Release Location
- Conclusions
- Discussions and Future Works

2

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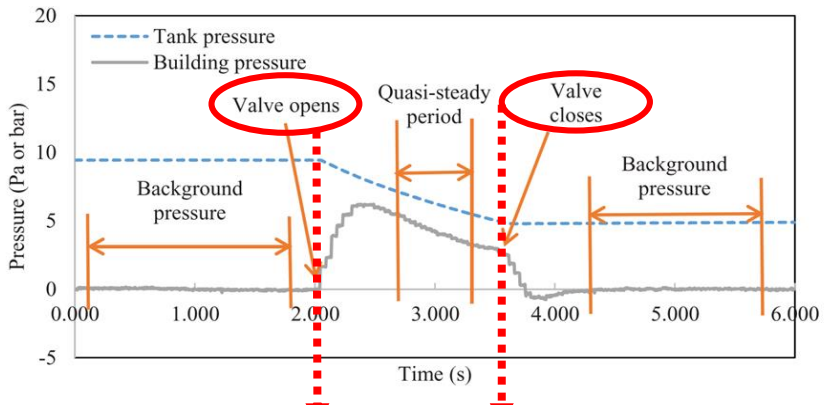
Research Motivation

3

Description of the Pulse Technique

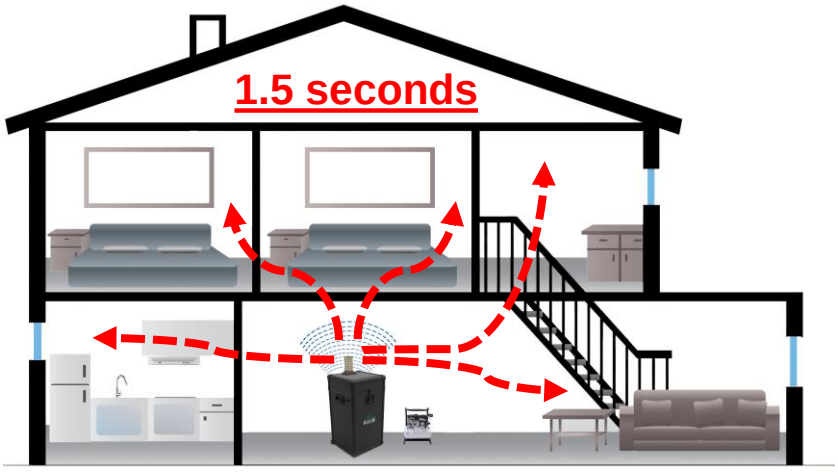


1.5 seconds

4

Research Motivation

1. Is there any uniformity of the pressure distribution during the air pulse release within 1.5 seconds?
2. Does the Pulse release location affect measurement results?



5

Dwelling and Equipment

6

Dwelling

Test Dwelling Details	
Dwelling	Wortley 5 University of Nottingham University Park, Nottingham
Type	Five-bedroom detached house
Year	Built in 1950 Retrofitted in 2018
Volume (m^3)	447
Envelope area (m^2)	416
Approximate ACH @50Pa	3.71 (Blower door tested on December 2018)
Approximate ACH @4Pa	0.73 (PULSE-60 tested on December 2018)









Floor Plans

7

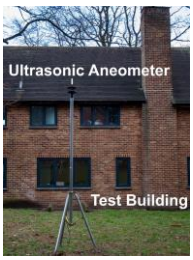
Equipment



PULSE-60 Unit with Control Box



Blower Door (Duct Blaster B)



Ultrasonic Anemometer



Differential Pressure Transducers

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Test Arrangement, Results and Analysis

1. Indoor Pressure Distribution During Pulse Test and Blower Door Test

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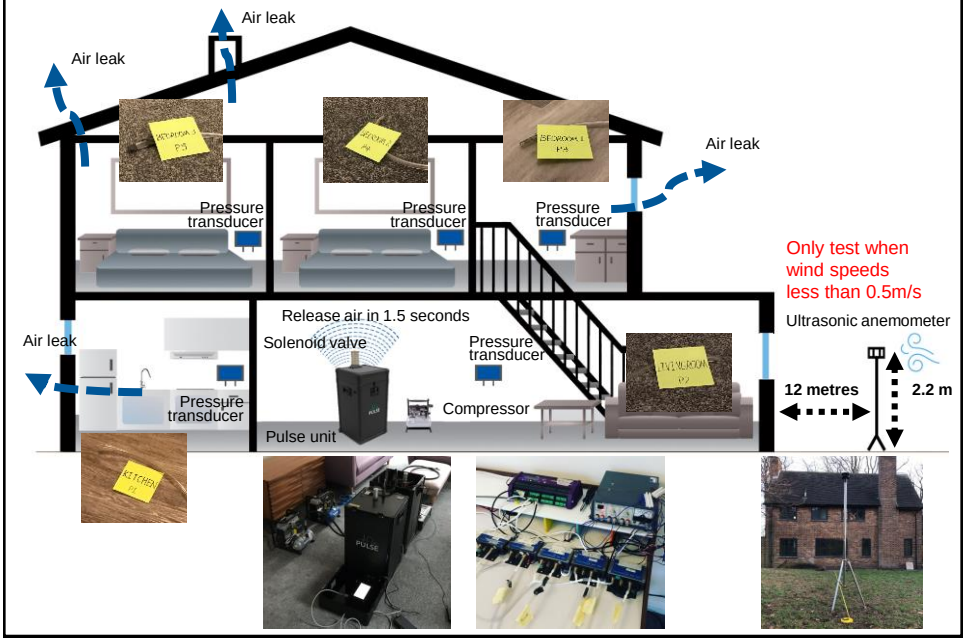
Indoor Pressure Distribution During the Pulse Test



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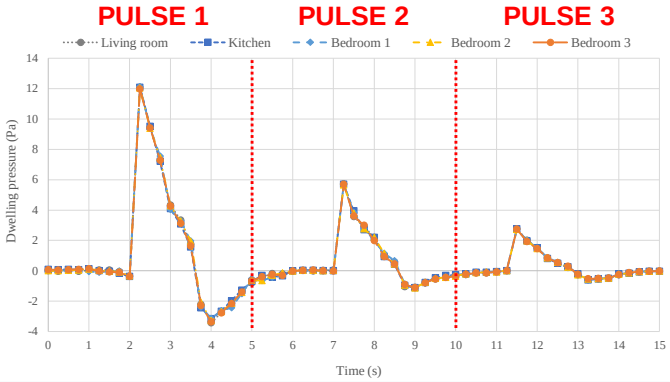
Pulse Test Results





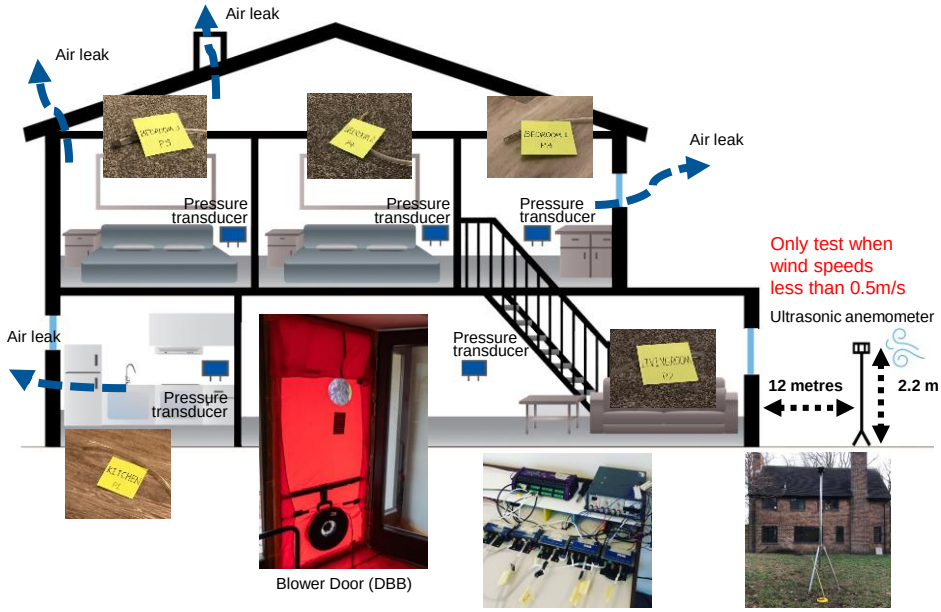
Pressure Distribution in each room for Pulse 1, Pulse 2 and Pulse 3 tests

	Living room	Kitchen	Bedroom 1	Bedroom 2	Bedroom 3	%* (Between Max & Min)	%** (Between Living room & other rooms)
Pulse 1	12.09 Pa	12.09 Pa	12.13 Pa	12.04 Pa	11.99 Pa	1.1%	0.8%
Pulse 2	5.73 Pa	5.71 Pa	5.72 Pa	5.65 Pa	5.69 Pa	1.4%	1.4%
Pulse 3	2.76 Pa	2.78 Pa	2.72 Pa	2.72 Pa	2.74 Pa	2.2%	1.4%

***Relative percentage difference between maximum and minimum**
****The maximum relative percentage difference between living room and the other rooms**

11

Indoor Pressure Distribution During Blower Door Test



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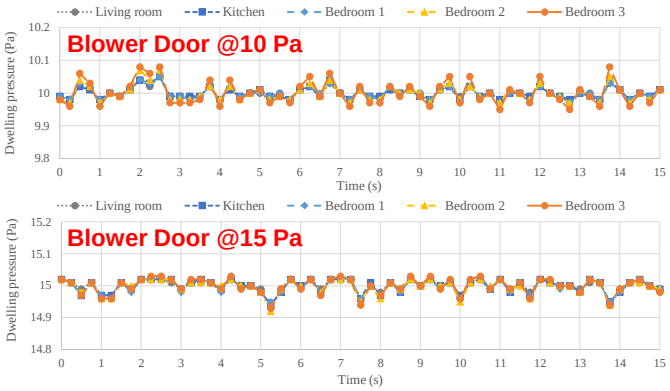
Blower Door Test Results





Pressure Distribution in each room for Blower Door tests at 10 Pa and 15Pa

	Living room	Kitchen	Bedroom 1	Bedroom 2	Bedroom 3	%* (Between Max & Min)	%** (Between Living room & other rooms)
Blower Door 10 Pa	10.03 Pa	10.04 Pa	10.03 Pa	10.05 Pa	10.08 Pa	0.5%	0.5%
Blower Door 15 Pa	14.93 Pa	14.94 Pa	14.95 Pa	14.92 Pa	14.93 Pa	0.2%	0.1%

*Relative percentage difference between maximum and minimum
**The maximum relative percentage difference between living room and the other rooms

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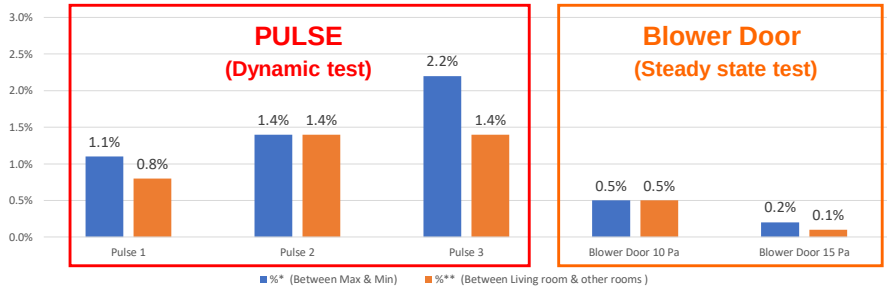
Comparison of Two Different Test Methods



Pressure Distribution in each room for Pulse and Blower Door tests

	Living room	Kitchen	Bedroom 1	Bedroom 2	Bedroom 3	%* (Between Max & Min)	%** (Between Living room & other rooms)
Pulse 1	12.09 Pa	12.09 Pa	12.13 Pa	12.04 Pa	11.99 Pa	1.1%	0.8%
Pulse 2	5.73 Pa	5.71 Pa	5.72 Pa	5.65 Pa	5.69 Pa	1.4%	1.4%
Pulse 3	2.76 Pa	2.78 Pa	2.72 Pa	2.72 Pa	2.74 Pa	2.2%	1.4%
Blower Door 10 Pa	10.03 Pa	10.04 Pa	10.03 Pa	10.05 Pa	10.08 Pa	0.5%	0.5%
Blower Door 15 Pa	14.93 Pa	14.94 Pa	14.95 Pa	14.92 Pa	14.93 Pa	0.2%	0.1%

*Relative percentage difference between maximum and minimum
**The maximum relative percentage difference between living room and the other rooms

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Test Arrangement, Results and Analysis

2. Effect of Pulse Release Location

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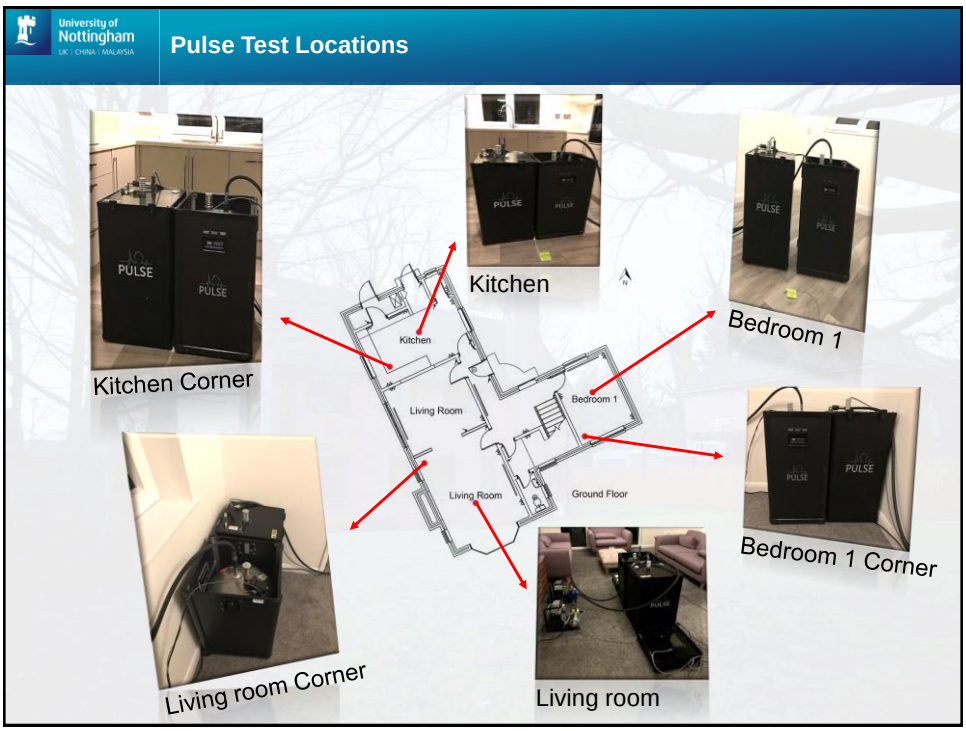

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Measurement Results for the Pulse Tests at Different Locations

Measurement results of building permeability ($m^3/h/m^2$) for the pulse tests at different locations

	Living room	Living room Corner	Bedroom 1	Bedroom 1 Corner	Kitchen	Kitchen Corner
Test 1	0.721	0.715	0.719	0.718	0.721	0.718
Test 2	0.730	0.719	0.726	0.723	0.726	0.722
Test 3	0.725	0.714	0.702	0.730	0.763	0.725
Test 4	0.732	0.722	0.733	0.764	0.732	0.709
Test 5	0.715	0.733	0.723	0.706	0.713	0.706
Location Average	0.725 (±1.38%) *	0.721 (±1.66%)	0.721 (±2.64%)	0.728 (±4.95%)	0.731 (±4.38%)	0.716 (±1.40%)
Overall Average	0.724					
%**	0.15%	0.40%	0.40%	0.65%	1.03%	1.05%

* Highest relative percentage difference between each test and average
** Relative percentage difference between location average and an overall average

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Conclusions

1. Experimental investigations were conducted on building airtightness measurement under calm weather conditions (wind speed <0.5m/s) using the Pulse technique and Blower door.

2. Uniformity of pressure distribution within the test building was achieved in Pulse test, with a minor pressure difference of indoor spaces (i.e. highest relative percentage difference of 2.2%).

3. In terms of the Blower door tests, the relative percentage difference of the maximum pressure level in each room is lower than Pulse test (0.5% at 10Pa and 0.2% at 15Pa).

4. An insignificant impact of Pulse test location on building airtightness measurement was observed with a subtle variation (i.e. 1.05%) in building air permeability when Pulse tests were conducted at different locations inside the test building.

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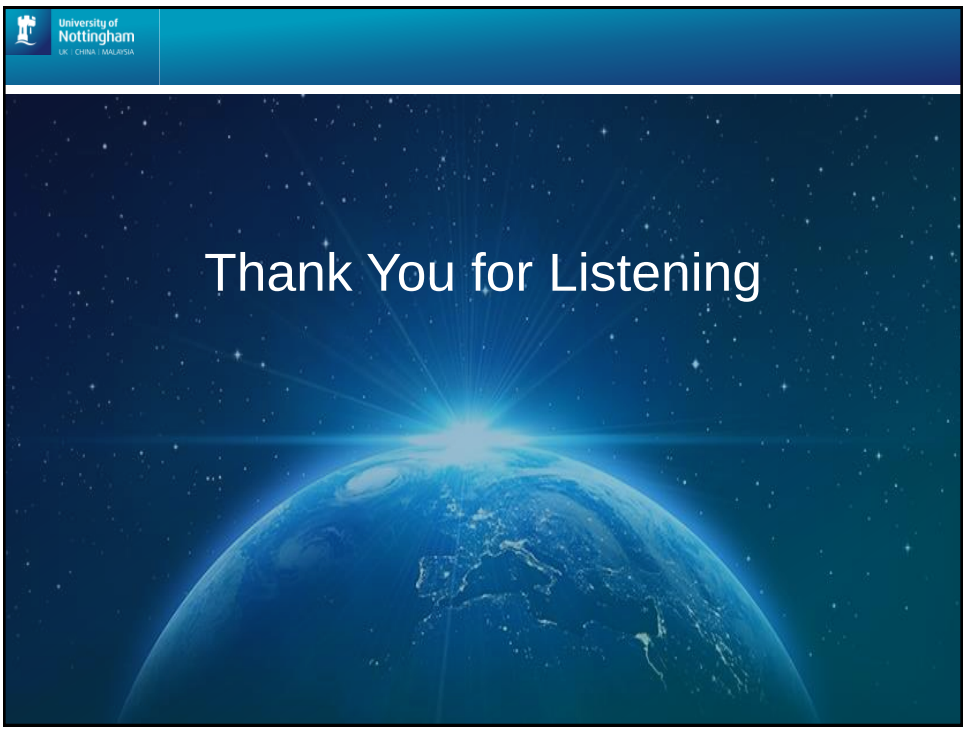
Discussions and Future Works

- Limitation: The “quasi-steady” condition of a Pulse test is achieved only in 0.8s, so limited pressure data were gathered by datataker with the maximum measurement frequency of 4Hz when connected with five pressure transducers.

- Future work: CFD-based numerical studies to identify how the pressure wave travel within the internal spaces of the test building and how the building pressure distributes across different zones within the building during the Pulse test.



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Insights into the Impact of Wind on the Pulse Airtightness Test in a UK Dwelling

Presenter: Yun-Sheng (Winston) Hsu

Authors: Yun-Sheng Hsu, Xiaofeng Zheng, Dimitrios Kraniotis, Mark Gillott, Shin-Ku Lee and Christopher J Wood

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Contents

- Research Motivation
- Dwelling and Equipment
- Test Arrangement, Results and Analysis
  1. Tests results in the wind speed range of 0 m/s to 10 m/s
  2. Evaluate whether multiple tests can achieve more accurate testing
- Conclusions
- Future Works

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Research Motivation

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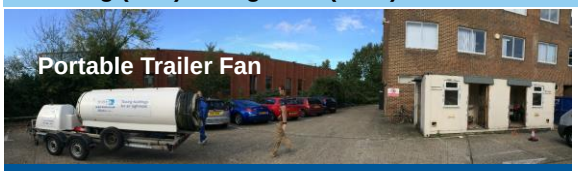
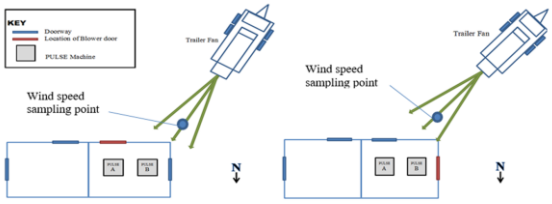
Research Motivation

39th AIVC - Impact of steady wind on the pulse test – Xiaofeng (Ken) Zheng et al. (2018)



Impact of Steady Wind (Oct-2017)



Findings: A small uncertainty (within ±3%) for wind speed < 3.5m/s. However, the uncertainty increased up to ±25.6% for the wind speed of 4.5-9m/s.

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Research Motivation



1. What is the impact of natural wind with different wind speeds on the Pulse airtightness test?
2. Whether multiple Pulse tests can achieve more accurate testing in natural wind conditions?

Dwelling and Equipment

Dwelling

Test Dwelling Details	
Dwelling	Wortley 5 University of Nottingham University Park, Nottingham
Type	Five-bedroom detached house
Year	Built in 1950 Retrofitted in 2018
Volume (m^3)	447
Envelope area (m^2)	416
Approximate ACH @50Pa	3.71 (Blower door tested on December 2018)
Approximate ACH @4Pa	0.73 (PULSE-60 tested on December 2018)









Floor Plans

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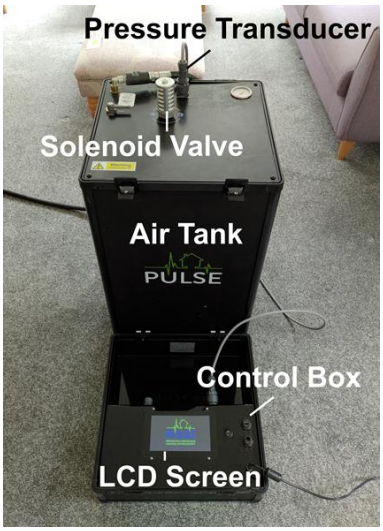
Equipment



PULSE-60 unit with control box



Ultrasonic anemometer

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Test Arrangement, Results and Analysis

1. Tests Results in the Wind Speed Range of 0 m/s to 10 m/s

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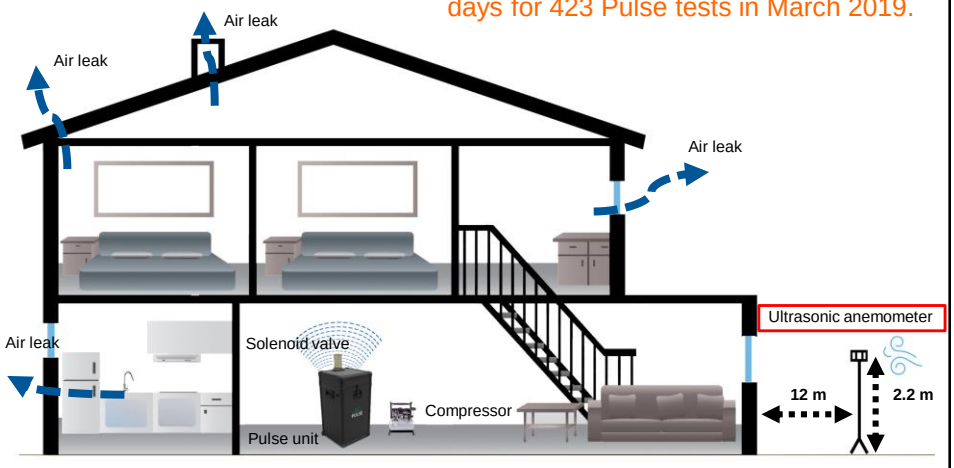
Indoor Pressure Distribution During the Pulse Test

Experimental work was conducted in 7 days for 423 Pulse tests in March 2019.



Testing wind speeds from 0 m/s to 10 m/s

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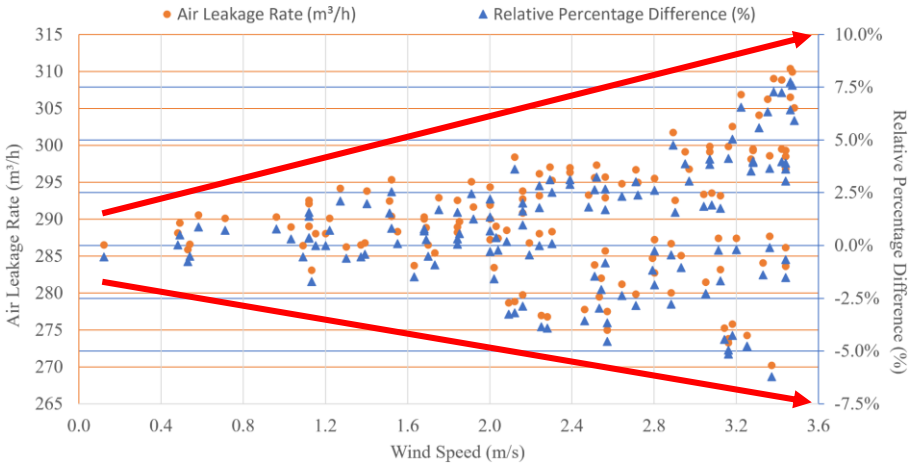
Tests Results in the Wind Speed Range of 0 - 3.5m/s



Wind Speed (Ground level)	Number of Tests	Average ALR <0.5 m/s (3 Tests)	RPD < ±3%	RPD < ±5%	Max RPD
0-3.5 m/s	133	288.02	2.08m/s	3.14m/s	±7.7%

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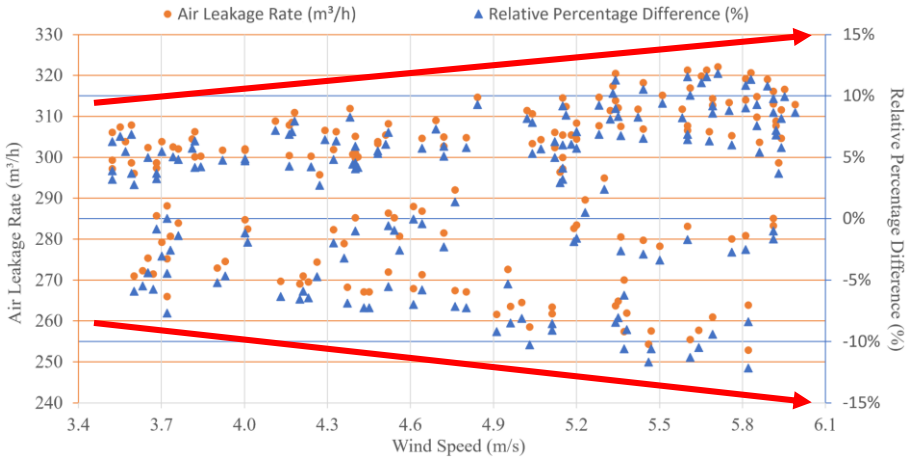
Tests Results in the Wind Speed Range of 3.5 - 6m/s



Wind Speed (Ground level)	Number of Tests	Average ALR <0.5 m/s (3 Tests)	RPD < ±8%	RPD < ±10%	Max RPD
3.5- 6m/s	173	288.02	4.38m/s	5.03m/s	±12.19%

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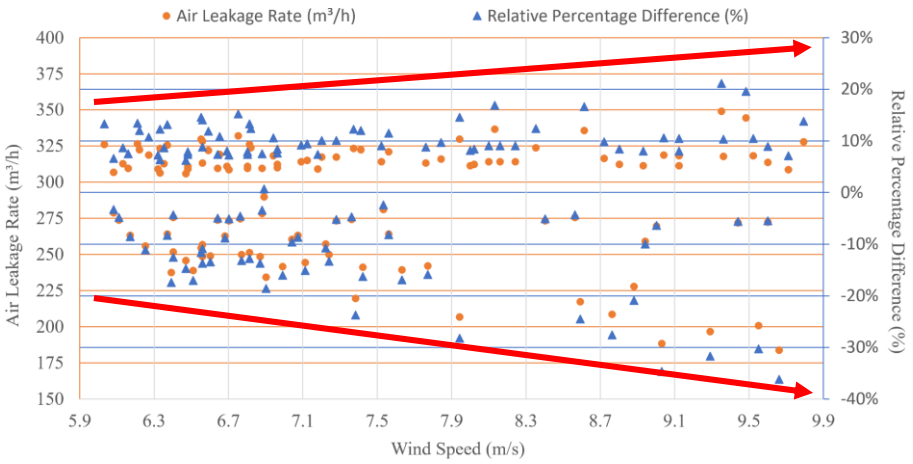
Tests Results in the Wind Speed Range of 6 - 10m/s



Wind Speed (Ground level)	Number of Tests	Average ALR <0.5 m/s (3 Tests)	RPD < ±20%	Max RPD
6 - 10m/s	117	288.02	7.37m/s	±36.23%

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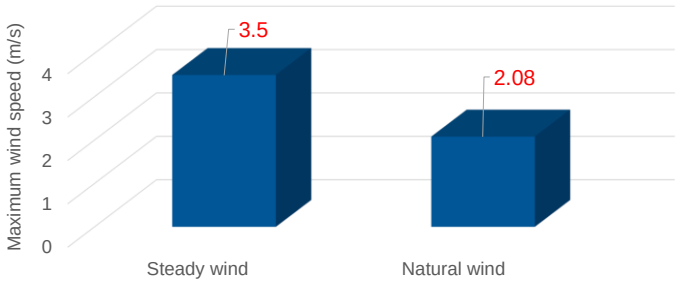
Comparison between steady wind and natural wind conditions

For the relative percentage difference within ±3%, Xiaofeng (Ken) Zheng et al. (2018) found under steady wind speed below 3.5m/s with fixed wind direction, while wind speed below 2.1m/s under natural wind condition within ±3% is noted in this study.

Compare maximum wind speed for RPD<±3% under steady and natural wind conditions



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Test Arrangement, Results and Analysis

2. Evaluate Whether Multiple Tests Can Achieve More Accurate Testing

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Analysis of Test ALR (m³/h) Results for 423 Pulse Tests

Test Group	Wind Speed (Ground level)[1]	Number of Tests	Group Average ALR	Group Average ALR (First three tests)	Relative percentage difference		
					Each Test[2]	Each Group[3]	First Three Tests[4]
A	0 – 0.5 m/s	3	288.02	288.02	-0.53%	0.00%	0.00%
B	0.5 – 1.0 m/s	5	288.66	287.64	-0.76%	0.22%	-0.13%
C	1.0 – 1.5 m/s	15	288.97	288.12	-1.72%	0.33%	0.03%
D	1.5 – 2.0 m/s	17	290.01	292.74	2.54%	0.69%	1.64%
E	2.0 – 2.5 m/s	28	288.84	289.72	-3.91%	0.28%	0.59%
F	2.5 – 3.0 m/s	26	288.63	292.25	-4.53%	0.21%	1.47%
G	3.0 – 3.5 m/s	39	293.85	291.30	7.74%	2.02%	1.14%
H	3.5 – 4.0 m/s	33	291.13	300.87	-7.68%	1.08%	4.46%
I	4.0 – 4.5 m/s	33	292.31	296.14	-7.28%	1.49%	2.82%
J	4.5 – 5.0 m/s	23	286.88	287.92	-9.18%	-0.40%	-0.03%
K	5.0 – 5.5 m/s	43	293.33	278.19	-11.69%	1.84%	-3.42%
L	5.5 – 6.0 m/s	41	301.65	301.69	-12.19%	4.73%	4.74%
M	6.0 – 6.5 m/s	24	294.78	304.01	-17.47%	2.35%	5.55%
N	6.5 – 7.0 m/s	33	288.54	274.40	-18.60%	0.18%	-4.73%
O	7.0 – 7.5 m/s	16	281.42	279.31	-23.77%	-2.29%	-3.03%
P	7.5 – 8.0 m/s	10	282.87	286.57	-28.18%	-1.79%	-0.50%
Q	8.0 – 8.5 m/s	8	312.50	312.63	16.93%	8.50%	8.54%
R	8.5 – 9.0 m/s	9	273.82	276.31	-27.56%	-4.93%	-4.07%
S	9.0 – 9.5 m/s	10	288.59	258.85	-34.59%	0.20%	-10.13%
T	9.5 – 10 m/s	7	275.05	263.75	-36.23%	-4.50%	-8.43%

Based on low wind speed condition 0 – 0.5 m/s (3 Tests)	Average ALR (m³/h)
	288.02

1. Wind Speed measured at the height of the 2.2m above ground
2. The maximum relative percentage difference of ALR of each single test to the average of low wind speed ALR
3. The relative percentage difference of average ALR of each group to the average of low wind speed ALR
4. The relative percentage difference of average ALR of first three tests to the average of low wind speed ALR

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Conclusions

1. 423 Pulse tests were conducted to measure the building airtightness of a five-bedroom house under various wind conditions (wind speed 0-10m/s).

2. A more precise building measurement can be achieved for testing under wind speed lower than 5m/s (i.e. a relative percentage difference <±10%).

3. When wind speed above 7.3m/s, the relative percentage difference of a single Pulse test can exceed ±20%, which indicates that the measurement may be imprecise owing to the wind impact.

4. Multiple Pulse tests could minimise the wind impact. For instance, the maximum RPD of a single Pulse test under wind speed of 5.0-5.5m/s can be decreased from 11.69% to 1.84%, by repeating 43 Pulse tests.

Future Works

Future work:

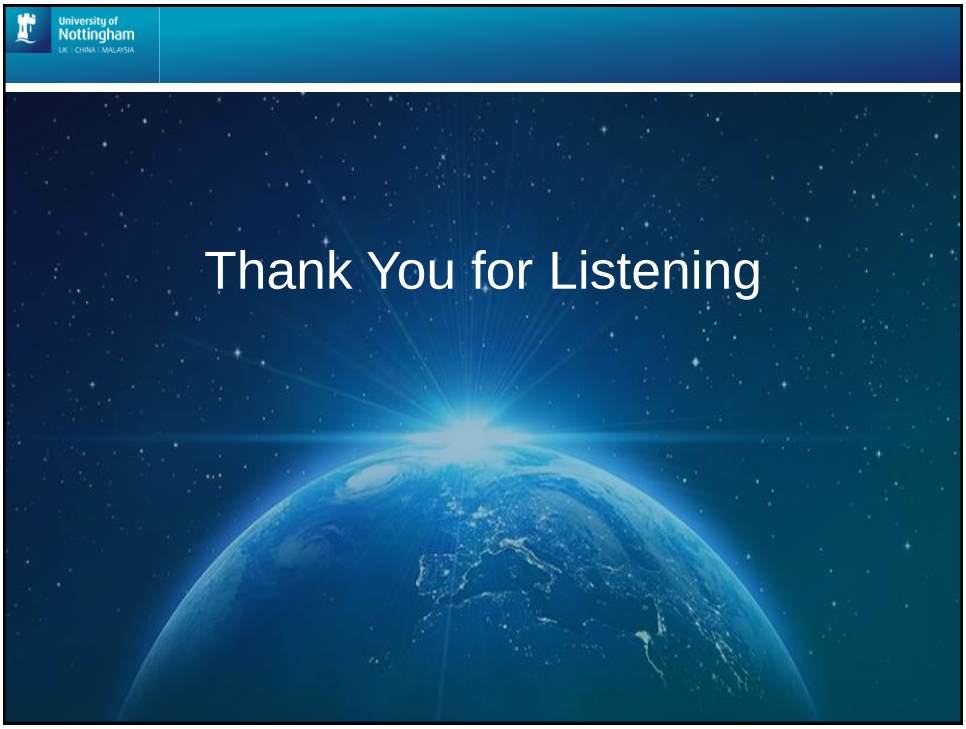
- Investigation of quicker air tank charging methods to allow more tests within a short period under similar wind conditions.

- Improving the algorithm of the Pulse technique to address the wind impact on measurement for wide applicability under high wind speed conditions.

Hopefully 41th AIVC –

1. Investigate impact of natural wind on the Pulse test based on long period observation.

2. Investigate wind impact on the Pulse test under controlled conditions using wind tunnel and validate with other experimental data.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Thank You for Listening

Estimation of Air Leakage Sizes in Building Envelope using High-Frequency Acoustic Impulse Response Technique

40th AIVC – 8th TightVent & 6th venticool Conference

Benedikt Kölsch et al.

German Aerospace Center (DLR) – Institute of Solar Research
Jülich, Germany

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag



1

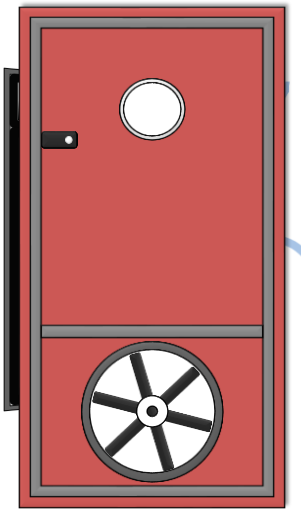
Air Leakage in Building Envelopes

Uncontrolled Airflow → increase **consumption of heating and cooling energy**

Measuring Airtightness: **Blower door test**

1. **Measuring air leakage** in buildings
2. **Comparing relative airtightness** of different buildings
3. **Determining reduction** of air permeability

→ Leakage detection **time-consuming** and **expensive**



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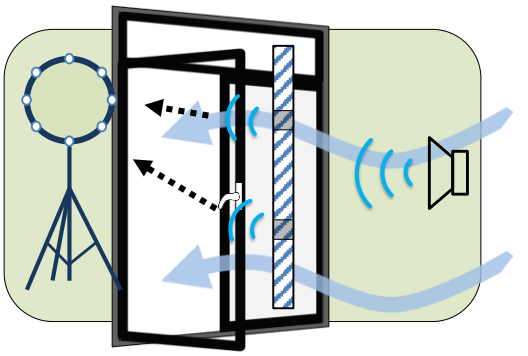
Why Acoustics?

Sound takes predominantly the **same paths** as **air** in fan pressurization method

Advantages:

- Can be applied while building is in use
- Independent from pressure or temperature differences
- Microphone arrays can localize leakage spots

→ Size quantification difficult



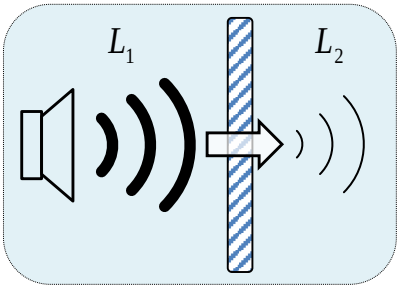
Is leakage size quantification possible?

Sound Transmission

Objective: Identification of **different leaks sizes** in **different materials**

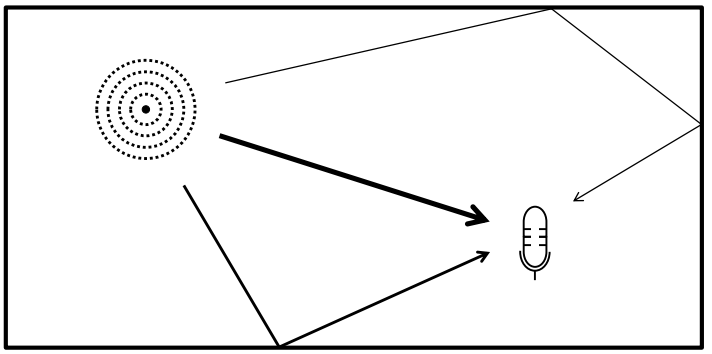
Airborne **sound insulation** depends significantly on **sound transmission through leaks**

→ Determination of frequency-dependent **sound level difference** through wall

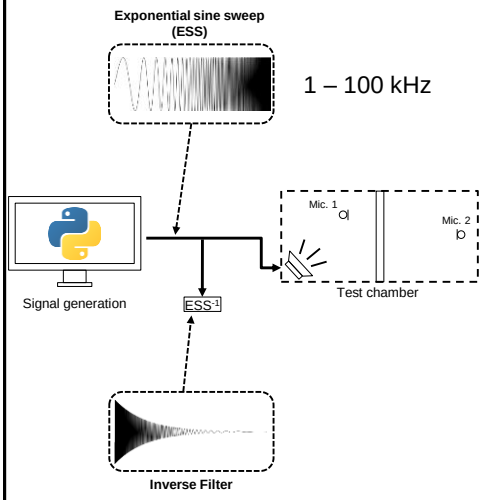


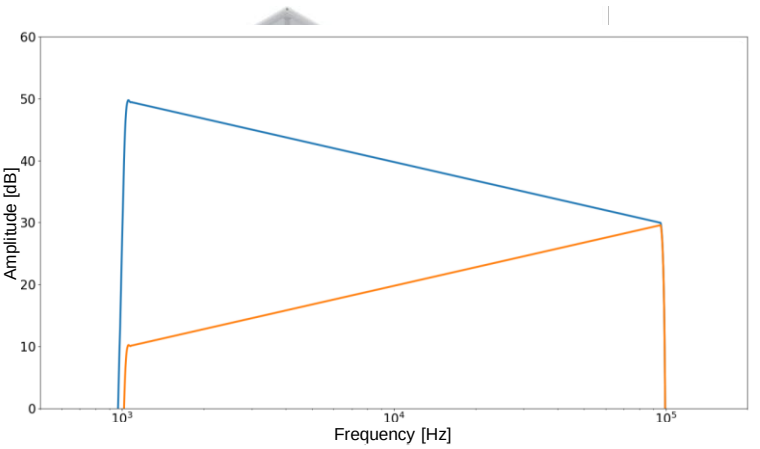
Room Impulse Response

- Response of a room to an impulsive stimulus
- Complete characterisation of a system → Acoustical „signature“ of a room

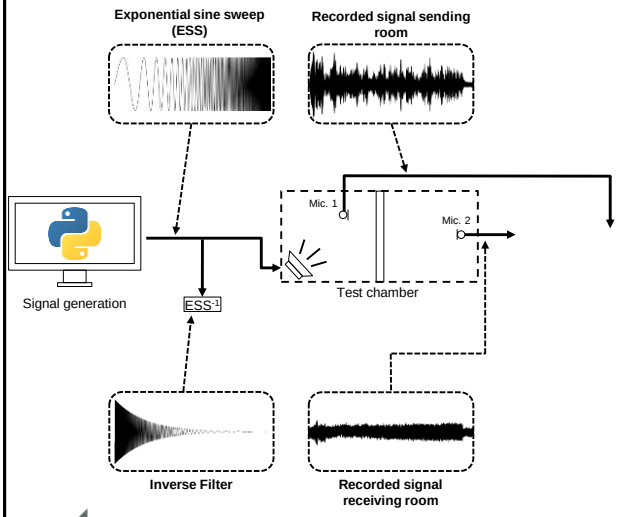


Measurement Concept – Sound Pressure Level ΔL_P

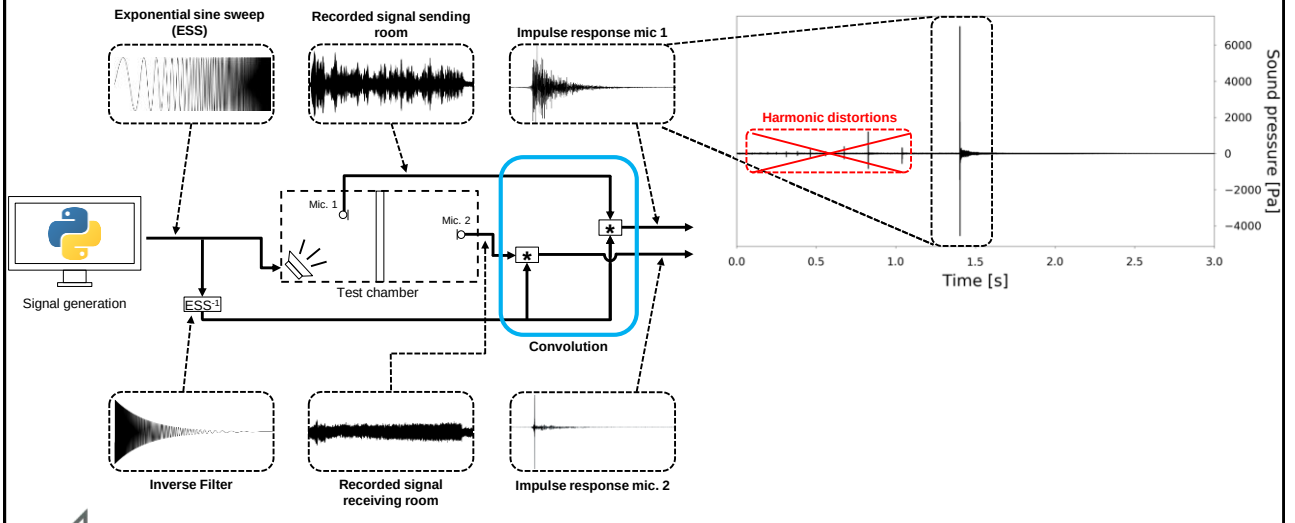




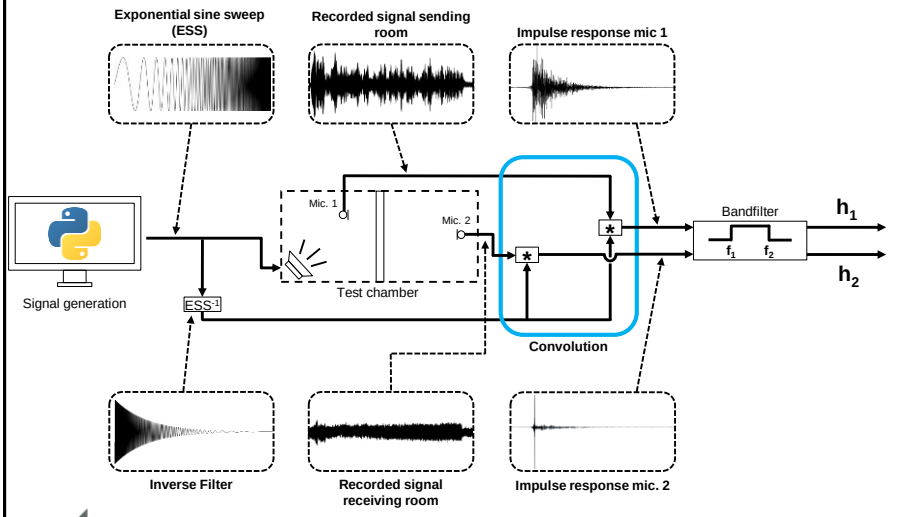
Measurement Concept – Sound Pressure Level ΔL_P



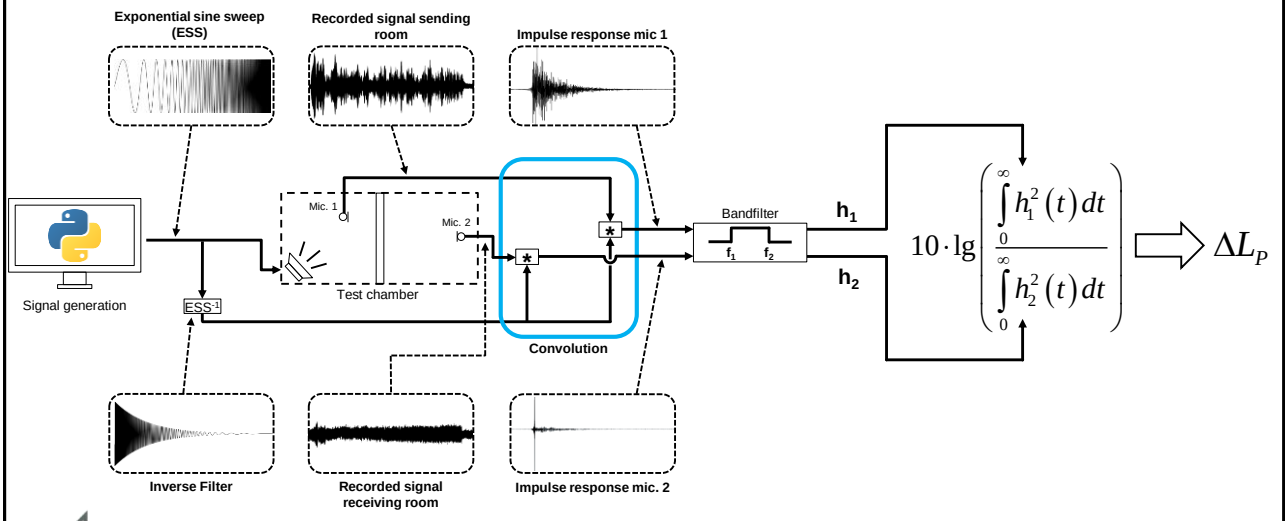
Measurement Concept – Sound Pressure Level ΔL_P



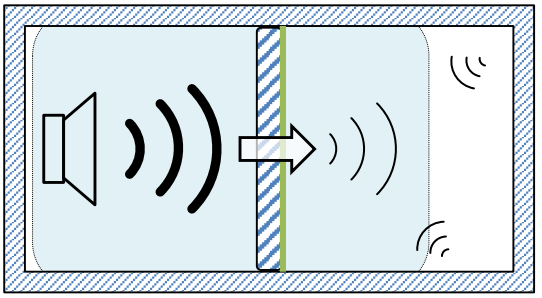
Measurement Concept – Sound Pressure Level ΔL_P



Measurement Concept – Sound Pressure Level ΔL_P



Sound Pressure Level ΔL_P vs. Sound Reduction Index R

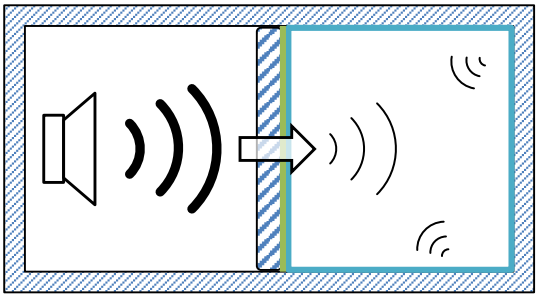


S: Surface area of wall [m²]

A: Equivalent sound absorption area [m²] = f(freq.)

$$R = \Delta L_P + 10 \cdot \lg\left(\frac{S}{A}\right)$$

Sound Reduction Index R – Equivalent Absorption Area

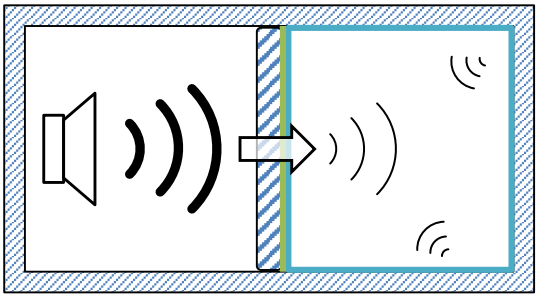


V: Volume of receiving room [m³]

T: Reverberation time [s] = f(freq.)

$$R = \Delta L_P + 10 \cdot \lg\left(\frac{S}{A}\right) = \Delta L_P + 10 \cdot \lg\left(\frac{S}{V\left(\frac{0.163}{T} - 4m\right)}\right)$$

Sound Reduction Index R – Equivalent Absorption Area



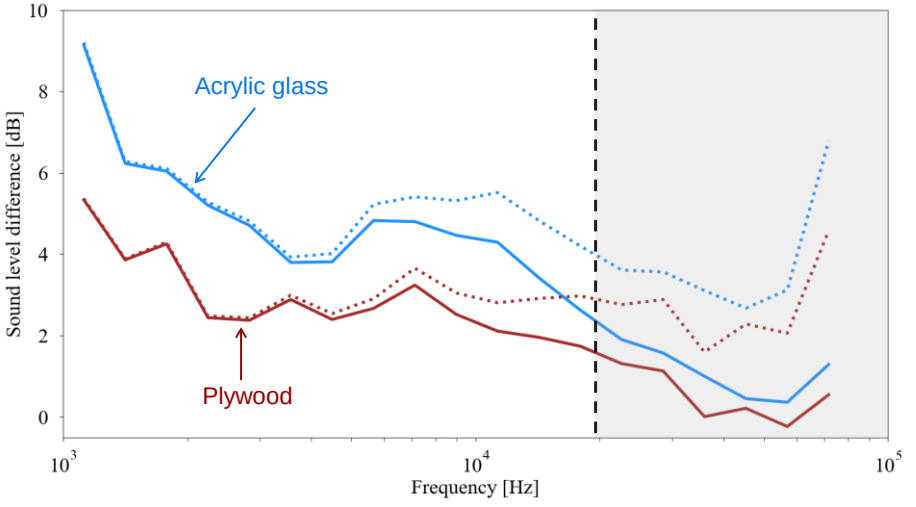
V: Volume of receiving room [m³]

T: Reverberation time [s] = f(freq.)

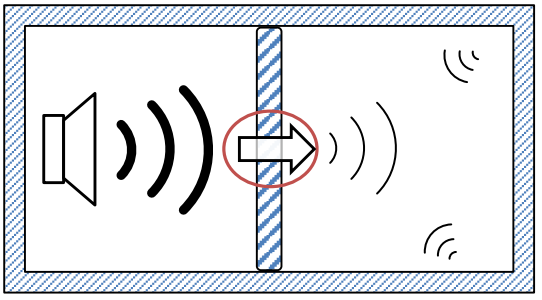
m: Attenuation coefficient [1/m] = f(freq., T_{air}, h_{air})

$$R = \Delta L_P + 10 \cdot \lg\left(\frac{S}{A}\right) = \Delta L_P + 10 \cdot \lg\left(\frac{S}{V\left(\frac{0.163}{T} - 4m\right)}\right)$$

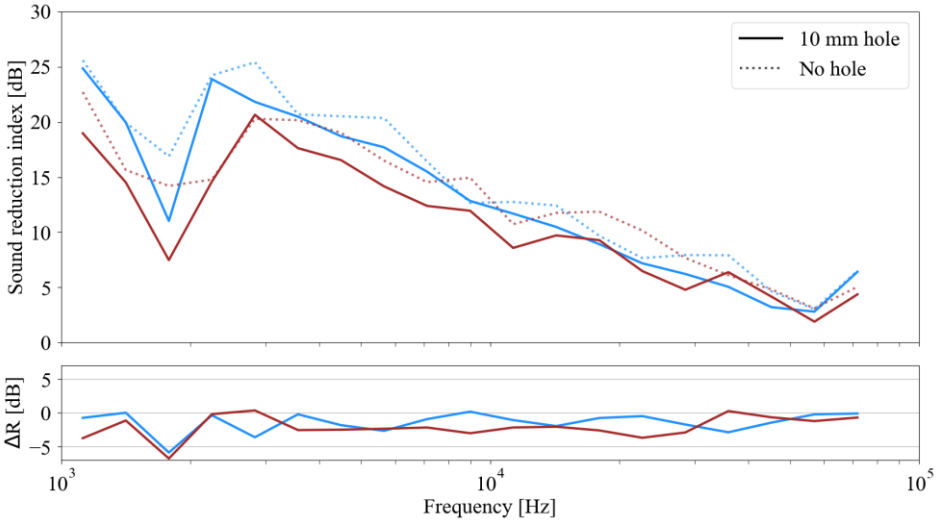
Influence of Attenuation in Air



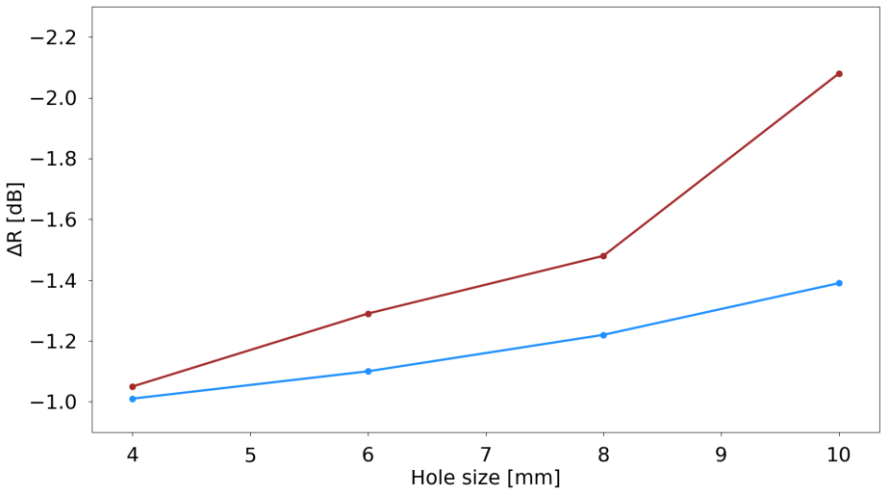
Sound Reduction Index R with Leakage



Experimental Results – Sound Reduction Index 10 mm



Experimental Results – Mean Sound Reduction Index Difference



Conclusion and Outlook

- **Utilization** of **impulse responses** and considering of **high frequencies**
- **Differentiation** between **leak-proof walls** and **walls with holes** possible
- **Distinction** between **leak sizes** and **material** possible
- **Determination** of **leak size** from **single measurement not possible** yet
- **Measurements** with **more realistic leaks** are necessary at test bench
- **Comparison** with **air infiltration** rates in same test bench will be possible

Thank you

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Deviation of blower-door fans over years through the analysis of fan calibration certificates

VALÉRIE LEPRINCE – PLEIAQ
CHRISTOPHE DELMOTTE – CSTC/BBRI
ISABELLE CARÉ - CETIAT

1

Introduction

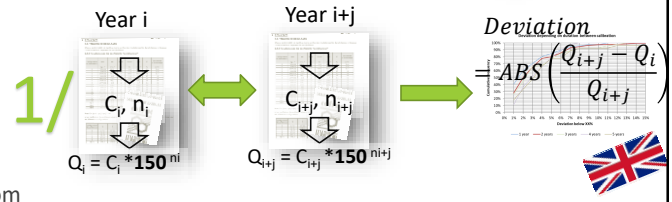


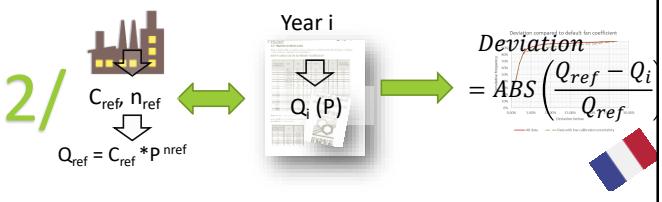
Gathering of calibration certificates from certified bodies
- mainly from UK and France.

Objective:
- Evaluate fan deviation over years

Methodologies
- 1/ Deviation of recalculated fan coefficients from the calibration points
  - systematic adjustment of fan coefficients
- 2/Deviation compared to the manufacturer coefficients.

Results on the impact of the calibration uncertainty





2

Data

4 Sources:

- Stromatech: calibration laboratory in UK
- CEREMA: testers depend on French ministry for building
- Syneole: Trade union of airtightness testers in France
- BCCA: Certification body in Belgium

1/ 12 fans up to 10 configurations per fan + multiple calibration

	1 year	2 years	3 years	4 years	5 years
Stromatech	67	55	43	32	21
Cerema	0	22	0	6	0
Syneole	11	76	10	6	0
BCCA	0	0	0	0	6
Total	78	153	53	44	27

2/ 62 calibration certificates, 325 configurations => 1007 data

Check of calibration uncertainty, reliable data:

$$U < \max\left(\frac{q_{vd} - q_{vr}}{3}; \frac{0.05\, q_{vr}}{3}; \frac{2}{3}\right)$$

3

Part 1



RECALCULATED COEFFICIENTS

4

Results part 1

To be kept in mind that results include

- calibration uncertainty
- the error due to the linear regression for the calculation of coefficients.

Large impact of the pressure used to calculate the flowrate

Year i



$Q_i = C_i * 150^{ni}$

Year i+j



$Q_{i+j} = C_{i+j} * 150^{ni+j}$

$$Deviation = ABS\left(\frac{Q_{i+j} - Q_i}{Q_{i+j}}\right)$$

Deviate of more than 10%:

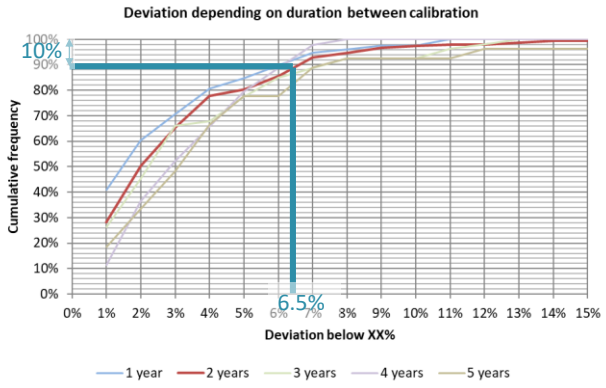
P↘ => Deviation ↗ 10% for 50 Pa

P↗ => Deviation ↘ 6.5% for 150 Pa

→ The linear regression on 3 points may induce large error

5

Part 1: Deviation according to the duration between calibration

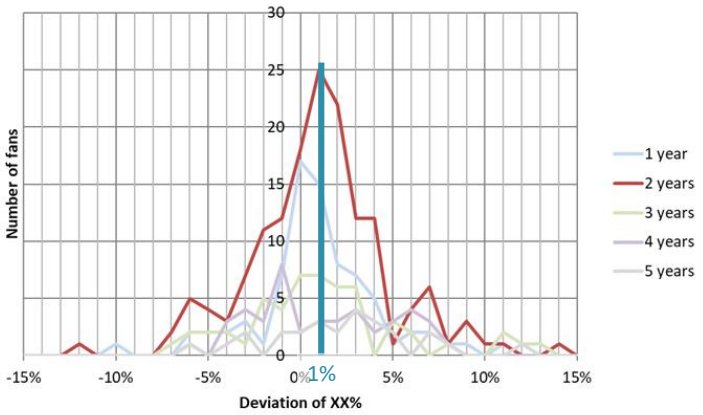


	Time between calibrations				
	1 year	**2 years**	3 years	4 years	5 years
Median	1.5%	**1.9%**	2.2%	2.5%	3.1%
Average	2.4%	**2.9%**	3.3%	3.1%	3.8%
Minimum	0.0%	**0.0%**	0.0%	0.1%	0.1%
Maximum	10.9%	**22.4%**	12.9%	7.9%	15.5%

10% of fans deviate of more than 6.5% after 2 years
5% of more than 8%.

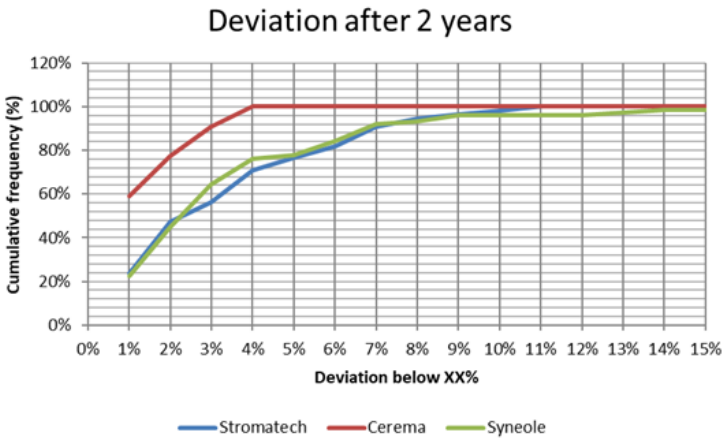
6

Part 1: Positive and negative deviation



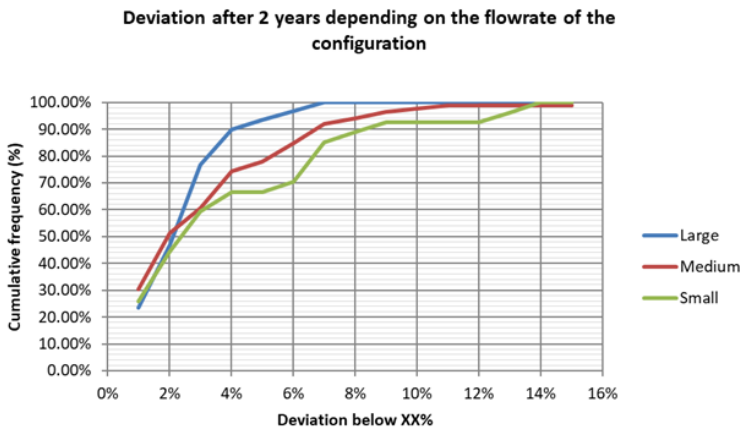
The flowrate measured by fans tends to increase very slightly but vary mostly randomly.

Part 1: Deviation according to the data provider



Smaller deviation of fan coming from CEREMA (well stored little used) than others.

Part 1: Deviation according to the flowrate of the configuration



Larger deviation for small flowrate:

10% of small flowrates configurations varies of more than 8%, while it is only 4% for large flowrate configurations

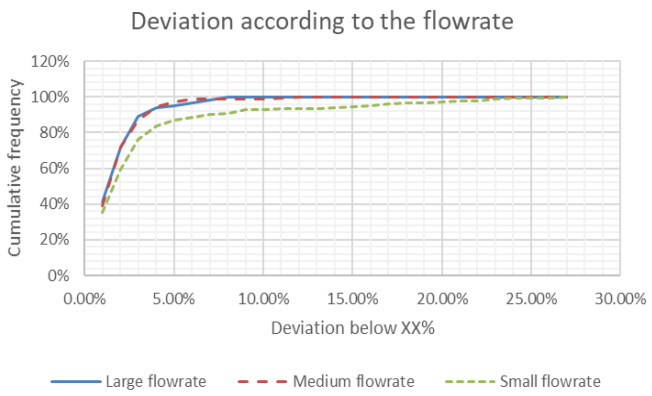
9

Part 2

COMPARISON WITH MANUFACTURER COEFFICIENTS

10

Part 2 : Deviation according to the flowrate



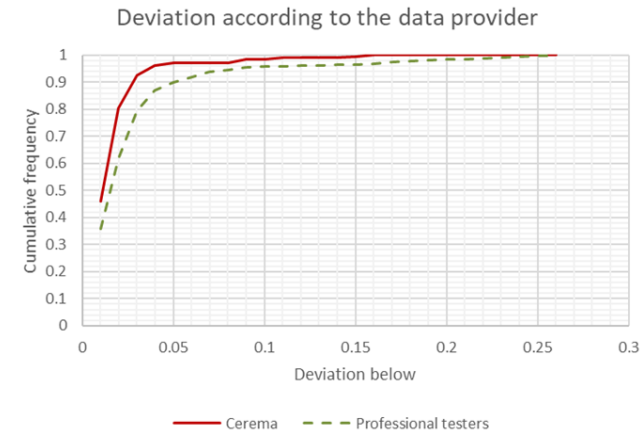
Medium and large flowrate configurations have a similar and low deviation

- 4% deviate of more than 5%.
- => 96% remain conform to the requirement

Small flowrate configuration have a larger deviation

- 10% deviate of more than 7%
- Maximum Permissible Error is also higher (2 m^3/h or 5% the biggest).

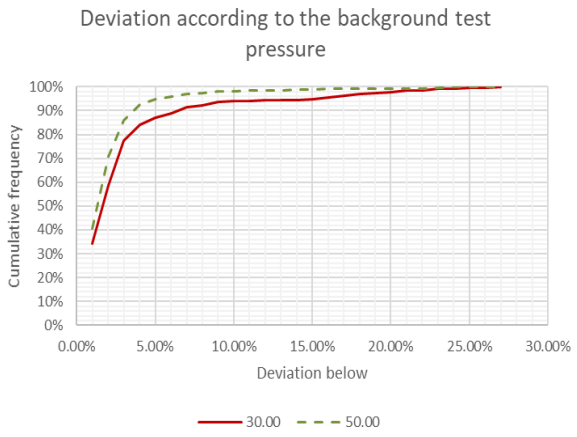
Part 2: Deviation according to the data provider



Cerema has provided 204 data out of the 1007. Low used and well-stored fans (CEREMA) deviate less than daily used ones.

- 204 out of 1007 data provided by CEREMA
- Statistic biased by the non-representability of devices used and calibration laboratories

Part 2: Deviation according to the background test pressure



Significant difference of deviation according to the background test pressure

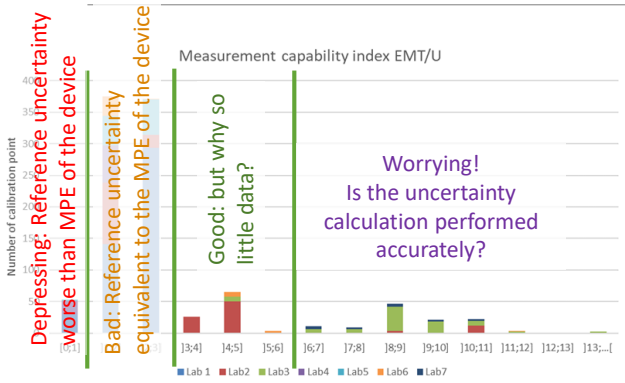
- With a 50 Pa background pressure 10% deviate of more than 3.5% and 5% of more than 5% which is very low
- With a 30 Pa background pressure 10% deviate of more than 5.5% and 5% of more than 15%.

Fan coefficients mostly suitable for 50Pa?

- when performing a multiple test point on-site, shall the uncertainty due to the variation of the fan coefficient shall be added to the global uncertainty calculation?
- Further investigation needed

Calibration uncertainty

Calibration uncertainty



Capability index
Cm= Maximal Permissible Error / Calibration uncertainty

Cm low => low probability of the conformity of the verification

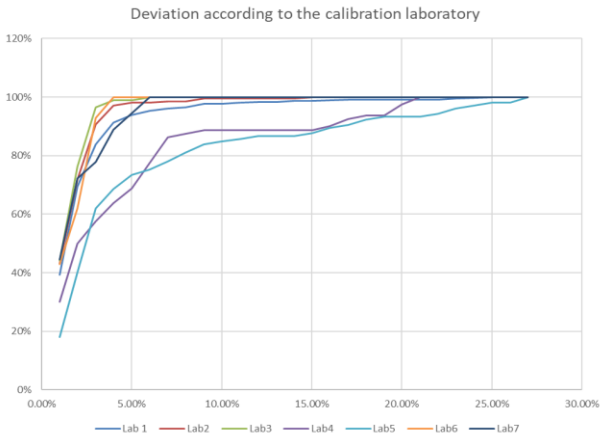
- Cm shall be above 3
- If Cm<1, reference device less accurate than the measuring device under calibration is supposed to be

Most laboratories have a Cm between 1 and 3.

Some laboratories get value above 6

- Is the uncertainty correctly estimated?
- Does it include both uncertainties (pressure and flowrate)?

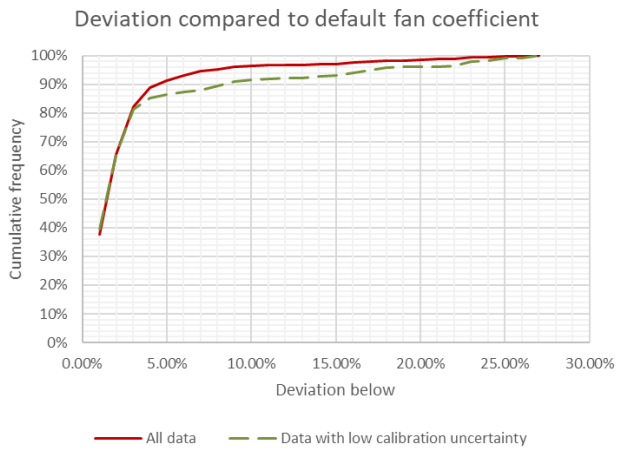
Deviation according to the calibration laboratory



Laboratories which have low measurement capability index also have a higher deviation

- The results may be biased by the fact that these laboratories may also check only certain kind of products.

Part 2: Deviation compare to default fan coefficient



All data:

- 10% deviate of more than 4.5% compared to manufacture coefficients and 5% of more than 8.5%.

"Reliable data"

- 10% deviate of more than 8.5% and 5% of more than 13.5%.

65 data out of the 1007(6.5%) are non-compliant with French standard requirement

- maximum of 5% of deviation or 2 m^3/h

Conclusion

Deviation quite similar in 1st part (recalculation) and 2nd part (manufacturer)

	Part 1:	Part 2
10% vary of more than	6.5%	4.5 %
5% vary of more than	8 %	8.5 %

6.5% of configurations do not comply with French requirements

- 10% of certificates get at least 1 configuration non compliant

The flowrate measured by fans tends to increase very slightly but vary mostly randomly.

Both the first and the second part of the study have shown that low-used and well-stored fans deviate less than daily used ones.

The significant difference of deviation according to the background test pressure shall be investigated

Requirements shall be made on calibration laboratory to improve the reliability of the verification

What shall we do with calibration?

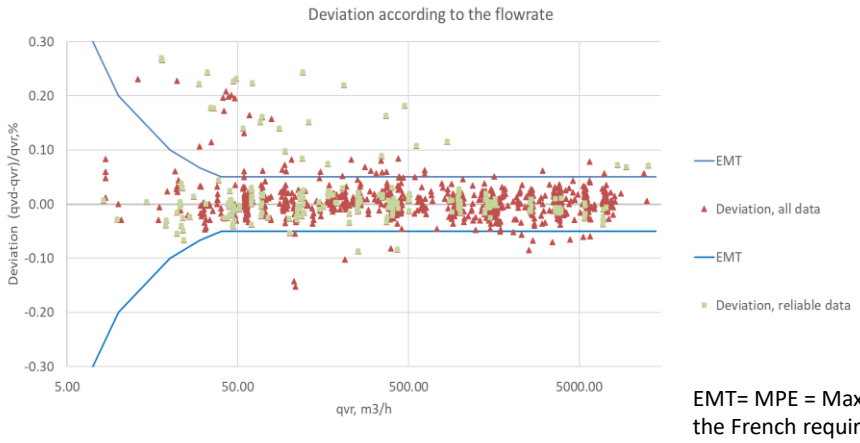
This study:
- Does not stress the need for high-frequency calibration
- Stress the need for reliable calibration and verification (above all the first one)
  - Clear requirements on laboratory

What requirements for laboratories?
- Having a measurement capability index above 3
- Provide a list of required data and the associated measurement uncertainty

Recalculation of coefficients or verification of manufacturers coefficients?
- No large difference between the 2 parts of the study (for a fan pressure of 150Pa)
- However, calculated coefficients seem less reliable than manufacturer ones
  - Huge difference between deviation of flowrate according the fan pressure
- Maybe better to
  - Verify if manufacturer coefficient remain below MPE
  - Recalculate only if needed but with more calibration points on the full range and perform an adequate regression

Data to be provided:
- Both for calibration and verification of calibration:
  - Reference flowrate
  - Uncertainty on the reference flowrate
  - Device flowrate (calculated with fan coefficients)
  - Fan pressure
  - Uncertainty of fan pressure
  - Background pressure
  - Uncertainty on background pressure
  - Measurement error
  - Uncertainty on measurement error
- In addition for verification of calibration
  - Maximal permissible error of the device
  - Probability of conformity
  - Measurement capability index
  - Decision rule
  - Conformity assessment
- In addition for adjustments:
  - calibration function, calibration diagram, calibration curve, or calibration table

Part 2: Observed deviation compared to manufacturer default coefficient



235 out of the 1007 have a measurement capability index above 3 and are named “reliable” in the following graph.

EMT= MPE = Maximum permissible error according to the French requirements: 2m3/h or 5% the highest

People in Building Performance Simulation

Univ. Prof. Dr. A. Mahdavi
Chair of Building Physics and Building Ecology
TU Wien
Vienna, Austria

People as

- developers of
- users of
- source of requirements in
- **modelled entities** in

Building Performance Simulation

Elements of building performance simulation


Building fabric


Building systems


Ext. conditions


Inhabitants


Algorithmic core

Values of performance indicators

How people affect buildings' performance

- Passive effects
  (e.g., emission of heat, moisture, pollutants, sound absorption, …)

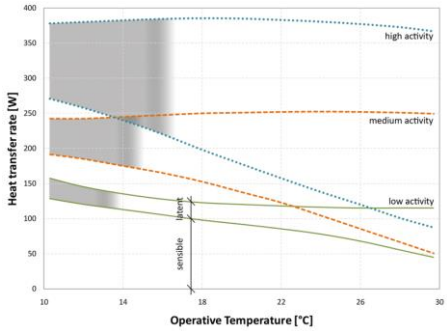


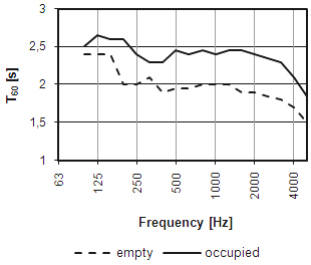
- Active effects
  (e.g., operation of buildings' environmental systems, electrical equipment, …)



Instances of passive effects

Heat generation

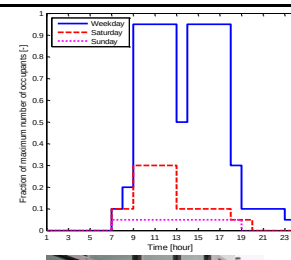




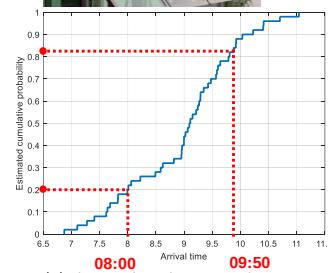
Acoustical absorption

Models of occupant presence and behavior

- Typical schedules
- Rule-based models
- Stochastic models

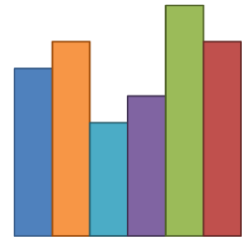


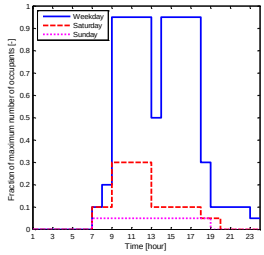


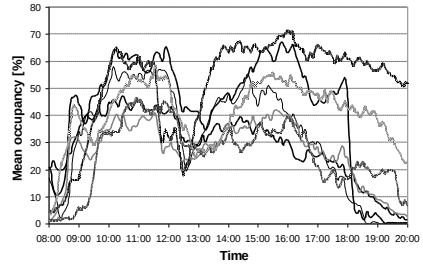


The "deterministic"-stochastic fallacy

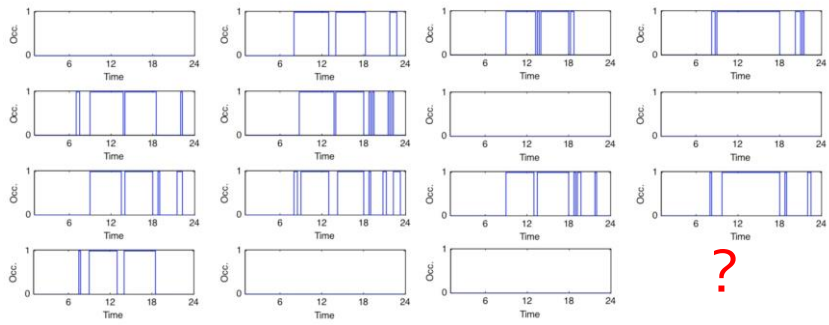






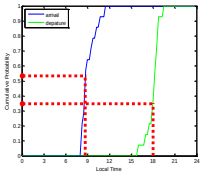


Presence models | Short-term predictions



Presence models | Short-term predictions

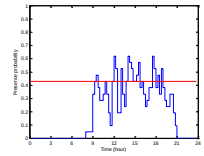
- Reinhart 2001 (probabilistic)



- Page et al. 2008 (probabilistic)

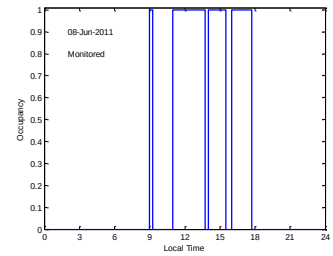


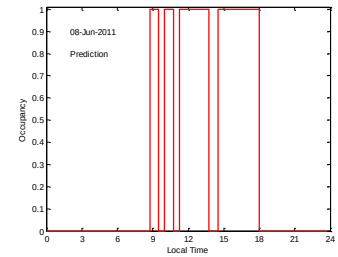
- Mahdavi & Tahmasebi 2015 (non-probabilistic)



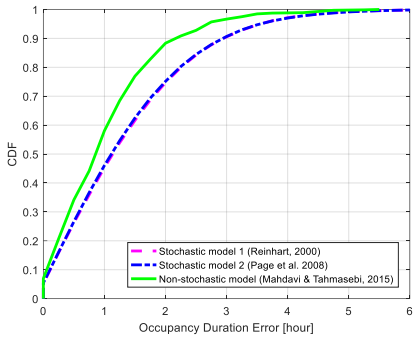
Presence models | Short-term predictions

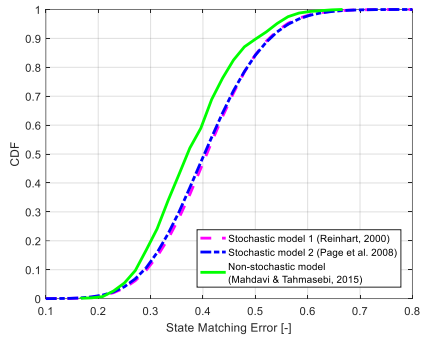
- **First Arrival time error [hour]**
  Predicted minus the monitored first arrival time.
- **Last Departure time error [hour]**
  Predicted the monitored first arrival time.
- **Occupancy Duration error [hour]**
  Predicted minus the monitored daily presence duration.
- **Occupancy State Matching error [-]**
  Fraction of wrongly predicted intervals in a day.
- **Number of Transitions error [-]**
  Predicted number of daily occupied-to-vacant transitions minus monitored number of transitions.





Presence models | Short-term predictions

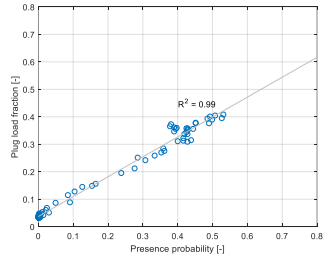




Plug load models - Use of office equipment

- Estimating plug loads based on
  - i) Presence information
  - ii) Installed equipment power
- Relationship between presence probability and use of electrical equipment

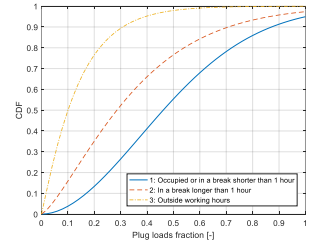
$$F_i = 0.53P_i + 0.09$$



Stochastic model

Weibull distributions to obtain plug load fractions at:

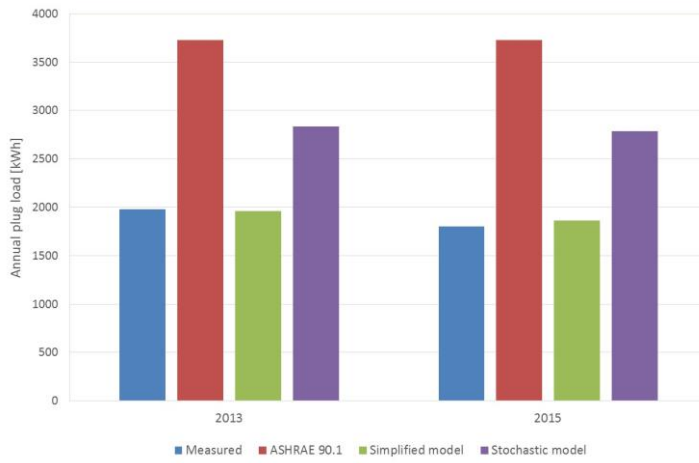
1) Occupied periods or intermediate absences shorter than one hour
2) Intermediate absences longer than one hour
3) Non-working hours



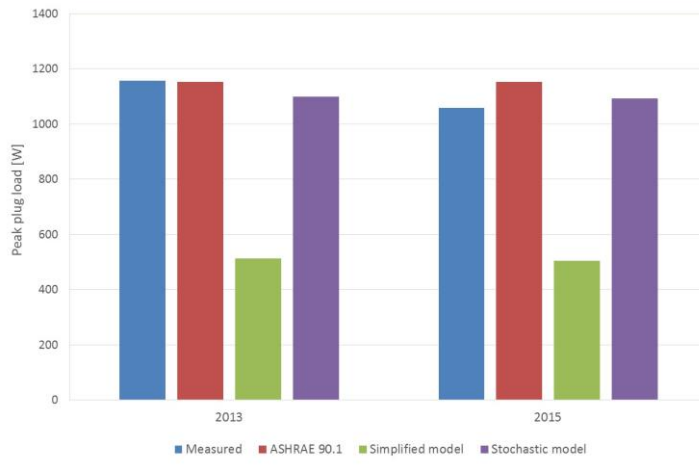
$$f(x|a,b) = \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} e^{-\left(\frac{x}{a}\right)^{b}}$$

Distributions	a (scale)	b (shape)
1	0.560	1.886
2	0.377	1.323
3	0.141	1.072

Results | Annual plug loads



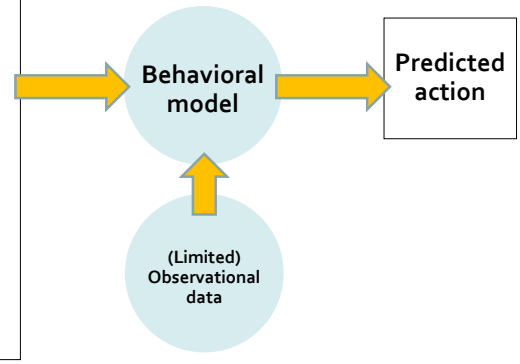
Results | Peak plug loads

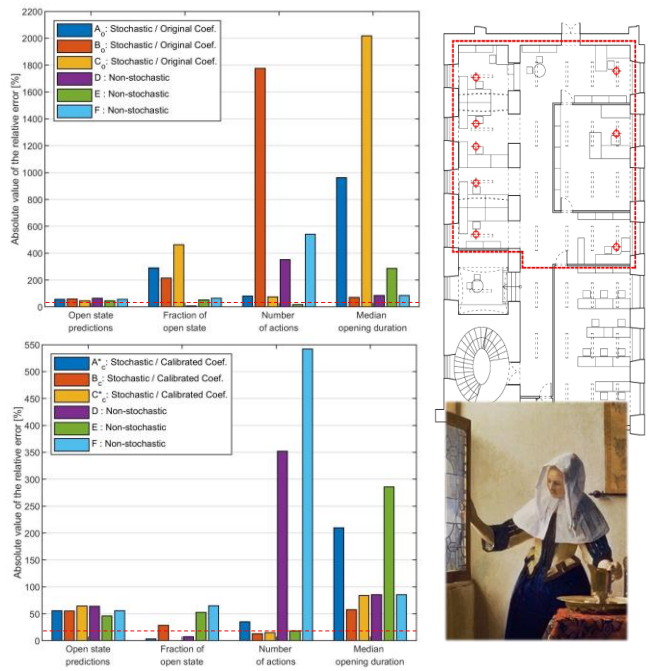


Do we know how to model people's behavior?

Independent variables

- Presence
- Indoor environment





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Independent variables

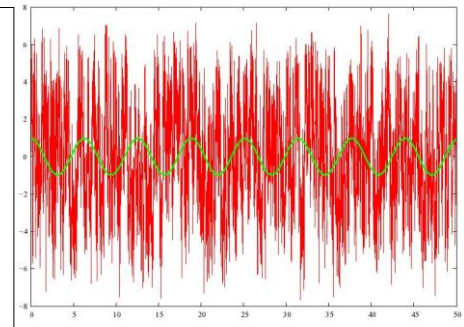
- Presence
- Indoor environment
- Outdoor environment
- Physiological parameters
- State of activity/clothing
- Cognitive load
- Attitudinal stance
- Physical settings
- Past experience
- Social situation



18

Independent variables

- Presence
- Indoor environment
- Outdoor environment
- Physiological parameters
- State of activity/clothing
- Cognitive load
- Attitudinal stance
- Physical settings
- Past experience
- Social situation



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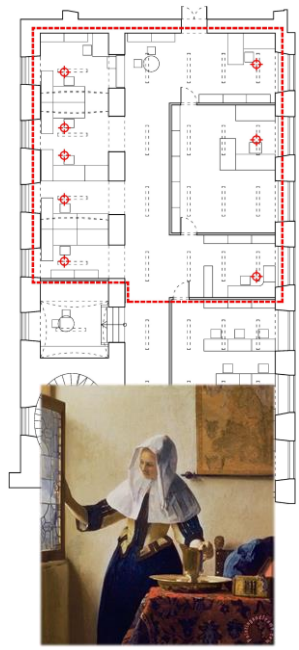
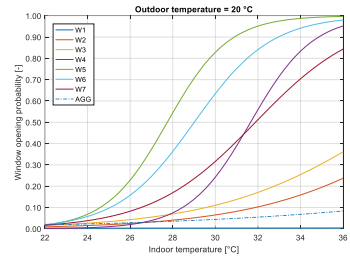
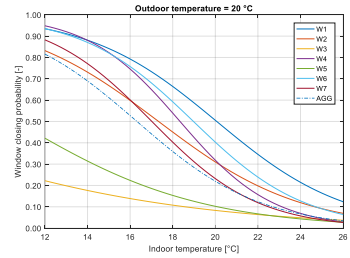






Slices through the response surface of individual and aggregate models for opening (up) and closing (down) of windows at an outdoor temperature of 20°C. (Tahmasebi and Mahdavi 2018)

20

Human behavior and the Rebound Effect

take back
snap back
backfire

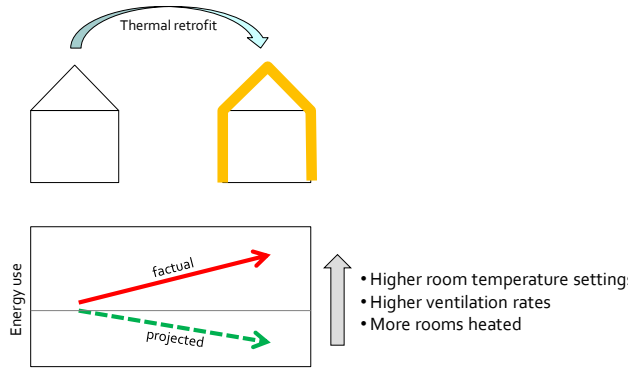


Discrepancy between projected and factual energy saving magnitude due to energy efficiency measures

$$RE = \frac{Saving_{theoretical} - Saving_{factual}}{Saving_{theoretical}} \cdot 100 \ [\%]$$

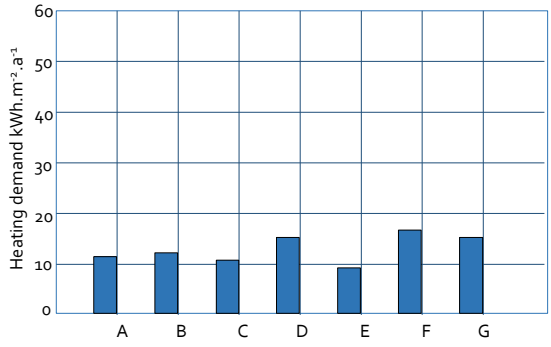
22

Rebound effect



23

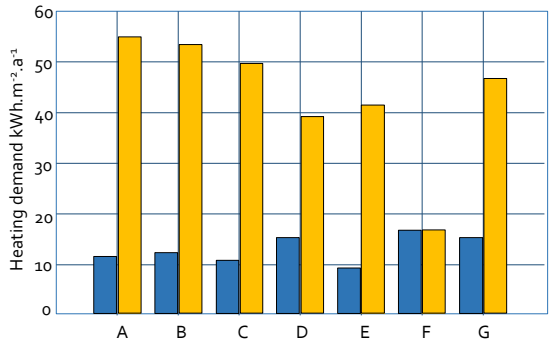
Predicted heating loads for retrofit projects





24

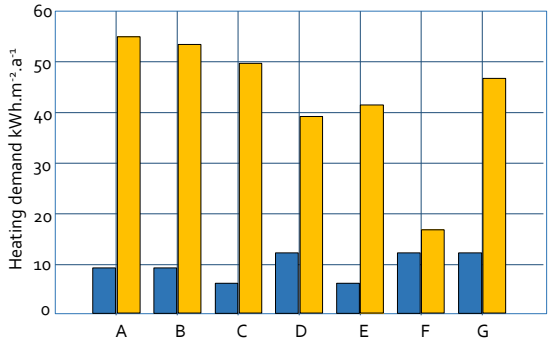
Predicted heating loads for retrofit projects versus actual values



25

Predicted heating loads for retrofit projects versus actual values

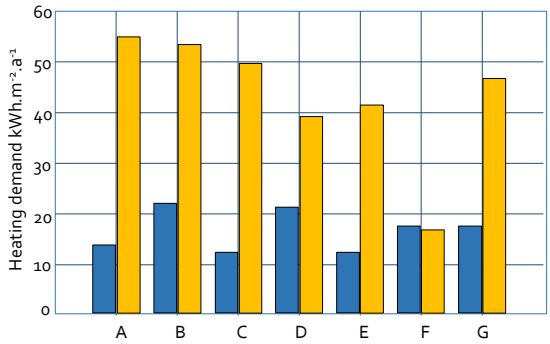
Corrected for weather conditions (2009/2010)



26

Predicted heating loads for retrofit projects versus actual values

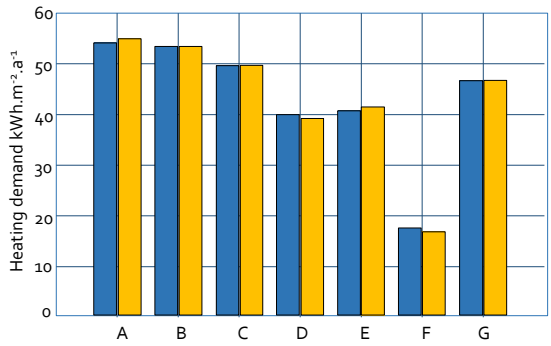
Corrected for monitored indoor air temperatures



27

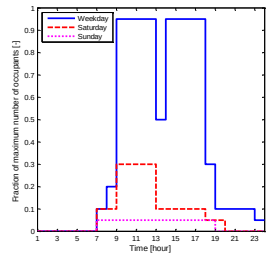
Predicted heating loads for retrofit projects versus actual values

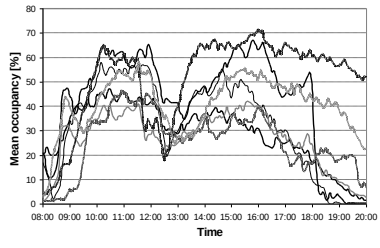
Corrected for ventilation rates (from about 0.2 h^{-1} to about 0.9 h^{-1})

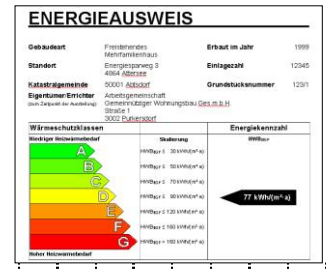


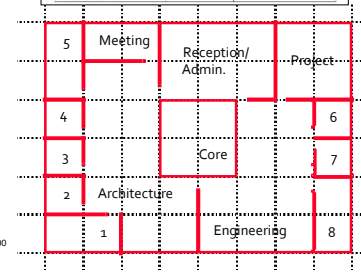
28

When use what model?









People in Building Performance Simulation – Univ. Prof. Dr. A. Mahdavi – TU Wien, Vienna, Austria

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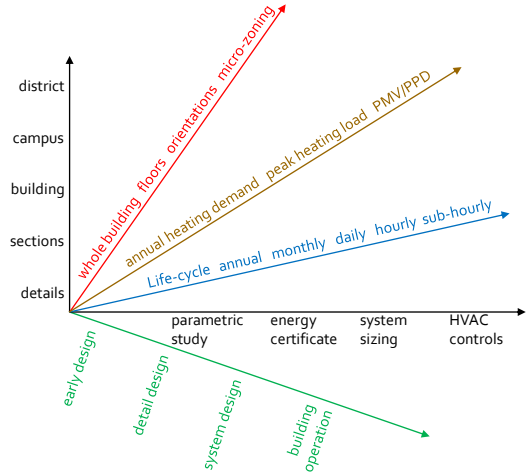
The dimensions of model application space



In conclusion, a few recommendations

Please:

1. Do not confuse simulation with prediction
2. Be careful using the expression "deterministic" while refering to fixed diversity profiles
3. Do not assume certain mathematical formalisms are per se more accurate
4. Do not confuse code-based benchmarking with energy use prediction
5. Do not claim you have "validated" an occupancy model without (or with just a "quick and dirty") comparison of calculations and observations
6. Do not confuse data sets for model development and evaluation
7. Do not extrapolate from a single limited behavioral study to all kinds of populations, building types, locations, climates
8. Safe-guard against bias (i.e. use double blind and round robin tests)
9. Be careful while incorporating behavioral models in simulation tools (inexperienced users may fall for the illusion of capturing "reality")

People in Building Performance Simulation

Univ. Prof. Dr. A. Mahdavi
Chair of Building Physics and Building Ecology
TU Wien
Vienna, Austria

The AIVC of the 20th Century

Martin Liddament

Reading, UK
mwliddament@gmail.com

1



AIVC Brief History

In the wake of uncertainty over oil supply the International Energy Agency (IEA) was established in 1974 (Part of OECD).

An important objective was to undertake activities in energy research to reduce dependency on fossil fuel.

Energy consumption in buildings was identified as a significant consumer of energy.

Executive Committee for Energy Conservation in Buildings and Community Systems (ECBCS) was formed with a responsibility for improving building energy efficiency by collaborative Tasks or Annexes.

Air infiltration into buildings was quickly identified as an area about which least was known. Annex 5, the Air Infiltration Centre (AIC), was established by the ECBCS in 1979 to undertake a programme of technical activities and provide an information service.

The Air Infiltration Centre became the Air Infiltration and Ventilation Centre (AIVC) in 1986.



2

Inaugural Staff



Air Infiltration Review

a quarterly newsletter from the IEA Air Infiltration Centre

Vol. 1 No. 4 August 1980

The Team at your Service

Dr Carolyn Allen joined the staff of the Air Infiltration Centre on 17 July 1980. She graduated in Geology and Astronomy at the University of Leicester in 1970, then proceeded to the University of Newcastle-upon-Tyne where she obtained her MSc in Geophysics and Planetary Physics as part of which she studied convection in fluids with variable viscosity. Subsequently she read for her Ph.D. in the Atmospheric Physics Research Group being largely concerned with the physics of splashing drops. This was followed by a period as a research assistant with the same establishment working on a mathematical model for boundary layer flow over complex terrain.

Carolyn Allen is to be involved in the systematic organisation of a data base suitable for the validation of mathematical models and the formulation of standardised procedures for reporting test results.

Carolyn Allen
Scientist

With the arrival of Carolyn Allen, the AIC staff is now up to full strength. The other members are:

Peter Jackman
Head—AIC

Martin Liddament
Senior Scientist

Sheila Manning
Librarian

Jenny Elmer
Secretarial Assistant

Now that the AIC has been established, the bibliographic data base inaugurated and the team of experts engaged, we are progressing rapidly in our studies on the technical aspects of air infiltration with particular emphasis on mathematical modelling procedures and the collection of reliable test data. Enquiries from research organisations in participating countries indicate that we are becoming recognised as a centre of valuable information and expertise.

Seminar on Air Quality

A seminar entitled 'Health in the Home' was held at the Electricity Council's Research Centre at Capenhurst in May and attended by the AIC's librarian, Sheila Manning. Seven papers were presented on the subject of the quality of air in dwellings.

Of particular interest was a paper presented by B.L. Davies of the National Radiological Protection Board on the problem of radon gas in the home. The paper included estimates of the lung cancer risks from radon and found inter alia that a mean winter ventilation rate of 0.5 air changes per hour would give a lung cancer risk equivalent to smoking 2.2 cigarettes per wk.

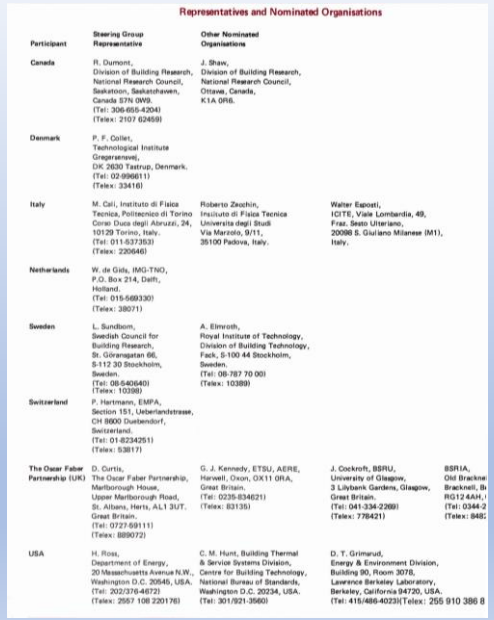
3

The Steering Group and Participating Countries

AIC (1979)
Eight 'Founding' Countries:

- Canada
- Denmark
- Italy
- Netherlands
- Sweden
- Switzerland
- UK
- USA

The Steering Group provided expertise and assistance to the staff of the Centre as well as providing a conduit to relevant research and activities in member countries. This approach has undoubtedly been instrumental in the success of the AIVC.



Representatives and Nominated Organisations

Participant	Steering Group Representative	Other Nominated Organisations		
Canada	R. Dumont, Division of Building Research, National Research Council, Saskatoon, Saskatchewan, Canada S7N 0W9. (Tel: 306-665-4204) (Telex: 2107 02459)	J. Shaw, Division of Building Research, National Research Council, Ottawa, Canada, K1A 0R6.		
Denmark	P. F. Collet, Technological Institute Gregersensvej, DK 2630 Taastrup, Denmark. (Tel: 02-996611) (Telex: 33416)			
Italy	M. Cali, Instituto di Fisica Tecnica, Politecnico di Torino Corso Duca degli Abruzzi, 24, 10129 Torino, Italy. (Tel: 011-537353) (Telex: 220646)	Roberto Zecchin, Instituto di Fisica Tecnica Universita degli Studi Via Marzolo, 9/11, 35100 Padova, Italy.	Walter Esposti, ICITE, Viale Lombardia, 49, Fraz. Sesto Ulteriano, 20098 S. Giuliano Milanese (MI), Italy.	
Netherlands	W. de Gids, IMG-TNO, P.O. Box 214, Delft, Holland. (Tel: 015-569330) (Telex: 38071)			
Sweden	L. Sundbom, Swedish Council for Building Research, St. Göransgatan 66, S-112 30 Stockholm, Sweden. (Tel: 08-540640) (Telex: 10398)	A. Elmroth, Royal Institute of Technology, Division of Building Technology, Fack, S-100 44 Stockholm, Sweden. (Tel: 08-787 70 00) (Telex: 10389)		
Switzerland	P. Hartmann, EMPA, Section 151, Ueberlandstrasse, CH 8600 Duebendorf, Switzerland. (Tel: 01-8234251) (Telex: 53817)			
The Oscar Faber Partnership (UK)	D. Curtis, The Oscar Faber Partnership, Marlborough House, Upper Marlborough Road, St. Albans, Herts, AL1 3UT. Great Britain. (Tel: 0727-69111) (Telex: 889072)	G. J. Kennedy, ETSU, AERE, Harwell, Oxon, OX11 0RA, Great Britain. (Tel: 0235-834621) (Telex: 83135)	J. Cockroft, BSRU, University of Glasgow, 3 Lilybank Gardens, Glasgow, Great Britain. (Tel: 041-334-2269) (Telex: 778421)	BSRIA, Old Bracknell, Bracknell, Be RG12 4AH, (Tel: 0344-2 (Telex: 848
USA	H. Ross, Department of Energy, 20 Massachusetts Avenue N.W., Washington D.C. 20545, USA. (Tel: 202/376-4672) (Telex: 2557 108 220176)	C. M. Hunt, Building Thermal & Service Systems Division, Centre for Building Technology, National Bureau of Standards, Washington D.C. 20234, USA. (Tel: 301/921-3560)	D. T. Grimsrud, Energy & Environment Division, Building 90, Room 3078, Lawrence Berkeley Laboratory, Berkeley, California 94720, USA. (Tel: 415/486-4023)(Telex: 255 910 386 8	

AIVC (1999)
Twelve Countries:

- Belgium
- Denmark
- Finland
- France
- Germany
- Greece
- Netherlands
- New Zealand
- Norway
- Sweden
- UK
- USA

4

Prof Arne Elmroth

BUILD TIGHT – VENTILATE RIGHT



Build Tight – Ventilate Right

This article has been submitted by Dr Arne Elmroth, Professor at the Royal Institute of Technology, Stockholm. It reflects the Swedish approach to the problem of energy losses and discomfort arising from air infiltration in dwellings.

The energy crises of 1973–1974 was a stark reminder of the need for energy-saving measures. The Swedish Building Regulations of 1975 increased the requirements for thermal insulation considerably. A significant news item was the introduction of completely new requirements and recommendations for a building's airtightness. The main aim of the new airtightness requirements was of course to save energy. Excess natural and uncontrolled ventilation of air leakage means that the heat required for ventilation increases for a number of reasons. Excess ventilation air must be heated to room temperature. A comparatively small reduction in unnecessary ventilation results in considerable energy savings.

Leaks can also cause local draughts which must be compensated by higher room temperatures to maintain comfort levels. If uncontrolled draughts are reduced, the circumstances for reducing the indoor temperature improve while still maintaining comfort levels–this in turn leads to beneficial energy savings. Air leakage can cause localised cooling of inside sections of external wall constructions causing a sensation of radiation draughts. Damage resulting from moisture penetration through gaps in the building shell have occurred all too often causing considerable damage. The risk of moisture damage is considered to be greater in houses with balanced ventilation than in houses with exhaust air ventilation. Even a small amount of internal positive pressure can cause moist air to leak through pervious structures causing, at worst, condensation and subsequent moisture damage. This problem has also been observed in Canada since it has a climate similar to Sweden. Apart from energy considerations, there is a number of hygienic and technical reasons for making a house's shell 'airtight'.

In Sweden, experience of how airtight houses should be built and how they function is now being gained. It appears that contractors have adapted comparatively quickly to building houses in which the requirements in the building regulations are fulfilled.

Different materials and building procedures demand different approaches. When using solid elements of lightweight concrete, leakage problems are confined to joints around windows and doors as well as at junctions between roofs and outside walls. In timber houses, the vapour barrier is commonly used to achieve airtightness. To produce good airtightness, the constructional details must be planned with greater care than has been the case to date. New age-resistant plastic films have been developed. Several different sized sheets are available to facilitate rational sealing work. However, it still remains to find simpler and safer methods for many different constructional details in order to further facilitate the work of building airtight houses. We also need solutions which fulfill tightness requirements over a very long time. Our experience to date in such matters is very limited.

How then do airtight houses function? Studies have been carried out on a number of detached houses which were very airtight–considerably tighter than that required by the building regulations. Studies have also been carried out on a number of houses which have only just fulfilled the stated requirements. In the houses which were very airtight–about 1 air change/hour at 50 Pa–the anticipated energy savings have been achieved by a good margin. Satisfactory building technology, in terms of carefully designed constructions with a high degree of thermal insulation, leads to considerable energy savings. The air quality has been kept to the required level (= 0.5 air changes/hour) almost independently of the outdoor climate merely by the use of an exhaust fan and air supplied via slot air vents in windows in all rooms. Satisfactory ventilation is achieved in all rooms if the speed of the fan is carefully adjusted. The fan's adjustment is of decisive importance for the amount of ventilation. In an airtight house, with carefully regulated ventilation, the ventilation will only vary to a very minor degree in relation to wind velocity and outdoor temperature. Consequently, very airtight houses can function extremely well.

Houses which are less airtight, or which have unsuitable ventilation systems, have sometimes functioned less satisfactorily. Condensation has formed on the inside of windows and, in extreme case, mould problems have been observed. Studies of air change rates in individual rooms in such houses have clearly shown that the ventilation is often quite insufficient. Low air change rates, which are quite unhealthy, have been measured in bedrooms. In insufficiently tight houses, uncontrolled air supply through leaks in the house can result in only certain rooms being ventilated in an acceptable manner. Houses with an air change rate of 3.0 changes/hour at 50 Pa provide an example. Exhaust air ventilation installed in the traditional manner in such detached houses is an example of ventilation design which can lead to certain rooms–usually bedrooms–having insufficient ventilation despite the house as a whole having the recommended average ventilation rate.

Only in sufficiently airtight houses can the ventilation be controlled and regulated to the required level in each section of the dwelling. Airtight houses are also necessary if heat recovery from the ventilation system is to function well and profitably. It is possible to build airtight houses today even if methods need to be further improved.

Standards and knowledge, of how a functioning ventilation system is to be designed for different airtight houses, are however incomplete. A considerably greater degree of collaboration between installation and building technology is necessary if we are to produce low-energy houses with good air quality and if we are to avoid [illegible] and unnecessary savings.

BUILD TIGHT–VENTILATE RIGHT.

AIR
Vol 1 N0 4
August 1980

5

Information Activities - *AIRBASE*

No GOOGLE search engine in 1980!

Bibliographic database, *AIRBASE*, was established in 1980.

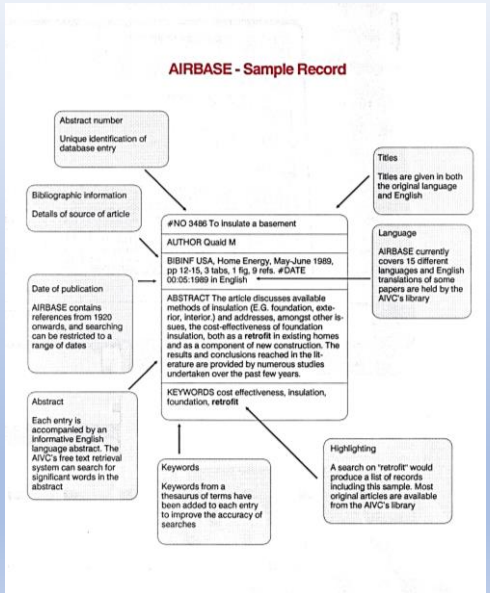
Interrogated through keyword or free text searching on author, title or abstract fields.

Direct international searching via modem was introduced in 1983.

Floppy disks and then CD-ROM versions made available from 1986.

Information for AIRBASE was derived from data and resources provided by the Steering Group, regular surveys of research and by direct library research.

Became a key information resource and was widely used.

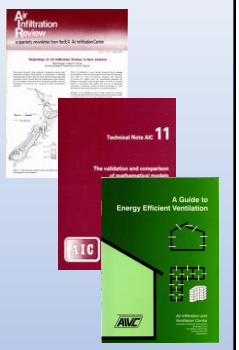


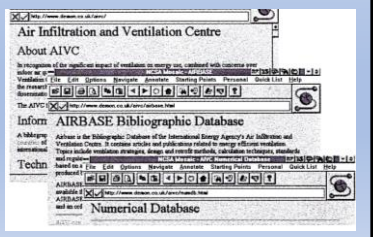
6

Information Dissemination

The AIVC disseminated information through a strong publication programme. Publications and activities included:

- Technical Notes based on work undertaken at the Centre and by associated Annexes within ECBCS;
- Technical Guides;
- Bibliographic Reviews based on topical information contained within AIRBASE;
- Quarterly Newsletter, Air Infiltration Review (AIR);
- AIVC Website (established in September 1995);
- Hosting visiting specialists;
- Annual conferences;
- Workshops.





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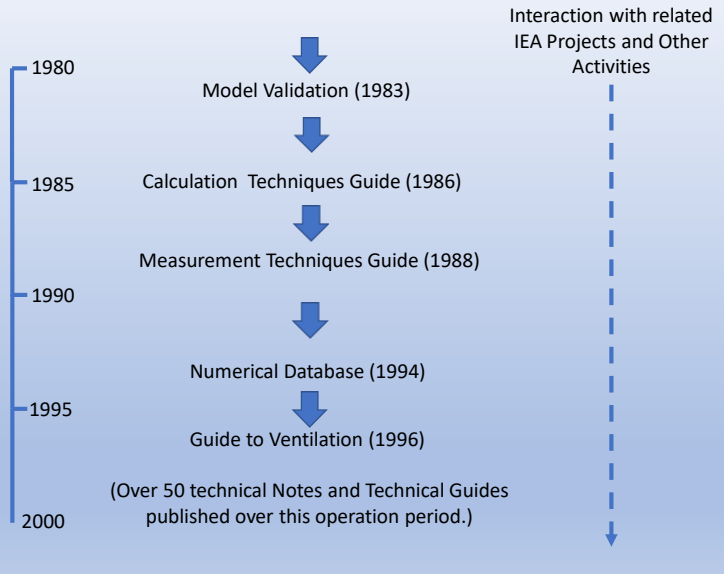
Technical Activities

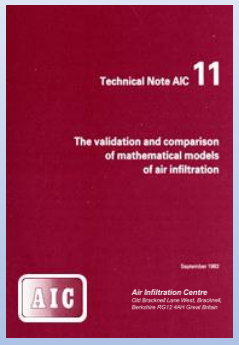


8

Technical Activities - Model Validation

A fundamental initial task of the AIVC was to undertake a programme to 'validate' mathematical models of air infiltration. This progressed in five stages, these being to:

- Select appropriate mathematical models;
- Establish the data needs of each model;
- Prepare suitable high-quality datasets based on measurements made on site;
- Use the available data to compare modelled results with actual infiltration measurements;
- Identify key parameters.



9

Model Validation

- Ten models were selected which were based on the solution of the equations of flow through openings in the building structure.
- Ranged from simplified single zone methods to multizone approaches.
- Very few complete datasets were available, and analysis was restricted to three naturally ventilated dwellings, each of which was configured for whole building ventilation monitoring.

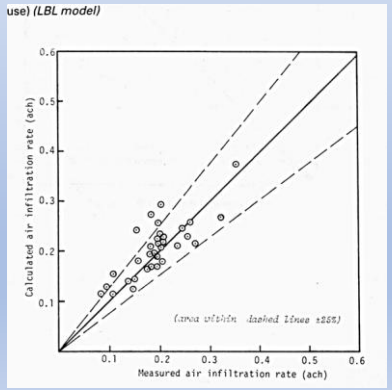
Table 2.1: List of selected models

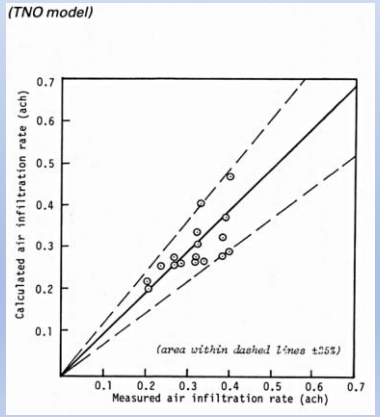
Ref No.	Name	Country
1	Building Services Research and Information Association (LEAKS)	United Kingdom
2	National Research Council	Canada
3	IG-TNO Institut voor milieuhygiene en gezondheidstechniek (ELA 4)	Netherlands
4	Oscar Faber Partnership (SWIFIB)	United Kingdom
5	British Gas model (VENT)	United Kingdom
6	Norwegian Building Research Institute (ENCORE)	Norway
7	Gas Research Institute/Institute of Gas Technology	United States of America
8	Lawrence Berkeley Laboratory	United States of America
9	Building Research Establishment	United Kingdom
10	Reeves, McBride, Sepsy model	United States of America

10

Model Validation

- Within the limitations of measurement errors and numerical errors , mostly the models produced results that were consistent with measured ventilation rates (mostly within 25%).
- Full details of the work and results are described in AIVC TechNote 11 Published 1983.

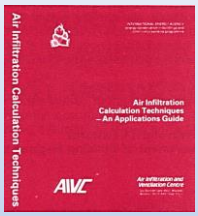




11

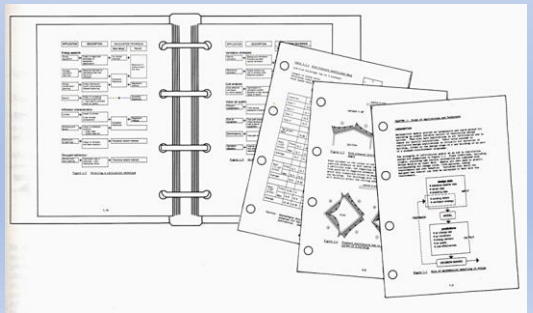
Calculation Techniques Guide

Experience gained in the AIVC modelling work was compiled into a calculation techniques guide. Topics covered:



- Ventilation and infiltration air flows;
- Empirical Techniques;
- Single and multizone numerical models;
- Heat recovery;
- Indoor air quality (dilution);
- Public domain models; and examples;
- Listing of available basic data;
- Not CFD.

The purpose of this guide was to provide step by step guidance on the application of modelling techniques in design.



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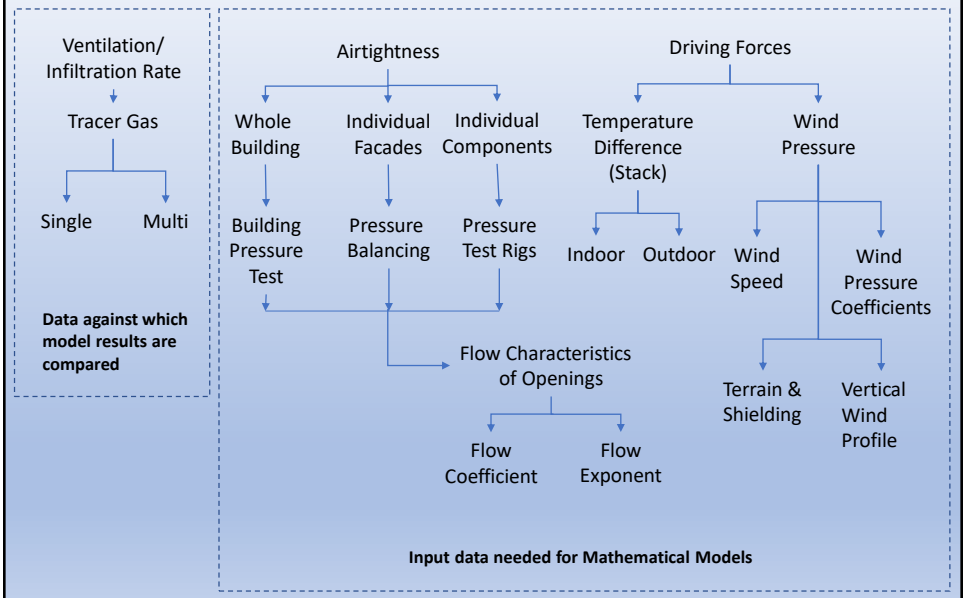
Model Validation - Need for Measurements

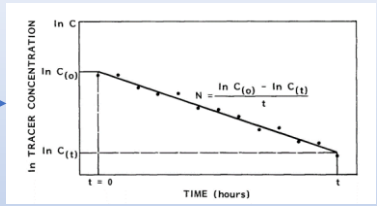


13

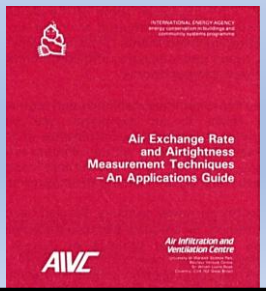
Measurement Techniques - Tracer Gas Analysis

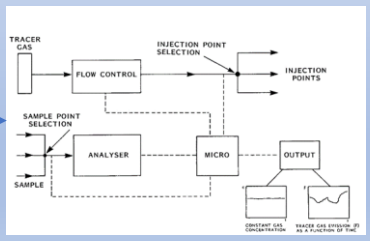
- Widely used throughout the 1980's to assess infiltration and ventilation rates.
- Inert 'tracer' gas dispersed into space and thoroughly mixed. Ventilation rate assessed on concentration behaviour.

- Tracer Decay
- Constant Concentration
- Constant Emission
- Multi-Room Single Tracer
- Multi-Room Multi Tracer
- Passive Emission
- Techniques for Ventilation Efficiency



Tracer Decay





Constant Concentration Schematic

14

Measurement Techniques - Tracer Gas Monitoring

Automated constant gas concentration multi room measurement system National Testing Institute Sweden, 1982 N_20

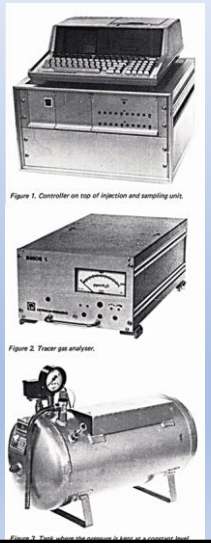


Figure 1. Controller on top of injection and sampling unit.

Figure 2. Tracer gas analyser.

Figure 3. Tank, where the nitrous is kept at a constant level.

Technological Institute, Taastrup, Denmark 1985 (N_20)

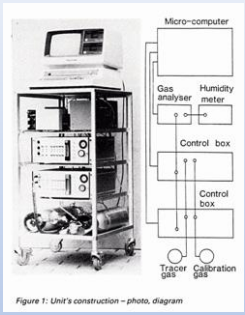


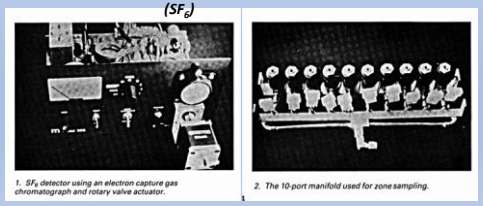
Figure 1: Unit's construction – photo, diagram

BRANZ New Zealand 1987 (N_20)



Constant concentration tracer gas device as used at BRANZ

NBS (NIST) US (SF_6)



1. SF_6 detector using an electron capture gas chromatograph and rotary valve actuator.

2. The 10-port manifold used for zone sampling.

Much interest in multi-zone tracer gas monitoring in the 1980's

15

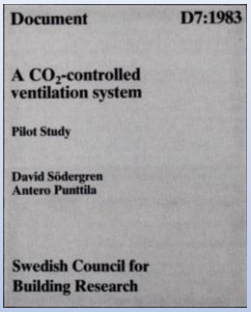
Common Tracer Gases of the 1980's

Common tracer gases were:

- Nitrous oxide;
- Per Fluoro Compounds (PFCs);
- Sulphur hexafluoride (SF6);
- Freon;
- Carbon dioxide.

- The complexity of monitoring systems generally restricted applications to the research sector, making it unattractive for general application.
- SF6, PFC's and Freon are significant greenhouse gasses with no significant decomposition, consequently, their use is now restricted.
- Similarly, nitrous oxide is no longer considered as non-toxic. As a consequence, the use of tracer gas monitoring has declined.
- The exception is the monitoring of carbon dioxide, which is now inexpensive and is often used to assess the adequacy of ventilation in occupied spaces.

Demand Controlled Ventilation



Document D7:1983

A CO_2-controlled ventilation system

Pilot Study

David Södergren
Antero Punttila

Swedish Council for Building Research

From an early period metabolically derived CO2 was considered as a possibility for use in demand control ventilation. The above study was based on a threshold value of 700 ppm.

16

Building Airtightness Measurements – Pressure Testing

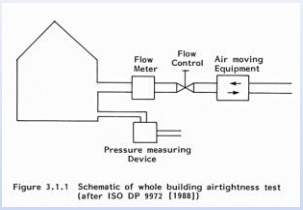


Figure 3.1.1 Schematic of whole building airtightness test (after ISO DP 9972 [1988])

- Specification of airtightness is essential for energy efficiency, modelling and design purposes.
- In the 1970's, whole building leakage monitoring was relatively uncommon.
- By 1980 the Swedish Government introduced airtightness requirements for housing (SBN 1980). This specified 3 air changes/hour at an induced indoor-outdoor pressure difference of 50 Pa for single dwellings.
- 50 Pa was primarily selected because it was generally above the value of natural driving pressure (at least for low rise buildings) but not so high that it could force joints in the façade to open or close. Also, it sets a reasonable flow capacity for fans.
- Measurement was made by removing an external door and replacing it with a fan that could drive enough air to monitor the required airtightness value.
- The 50 Pa pressure standard has largely remained the same to this day, although the use of air change rate has given way to façade air permeability.

17

Blower Doors

Initially, blower fans were laboratory designed but, by 1983, 'blower doors', as recognised today, were in use.



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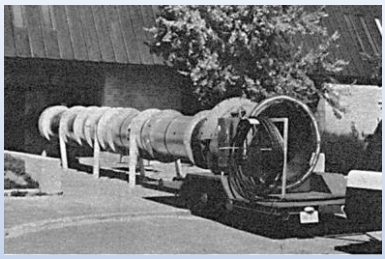
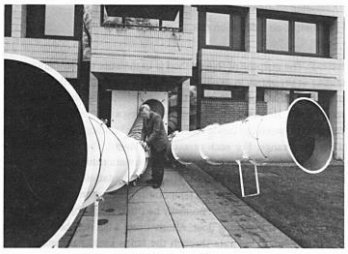
Industrial Blower Doors



Shaw (NRC Canada)1st AIVC Conference Sept 1980

BRE (UK) circa 1980s



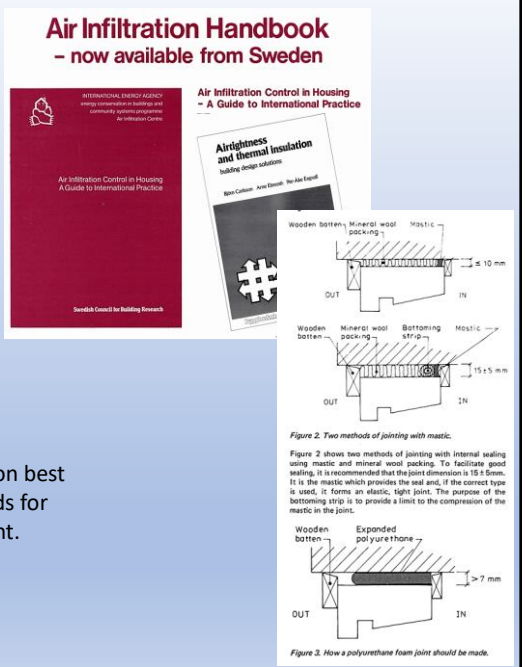
(b) Large Building Multi-fan System
(Crown copyright - UK Building Research Establishment)

Giant trailer fans for larger buildings were also in use by the 1980s

19

Airtightness - Swedish Handbooks

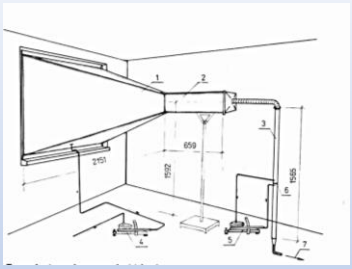
- Airtightness and Thermal Insulation – Building Design Solutions (1980).
- Air Infiltration in Housing – A Guide to International Practice (AIVC Publication 1982);



These publications focused on best practice designs and methods for making building joints airtight.

20

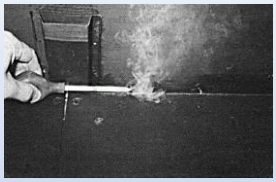
Miscellaneous tracer gas, leakage and airflow measuring methods



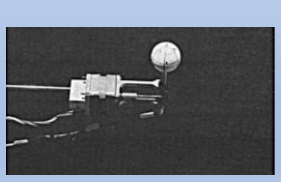
In situ component leakage testing, shematic (Polytechnical Institute of Silesia, Poland circa 1983)



CO_2 detector tubes for tracer decay circa 1987 (Sweden)



Leak detection using a smoke stick (Building Sciences UK circa 1987)



3-D hot wire anemometer, (University Essen, Germany, 1988)



Flow Finder for measuring flow rate through grilles (TNO, Netherlands circa 1988)



Classifying odour intensity (0lfs) circa 1989 (Denmark)

21

Evaluation of Wind Pressure

One of the most difficult tasks in modelling infiltration and natural ventilation rates was evaluating the wind pressure acting on openings. Two issues were:

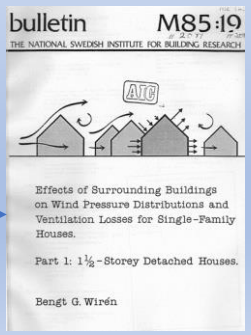
- Specifying a datum height for wind speed and local terrain condition. This was different to the height and wind speed that was often measured some distance away. Terrain and wind profile equations were used to make this correction.
- Specification of wind pressure coefficients. Initially these were based on wind loading studies that referred to buildings at exposed sites. This gave poor results and values representative of urban environments were needed. Such data were obtained from wind tunnel studies. The two key studies used by the AIVC for its analysis of models were by Bowen at NRC Canada and Bengt Wiren at the National Swedish Institute for Building Research in Sweden.



LABORATORY TECHNICAL REPORT

LTR-LA-209

A WIND TUNNEL INVESTIGATION USING SIMPLE BUILDING MODELS TO OBTAIN MEAN SURFACE WIND PRESSURE COEFFICIENTS FOR AIR INFILTRATION ESTIMATES



bulletin M85:19

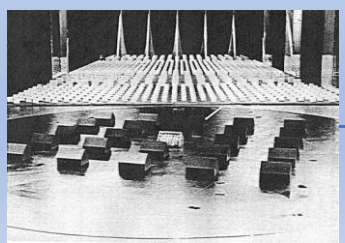
THE NATIONAL SWEDISH INSTITUTE FOR BUILDING RESEARCH

AIC

Effects of Surrounding Buildings on Wind Pressure Distributions and Ventilation Losses for Single-Family Houses.

Part 1: 1½-Storey Detached Houses.

Bengt G. Wirén



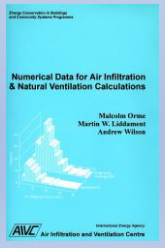
22

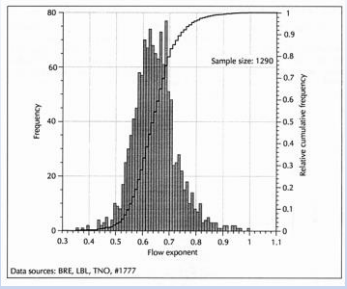
Numerical Database

Data collected and used by the AIVC were incorporated into a numerical database. Data included:

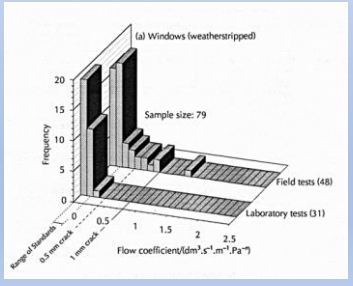
- Whole building leakage;
- Component leakage;
- Wind pressure coefficient data.

An analysis of the data was published in AIVC Tech Note 44 (1994).





Flow exponent comparison on whole building airtightness (1290 measurements).



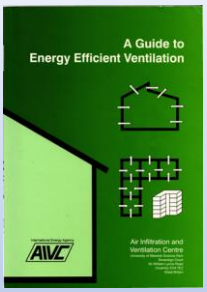
Flow coefficient comparison for windows.

23

Guide to Energy Efficient Ventilation

Published in 1996, this Guide was aimed at providing background knowledge for policy makers and practitioners that needed basic information. It was primarily descriptive with equations restricted to a minimum and only included in the final chapter. Some summary data were included as appendices, along with a simple algorithm to allow basic infiltration and ventilation calculations. Topics covered:

- Basic definitions;
- Indoor air quality and comfort issues;
- Energy impact;
- Design criteria;
- Ventilation Strategies;
- Cooling;
- Filtration;
- Ventilation efficiency;
- Maintenance;
- Measurement methods;
- Calculation techniques;
- Basic data and simple algorithm.



24

Interaction with other IEA Technical Tasks and Activities

The AIVC interacted with several other IEA annexes and published various reports from these activities. There were also other key ventilation research projects that the Centre interacted with. These included:



IEA Tasks

- Annex 8 Inhabitants behaviour with respect to ventilation (Willem de Gids, 1984-87);
- Annex 9 Minimum ventilation rates and measures for controlling indoor air quality, (Lutz Trepte 1982-86);
- Annex 18 Demand controlled ventilation (Lars-Goran Mansson 1987-92);
- Annex 20 Airflow patterns within buildings, (CFD and Multizone, Alfred Moser 1985-91);
- Annex 23 Multizone airflow modelling (COMIS Helmut Feustel 1990-96);
- Annex 25 Realtime HEVAC simulation (1991-95);
- Annex 26 Energy efficient ventilation of large enclosures (1993-96);
- Annex 27 Evaluation and demonstration of domestic ventilation systems (Millet J-R, Villenave J G, 1995).

Other Activities

- European NatVent Project (Earle Perera, 1999).

25

Other Issues

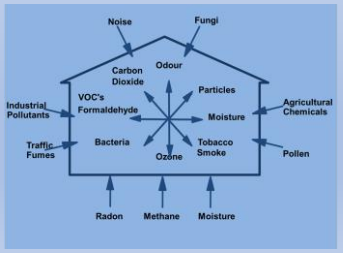
Ventilation Strategies 1980 – 2000

- Buildings started leaky but much effort was put into understanding and improving airtightness.
- Strategies depended on climate with natural (or adventitious) ventilation widely used, especially for dwellings in milder climates.
- There was increasing interest in mechanical systems, especially incorporating heat recovery and demand control.
- Designs for improved ventilation efficiency and contaminant removal effectiveness were developed (displacement systems).

Indoor Air Quality

Issues of the time included:

- Radon;
- Tobacco smoke;
- House dust mites (inducing asthma);
- Moisture, condensation and mould growth;
- VOC's and formaldehyde (from insulation and furniture);
- Odour;
- Sick building syndrome.



26

Conclusions

- The AIVC presented a unique opportunity to develop and promote an understanding of energy efficient ventilation.
- Initially, the Centre's task focused on minimising air infiltration energy loss. Over time, however, the AIVC evolved to respond to indoor climate, comfort and air quality concerns.
- During the 1980s and 90s there were considerable advances in multi-zone and CFD calculation methods. These were conducted through the AIVC and Annexes 20 and 23.
- To support this, the Centre compiled much numerical data covering building and component leakage was well as wind pressure data. These data have been widely incorporated into ventilation and thermal models.
- Tracer gas was especially important for infiltration measurements. There was wide use of multi-gas and multi-zone monitoring systems for determining fresh air ventilation air movement through buildings in the 1980s.
- By the 1990s tracer gas monitoring declined in use, possibly due to complexity and restrictions on the choice of gas. However, there was increasing use of carbon dioxide monitoring as a method to assess ventilation rates as well as to control ventilation systems.
- Blower doors for pressure testing were available by 1983. This technique is now in common use.
- Energy efficient ventilation systems evolved in the 1990s with particular interest in displacement systems and demand control.



The AIVC of the 21st century

P. Wouters

Operating Agent AIVC

1

AIVC in 20th century

- In 1980 very little was known in most countries about airtightness
- Only few countries had ventilation requirements
- 'Built tight' was in most countries not at all a point of attention
- Very few regulations with attention for airtightness
- No regulations with attention for energy efficient ventilation
- In many countries limited attention for summer comfort and ventilative cooling

AIVC in 21st century

- Research related to airtightness, ventilation and health has exponentially grown
- Wide range of organisations dealing with ventilation and airtightness
- In most countries a lot of attention for building airtightness
- Overall growing interest for 'healthy indoor climate' including good indoor air quality
- Ventilation and airtightness receive now in many countries a lot of attention from practitioners
- A wealth of information available

2

Give me five: 5 priorities to change with ambition and pragmatism



3

Give me five: 5 priorities to change with ambition and pragmatism

3. Communicate more and be

4. AIVC 4.0 for Construction

5. Collaborations and partnersh



4

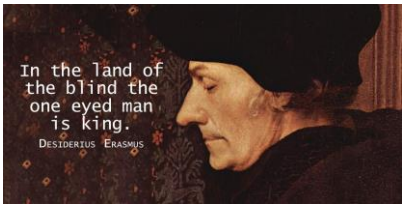
1. Innovation with vision

- 1985: Crucial to couple infiltration with ventilation AIC → AIVC
- 1995: Crucial role of ventilation in summer comfort strategies
- 2005: Energy legislation can be major driver for energy efficient ventilation (in particular in Europe due to EPBD)
- 2010: Large scale market uptake of airtightness is crucial and challenging → launch of Tightvent platform
- 2020: smart ventilation for good indoor climate

Give Me Five

5

2. More added value



- 1979: AIC was with one eye king in the land of the blinds
  Central AIVC staff was efficient to achieve high quality publications
- 2000: not longer evident to have a central staff of 5…6 persons
  - Very large number of research teams worldwide
  - Financing by member states not longer evident
- 2010: Increased focus on market implementation and stakeholders interactions
- 2012: Launch of concept of “AIVC projects”

Give Me Five

6

AIVC projects (Status June 2017)

- Philosophy on airtightness requirements
- How tight and insulated ducts should be?
- Durability aspects of airtightness
- Quality management of airtightness
- TAAC (TightVent A…
- Ve…
- Ve… and health
- Steps to improve the quality of residential ventilation systems
- Residential cooker hoods in low energy buildings

AIVC projects are 'small annexes'

7



3. Communicate more and better

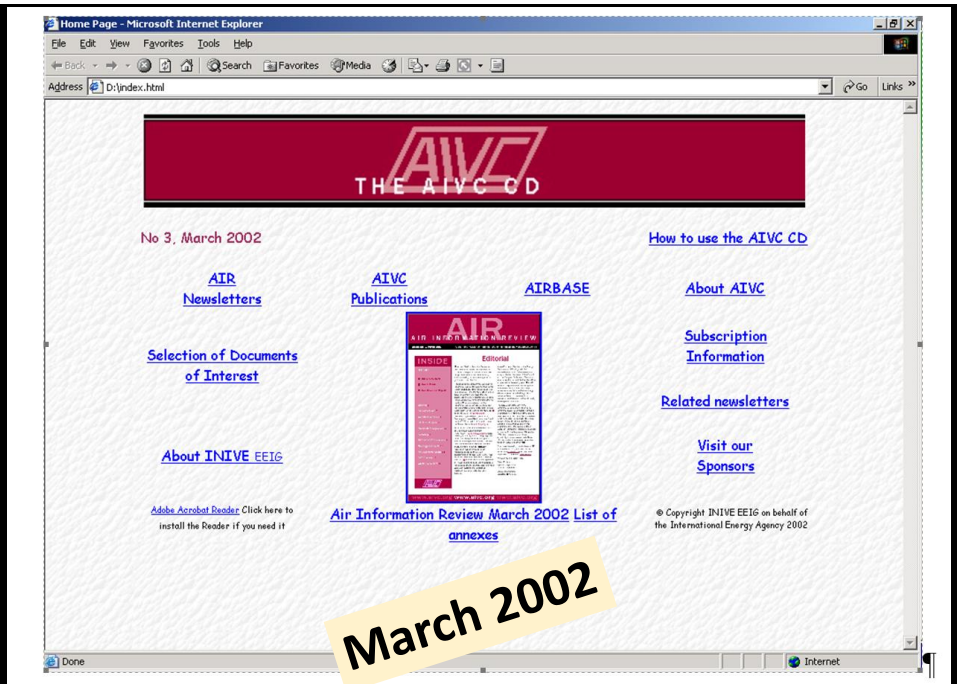
- 1979: Paper based society with mailing by post and use of stamps
- First AIVC website in September 1995!
- Newsletter with CD-ROM
- Webinars
- Continuous attention for good contacts database
- Topical sessions at conferences
- Social media



→ **Further efforts are needed!**



8



figure·2:··Homepage·when·inserting·AIVC-CD·in·computer·(version·March·2002)

9





10

AIVC workshops since 2008

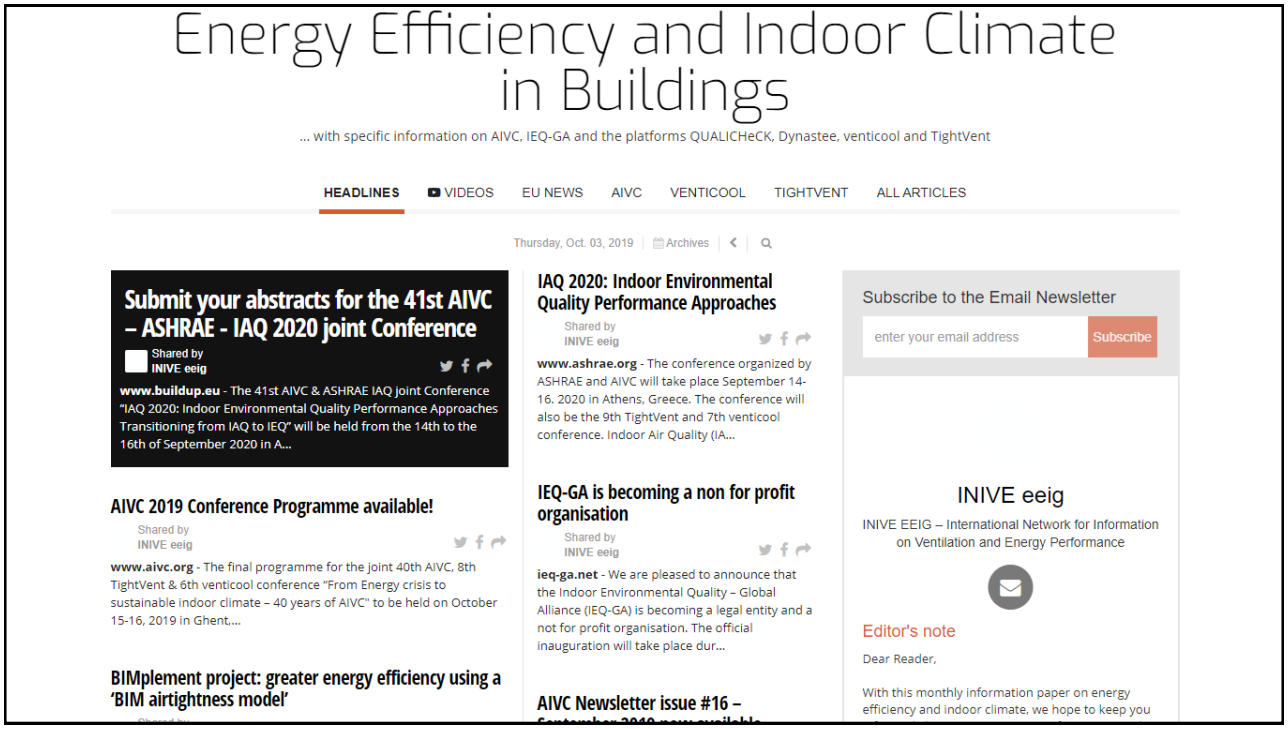
March 2019	Quality ventilation is the key to achieving low energy healthy buildings (Dublin)
April 2018	Building energy performance assessment and quality assurance based on in-situ measurements (Brussels)
March 2018	Ventilation for Indoor Air Quality and Cooling (Sydney)
March 2018	Towards Higher Performing Homes: The Role of Ventilation and Airtightness (Wellington)
March 2017	Is ventilation the answer to indoor air quality control in buildings?
January 2017	Renewable heating and cooling systems for buildings
December 2016	Performance of thermal insulation in low energy buildings and advanced building renovation projects
March 2016	Summer comfort technologies in buildings
March 2015	Ventilation and Airtightness: Voluntary and Regulatory Frameworks to Improve Quality and Compliance (Lund)
March 2014	Quality of Methods for Measuring Ventilation and Air Infiltration in Buildings (Brussels)
April 2013	Airtightness – Design, implementation, control and durability: feedback from practice and perspectives (Washington DC)
March 2013	Ventilative cooling (Brussels)
March 2013	Securing the quality of ventilation systems in residential buildings (Brussels)
May 2012	Ventilation and health (Brussels)
April 2012	Super insulating materials (Brussels)
March 2012	Achieving relevant and durable airtightness levels (Brussels)
May 2011	Reliable assessment of energy performances (Copenhagen)
March 2011	Full scale test facilities for evaluation of energy and hygrothermal performances (Brussels)
October 2010	Dynamic Methods for Building Energy Assessment (Brussels)
June 2010	Large scale implementation of airtightness plans (Brussels)
March 2010	Innovation and energy performance (Amsterdam)
September 2009	Impact, compliance and control of energy legislations (Brussels)
March 2009	Summer comfort and cooling (Barcelona)
March 2008	National trends in ventilation markets (Ghent)

11

AIVC webinars since 2011

23 May 2019	New perpectives on kitchen ventilation
25 April 2019	Ductwork airtightness measurements: protocols
4 September 2018	Using Metal Oxide Semiconductor (MOS) sensors to measure Volatile Organic Compounds (VOC) for ventilation control
25 April 2018	Ventilative cooling and summer comfort: Freevent project in France
6 March 2018	IAQ sensors for smart ventilation of buildings
25 January 2018	Ductwork airtightness: Standardisation's ongoing work and an overview of status and trends in Sweden, Japan, Spain and Portugal
13 January 2017	On The Quest For Indices Defining Indoor Air Quality. What Is A Reasonable Approach?
12 January 2016	Building airtightness and initiatives to improve the quality of the works
17 December, 2015	Ventilative cooling potential and compliance in Energy Performance regulations Status and perspectives in Belgium, Estonia, Greece
8 December, 2015	Assessing ventilative cooling potential in Energy Performance regulations Status and perspectives in Austria, Denmark, France
20 November 2014	Airtightness testing part 3: Status and trends in competent tester schemes in Denmark, Ireland and Sweden
22 November 2013	Airtightness testing part 2: Status and trends in competent tester schemes in Germany, the Czech Republic and France
14 November 2013	Airtightness Testing part 1: Status and trends in competent tester schemes in the UK and Belgium
8 October 2013	Building Airtightness Solutions: System approach and characterisation of air barrier and moisture management systems
4 June 2013	Building Airtightness Solutions: Recent Research and Characterisation of Sealants and Tapes
26 November 2012	Demand-Controlled Ventilation in the European context Approaches in 4 countries and at EU level
25 May 2012	The need for structured air leakage databases in energy conservation in buildings policies
9 November 2011	Achieving better envelope in practice – Norway

12





4. AIVC 4.0 for Construction 4.0

- **Broad range of new 4.0 technological developments**
  - BIM
  - Sensors and smart controls
  - Internet of Things
  - Data in the cloud
  - Artificial intelligence
  - Drones
  - Smart grid
  - …
- **Construction 4.0?**
  - … for Ventilation for IAQ
  - … for Ventilation for summer comfort control
  - … for Building airtightness



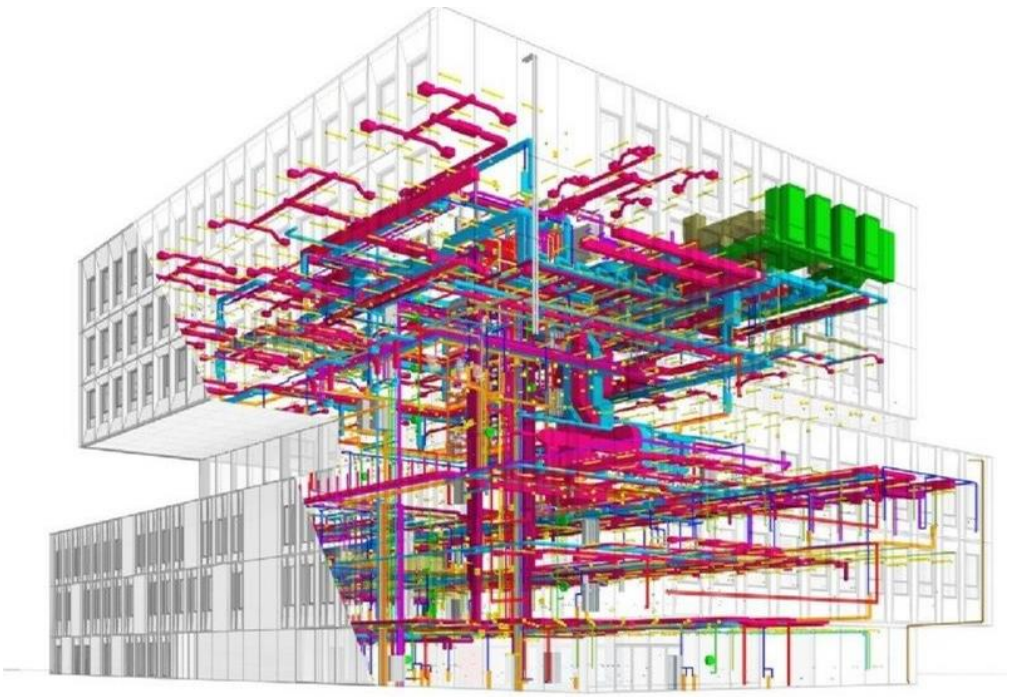
Augmented reality



Mixed reality



15

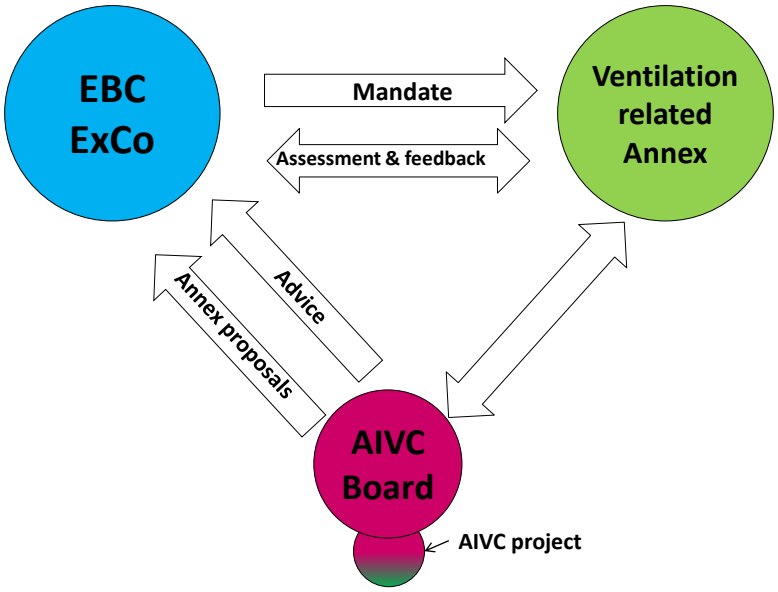


16

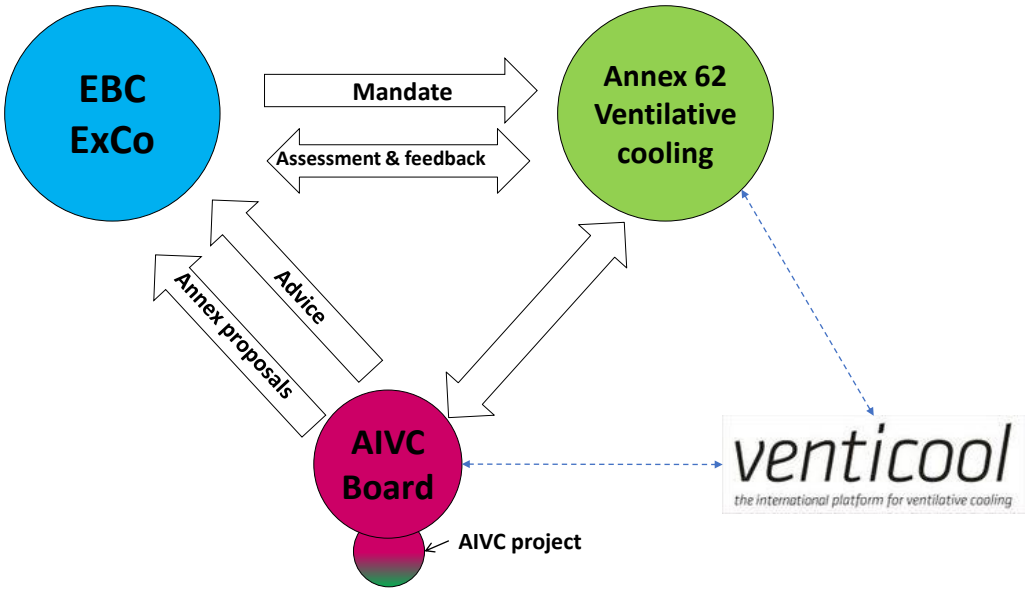
5. Collaborations and partnerships

- 1999: AIVC conference in collaboration with Indoor Air
- 2016 & 2020: AIVC conference together with ASHRAE IAQ conference
- Collaborations with other organisations
  - REHVA, ASHRAE, …
- Active interaction and support for IEA EBC ventilation related projects
- Active collaboration with Tightvent Europe and venticool platforms
- Active support for structural collaborations – IEQ-GA

Supporting Ventilation related EBC annexes



Supporting Ventilation related EBC annexes



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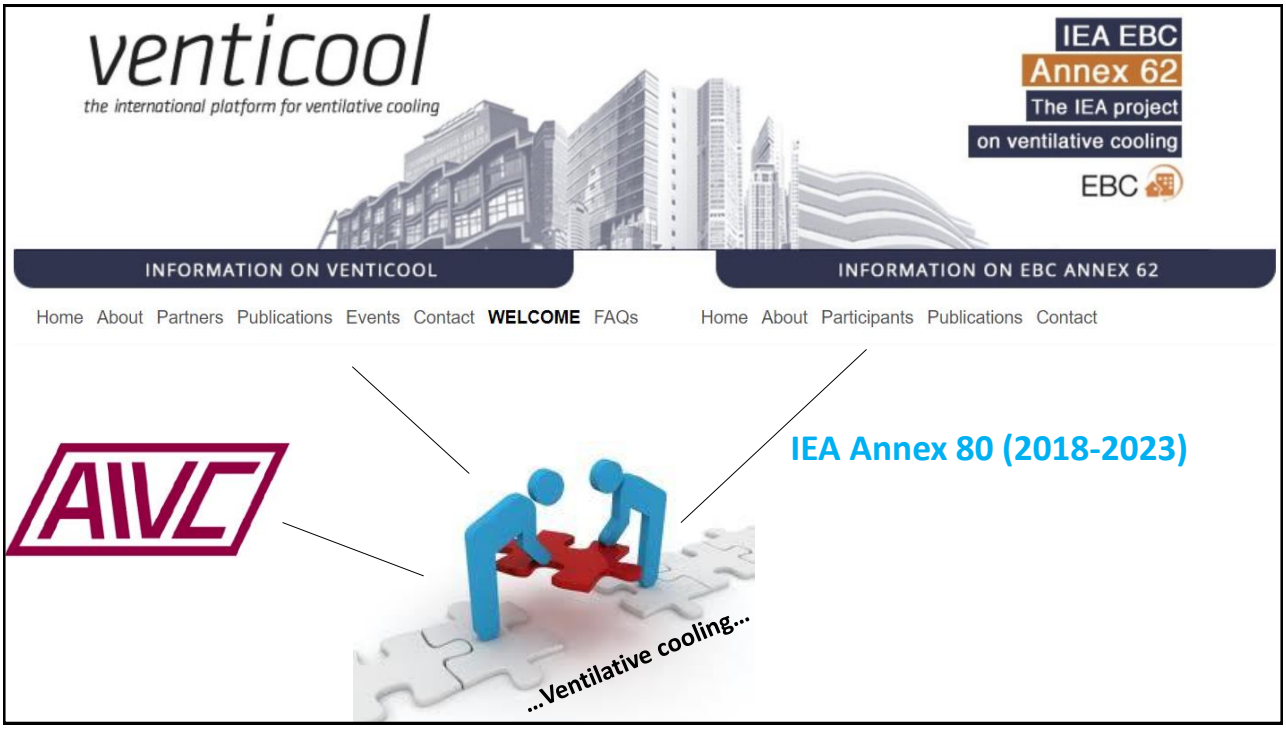

20

venticool

the platform for resilient ventilative cooling

IEA EBC Annex 80 The IEA project on resilient cooling

IEA EBC Annex 62 The IEA project on ventilative cooling

Welcome FAQ

Information on Venticool | Information on Annex 62 | Information on Annex 80



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IEQ Global Alliance

For better indoor environment quality



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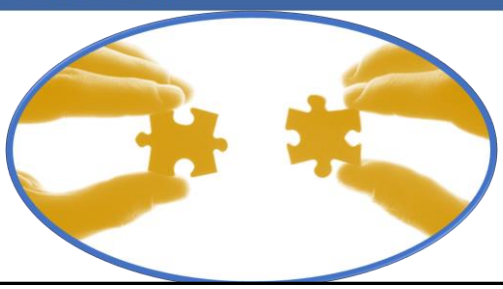

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Conclusions

- Ventilation and airtightness have become major points of attention in building practice
- AIVC has tried to regularly optimise its operation in this quickly changing context
- Collaboration becomes more and more important
- It is crucial to continue this evolution for the envisaged new operating period 2022-2026

40 Years of Modeling Airflows

Iain Walker
Lawrence Berkeley National Laboratory

1

In the beginning…….

1973 – first "energy crisis"

- Need to understand air exchange in buildings
- Experiments correlated air exchange with air leakage and weather
- Needed methods to predict air exchange
- AIVC formed in 1977





2

The Early Years – Modeling Principles

Quickly moved from basic correlations to physics-based calculations (1st AIC conference)

- Stack Effect
- Wind Effect
- Leakage
  - Pressure-flow relationship
  - Magnitude: blower door testing
  - Location on the building shell

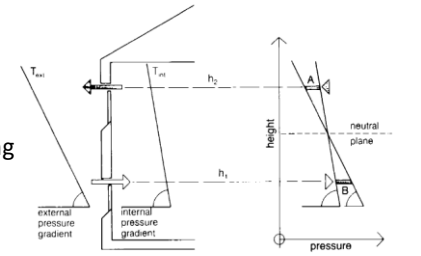
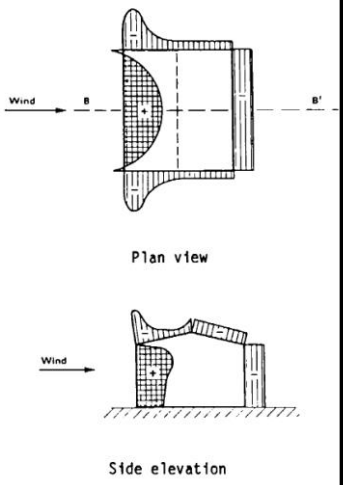


Figure 3.7 Stack induced pressure between two vertically placed openings



Two distinct approaches

1. Simple models

Semi-analytical approaches and simplifying assumptions allow for hand calculation

- More common for homes
- Early models often empirical correlations
- Single zone

2. Complex Models

Require computation to solve the non-linear mass balance equations

- More common for large buildings
- Multi-zones include internal air flows
- Contaminant transport

Simple models combine stack and wind *flows*

Quadrature:

$$Q_{total} = \sqrt{Q_s^2 + Q_w^2}$$

Pressure addition with correction:

$$Q_{total} = \left(Q_s^{\frac{1}{n}} + Q_w^{\frac{1}{n}} + B(Q_s Q_w)^{\frac{1}{2n}}\right)$$

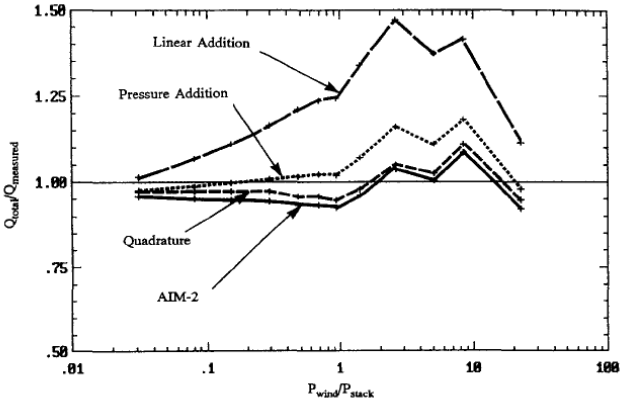


Fig. 9. Superposition errors for house #5 with no furnace flue (541 hours).

5

Simple models: Natural Infiltration and Mechanical Ventilation

Balanced systems add

Unbalanced sub-additive

- Many empirical approaches - sometimes for special cases:
  - e.g., strong exhaust or no wind : add half of fan flow
- Quadrature works well over a wide range of conditions
- More recently semi-empirical relationships

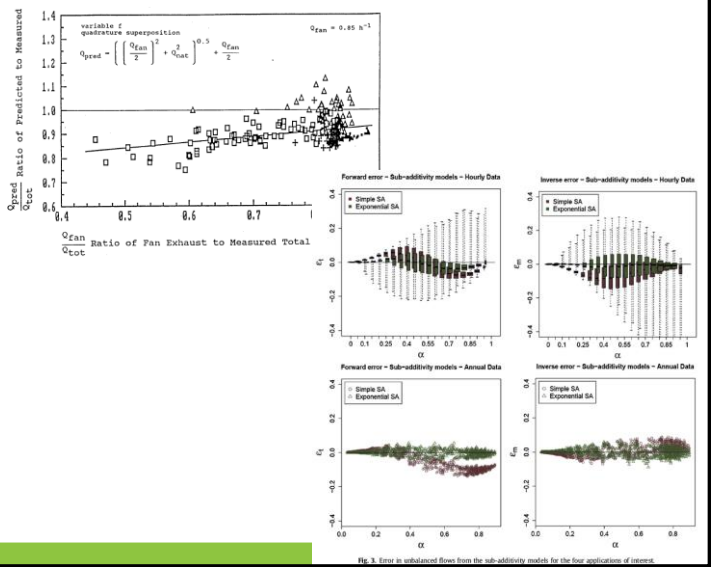


Fig. 3. Error in unbalanced flows from the sub-additivity models for the four applications of interest.

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Complex models combine stack and wind *pressures*

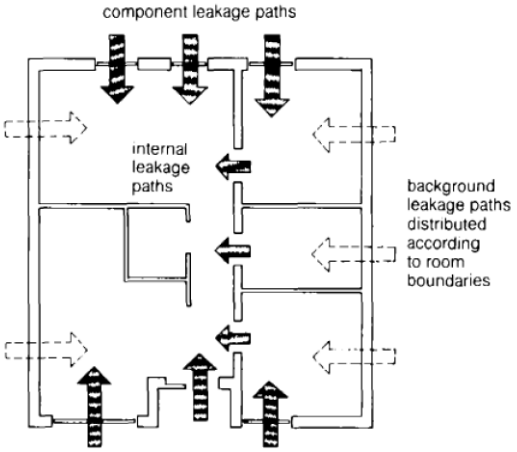
Numerical solutions to mass balance unknown(s) are interior pressure shifts

Include mechanical systems directly

$$0 = \sum_{l=0}^{m} \left\{ \sum_{j=0}^{k} \left[\rho\, C_{j,l} \mid P_{o_{j,l}} - P_i \mid^{n_{j,l}} \left(\frac{P_{o_{j,l}} - P_i}{\mid P_{o_{j,l}} - P_i \mid} \right) \right] \right\}$$

with:

ρ	density of air
$C_{j,l}$	flow coefficient for flow path j of zone l
$P_{o_{j,l}}$	external pressure for flow path j of zone l
P_i	internal pressure
$n_{j,l}$	flow exponent for flow path j of zone l

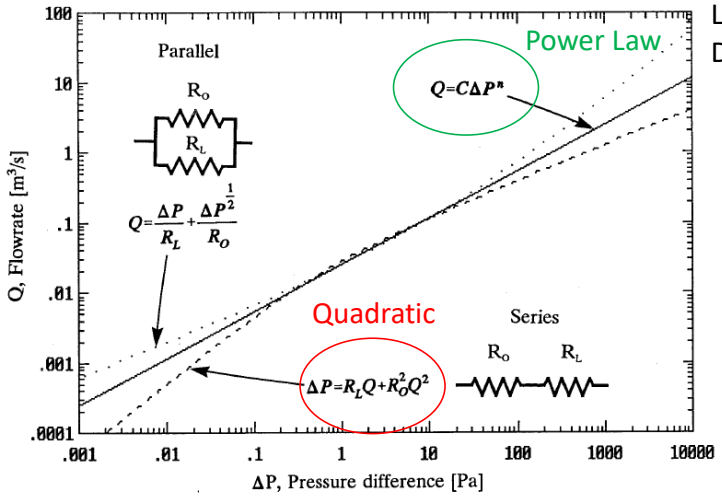


The Early Years - AIVC Tech Note 11 (1983)

- all the models gave reasonable predictions (+/- 25%) compared to measured data
- biggest source of uncertainty was estimating wind pressure changes due to shielding and different building shapes
- computing limitations
  - number of allowed nodes and connection in multi-zone models
  - computer memory requirements



The Power Law Rules – OK!



Laboratory studies:
Developing flow n ~ 2/3

Some models simplified to:

$$Q = KArea\Delta P^{1/2}$$

Introduced concept of leakage AREA:

- If you put all the holes in the building in one place – how big would that hole be?
- Needs a fixed reference pressure – usually 4 Pa or 10 Pa

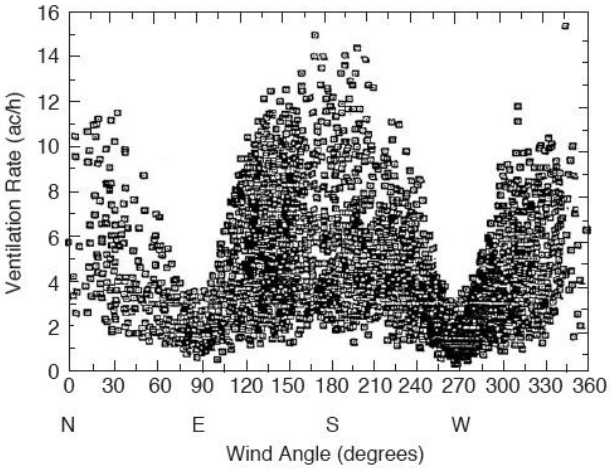
Wind Issues

hardest to model due to:

- local wind direction
- sheltering effects
- building shapes

Simple models based on assumed leak locations and assumed pressure coefficients

Complex models introduce individual surface pressure coefficients

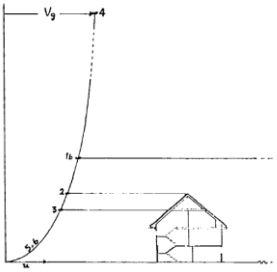


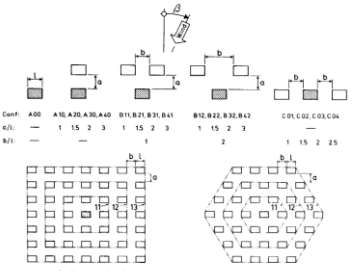
The Early Years - AIVC Tech Note 13 (1984)

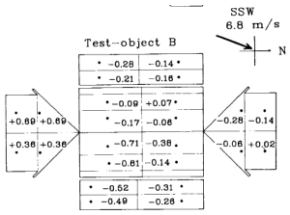
AIVC wind pressure workshop TN13.1

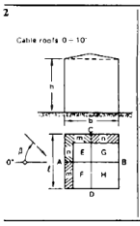
Improve estimates of wind pressures

- Wind direction
- Shelter
- Boundary layer profiles
- Turbulence









Internal pressure coefficient $C_{p,a}$ for $h:b:l = 1:1:1$

β	A	B	C	D	E	F	G	H
0°	+0·9	−0·5	−0·6	−0·6	−0·7	−0·7	−0·5	−0·5
15°	+0·8	−0·5	−0·7	−0·5	−0·7	−0·6	−0·5	−0·6
45°	+0·5	−0·5	+0·5	−0·5	−0·8	−0·5	−0·5	−0·4
45°	For section "m" $C_{p,a} = -1{\cdot}2$; "n" $C_{p,a} = -0{\cdot}8$							

Closed square building

Internal pressure coefficient $C_{p,i}$ for β =

	0°	15°	45°
Openings uniformly distributed	±0·2	±0·2	±0·2
Openings on side A predominating	+0·8	+0·7	+0·4
Openings on side B predominating	−0·4	−0·4	−0·4
Openings on side C predominating	−0·5	−0·6	+0·4

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The 1990s

AIVC

- Comparisons to measured data – TN 27. Wind direction and leak location biggest sources of uncertainty
- COMIS multizone model TN29 – improved wind pressures and duct systems
- TN 41 and 44 provided databases of measured data with well characterized buildings for model development

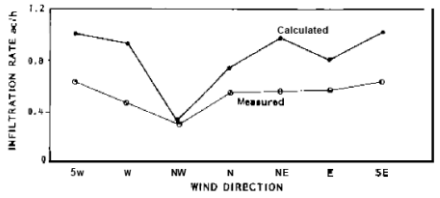

Figure 5.7 Measured and calculated infiltration rates into the roof space of house C for different wind directions.

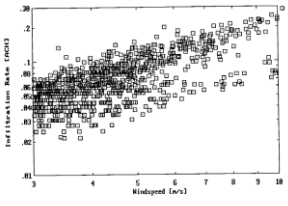

Figure 7. Windspeed Dependence of Infiltration Rate with ΔT < 10°C and U > 3m/s (866 Hours).

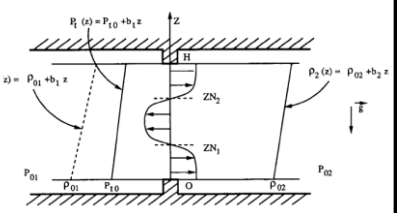

Fig. 16: *The General Problem of Gravitational Flow through a Vertical Opening*

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State of the art in 2000 (AIVC TN 51) – Subject Mature

Simple models well established:
- AIM2, CEN, LBL, AIDA and VENT
- Used in building codes/standards/design guides

Natural ventilation through large deliberate openings + ventilation cooling
- NatVent, NiteCool and SUMMER-Build

Multizone
- AILOS, BREEZE, COMIS, CONTAM
- Contaminant transport

User interfaces……..



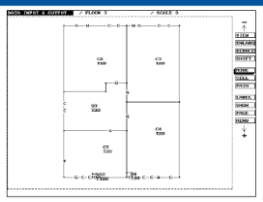
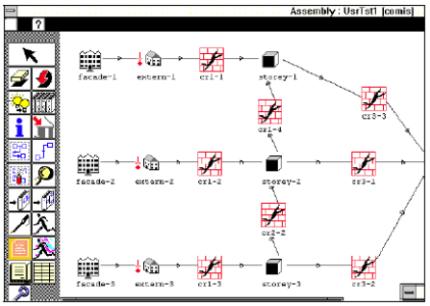
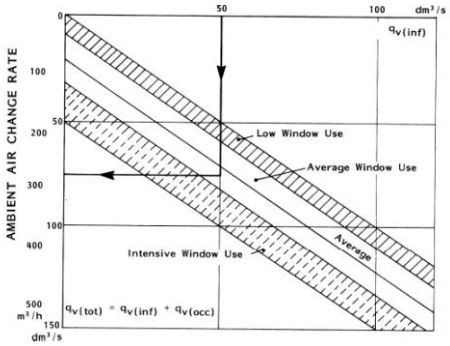


Figure 7 Example BREEZE input screen



2000 to 2017 - incremental improvements

- AIVC Guideline 5 – Ventilation Modeling Data
- wind pressure libraries
- natural ventilation/window opening



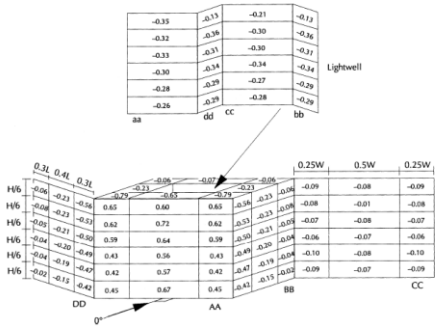


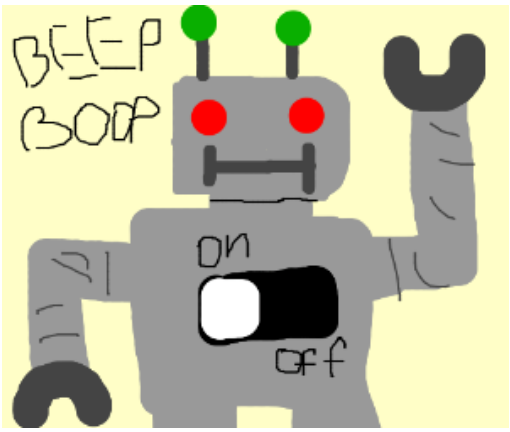
Figure F1 Wind pressure coefficients for a three-level office with lightwell

The future?

- Better user interfaces
- Better input data
- Improved wind pressure estimates for natural ventilation systems
- Better integration with:
  - Energy Calculations
  - Moisture Calculations
  - CFD for internal flows
  - Health metrics

The future?

- Better user interfaces
- Better input data
- Improved wind pressure estimates for natural ventilation systems
- Better integration with:
  - Energy Calculations
  - Moisture Calculations
  - CFD for internal flows
  - Health metrics
  - **Smart/advanced ventilation controls – real time calculations**



The Role of Carbon Dioxide in Ventilation and IAQ Evaluation: 40 years of AIVC

Andrew Persily
National Institute of Standards and Technology
Gaithersburg, Maryland USA



40th AIVC - 8th TightVent & 6th venticool Conference, 2019
Ghent BELGIUM, 15-16 October 2019

1

AIVC and Indoor Carbon Dioxide

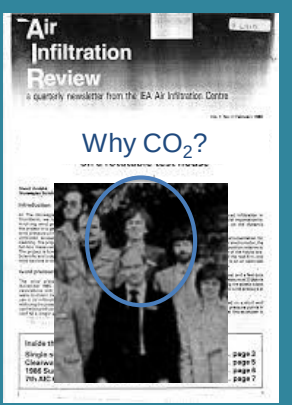
- Demand control ventilation
- Tracer gas measurements
- IAQ assessment
- IAQ metric
- CO_2 generation rates
- Standards and guidelines
- Impacts on building occupants

2

Demand Control Ventilation
H. Han, K-J Jang, C. Han and J. Lee. 2013. Occupancy estimation based on CO2 concentration using dynamic neural network model, 34th AIVC Conference.
A. Persily, A. Musser, S. Emmerich, M. Taylor. 2003. Simulations of indoor air quality and ventilation impacts of demand controlled ventilation in commercial and institutional buildings. 24th AIVC and BETEC Conference.
Villenave J.G., Bernard A.M., Lemaire M.C. 2003. Simulations of indoor air quality and ventilation impacts of demand controlled ventilation in commercial and institutional buildings. 24th AIVC and BETEC Conference.
Chan G Y, Chao C Y, Lee D C, Chan S W, Lau H. 1999. Development of a demand control strategy in buildings using radon and carbon dioxide levels. Indoor Air 99 and 20th AIVC Conference.
Fleury B. 1992. Demand controlled ventilation: a case study. 13th AIVC Conference.
Zamboni M, Berchtold O, Filleux C, Fehlmann J, Drangsholt F. 1991Demand controlled ventilation - an application to auditoria. 12th AIVC Conference.
Fahlen P, Andersson H. 1991. Demand controlled ventilation: full scale tests in a conference room. 12th AIVC Conference.
Donnini G, Haghighat F, Van Hiep Nguyen. 1991. Ventilation control of IAQ, thermal comfort and energy conservation by CO2 measurement. 12th AIVC Conference.
Fahlen P, Ruud S, Andersson H. 1991. Demand controlled ventilation - evaluation of commercially available sensors. 12th AIVC Conference.
Raatschen W. 1988. Market analysis of sensors for the use in demand controlled ventilating systems. 9th AIVC Conference.
Smith B E, Prowse R W, Owen C J. 1984. Development of occupancy-related ventilation control for Brunel University Library. 5th AIVC Conference.

3

General AIVC publications



Liddament, 1996

Tracer gas; IAQ evaluation; occupancy indicator



deGids & Wouters 2010

IAQ indicator; ventilation control

4

Demand control ventilation

2001 Literature List, 30 publications

1984 to 2013: Sensors, energy and IAQ impacts, case studies in variety of building types



Tracer gas

Liddament & Thompson (1983), Tech Note 10

6 publications, 1993 to 2014



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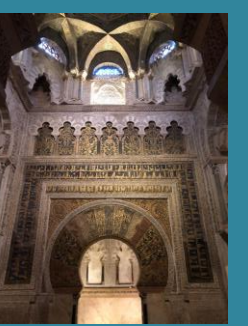
IAQ assessment

15 AIVC conference papers, 1985 to 2014

CO_2 often measured; no explanation or reference value



IAQ metric

More recent interest of AIVC; 2 papers in AIVC proceedings



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CO_2 generation rates

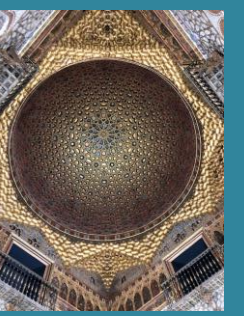
3 AIVC papers (2 authors)
since 2014



Standards & Guidelines

Impacts on building occupants

3 papers each since 2015



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AIVC and Indoor CO_2

Same topics as broader IAQ discussions

- **Demand control ventilation**
- **Tracer gas measurements**
- **IAQ assessment**
- **IAQ metric**
- **CO_2 generation rates**
- **Standards and guidelines**
- **Impacts on building occupants**

8

IEA EBC Annex 68 - Indoor Air Quality Design and Control in Low Energy Residential Buildings

Energy in Buildings and Communities Programme

Subtask 4 - Strategies for design and control of buildings

TOPICAL SESSION: "Ventilation design and control in residences - current challenges, innovative solutions and case studies gathered by IEA-EBC Annex 68"

"Introduction: How IEA EBC Annex 68 identified challenges and potential solutions in design and control of ventilation system in residences"

40th AIVC conference, Ghent, Belgium

Esfand Burman
Daria Zukowska, Gabriel Rojas, Gaelle Guyot, Maria del Carmen Bocanegra-Yanez, Jelle Laverge, Guangyu Cao and Jakub Kolarik

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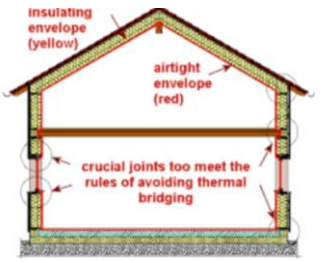
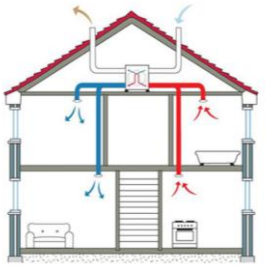
Introduction – IEA EBC Annex 68



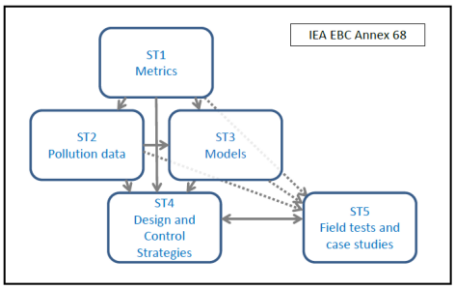


- Highly energy efficient residential buildings are airtight, and their need for ventilation should be optimized
- Inappropriate ventilation leads to risk of high levels of pollutants indoors
- Annex 68 shall focus on design and operation of buildings towards highest energy efficiency while ensuring good & healthy indoor conditions
- Annex 68 should consider latest scientific data regarding indoor air pollution as well as available modelling tools
- Annex 68 shall provide guidance regarding design and operation with a specific target of new and refurbished residential buildings

2

Subtasks

- ST1 - Defining the metrics
- ST2 - Pollutant loads in residential buildings
- ST3 - Modeling
- ST4 - Strategies for design and operation
- ST5 - Field measurements and case studies



Subtask 4 - Objectives

- Gather results and approaches of the other subtasks of the Annex 68 and annex participants
- Address optimal and practically applicable design and control strategies for high IAQ in residential buildings
- Present results in context with existing knowledge

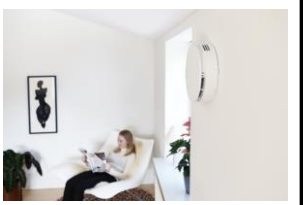
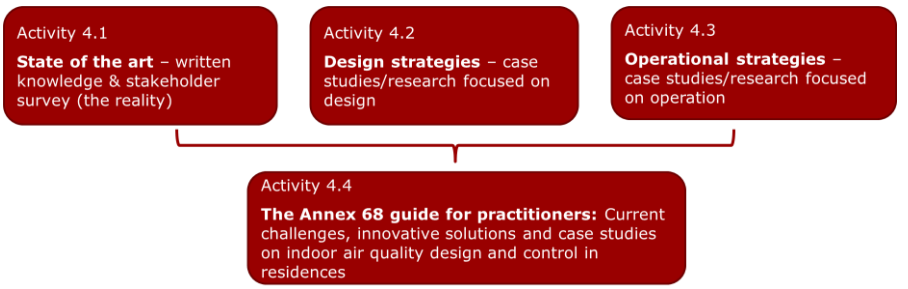


Figure: Sustain Solutions A/S

Approach and structure

Focus of the subtask is on energy efficient and comfortable mechanical ventilation in tight, low energy residences

Structure:



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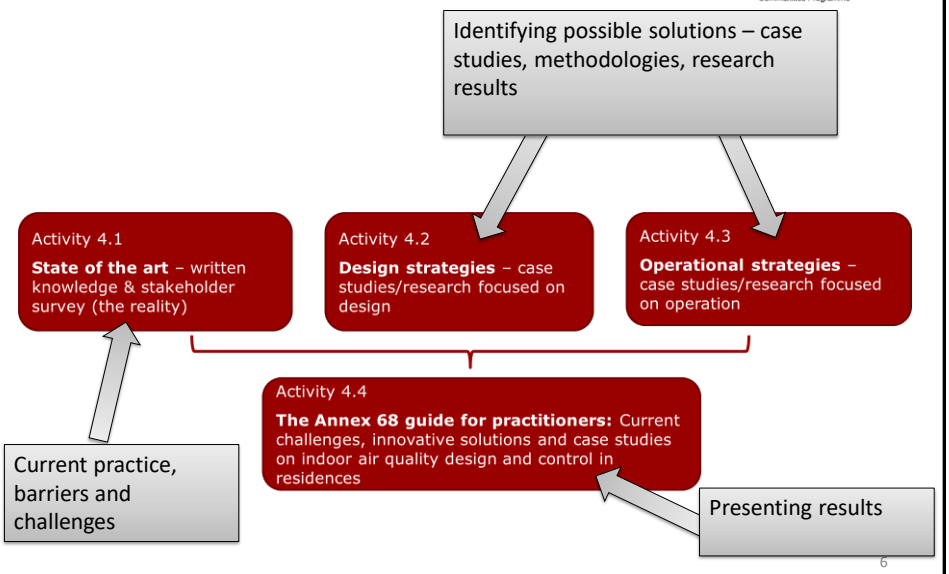
Approach and structure



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6

Activity 4.1 State of the art, challenges & barriers

Objective:
To identify improvement opportunities for the design and operation of mechanical ventilation in residential buildings

"Transition from requirements to practice"



National building codes & Standards	Guidelines, internet-based knowledge bases, computational tools, etc.	Stakeholder survey

Methods

Review of ventilation requirements	Stakeholder survey

- Recommended ventilation systems
- Background and nominal ventilation rates
- Supply and extract airflows
- Requirements for heat recovery efficiency
- Requirements for specific power input (SPI)
- Requirements for demand-controlled ventilation (DCV)

Overview about today's practice in design, operation and commissioning of ventilation systems in residential buildings in different countries

Stakeholder groups:

A – Ventilation designers and Consultants

B – Facility management and Building administration

C – Public authorities

D – Housing developers

E – Producers of ventilation systems

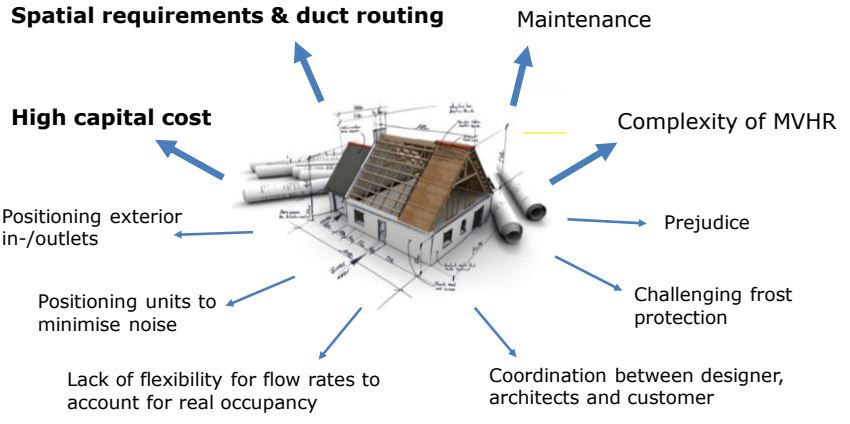
Survey results – Conducted interviews

	A	B	C	D	E	Total
	Designers	Admin.	Authorities	Developers	Producers	
Austria	2		1	2	1	**6**
Belgium	4	2	2		2	**10**
Denmark	4				1	**5**
Estonia	1	1	1		1	**4**
France	2		2		1	**5**
Norway	2		2	3		**7**
UK	2		1	3	1	**7**

Total: 44 interviews

Identified Barriers & Problems

Design (decision making, concept design, detail design)



Identified Barriers & Problems

Construction (installation & commissioning)



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13

Identified Barriers & Problems

Post-handover (operation & maintenance)



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Suggestions for improvements by survey participants

Legislative pushes:

- More flexibility in legislation including a more holistic approach allowing for trade-offs
- Coordinated approach to energy and IAQ
- Strengthen requirements to installation, commissioning and maintenance

Technical pushes:

- Training and accreditation of installers
- Simple design and user control flexibility / Zonal control and more sensors
- Identification of risk factors and failure modes of a design strategy
- Specify appropriate mitigation measures throughout the building procurement process

Suggestions for improvements by survey participants

Financial incentives pulls:

- Government subsidy or grants for systems
- Insurance incentives for system maintenance

Market pulls:

- Quality labels for ventilation systems
- Low emission building products
- Market interventions to balance energy efficiency and cost of installation
- Level playing field in the market
- Stricter regulatory requirements

Outreach programmes:

- Clear government guidance on IAQ
- Feedback to designers on actual performance of systems
- Enhanced training for practitioners
- Outreach campaign on benefits of mechanical ventilation systems

Activity 4.4 – Presenting results

A guide through innovative solutions, current challenges, and selected case studies on indoor air quality, ventilation design and control in residences

TABLE OF CONTENTS	EDITORS
1/INTRODUCTION	Jakub Kolarik & Carsten Rode
2/STATE OF THE ART AND CURRENT CHALLENGES How do we design residential ventilation today?	Daria Zukowska Esfand Burman
3/DESIGN Ways to design residential ventilation in the future/How to overcome nowadays challenges?	Gabriel Rojas Guangyu Chao
4/OPERATION Towards better performance, user satisfaction and easier maintenance	Jakub Kolarik Kevin Smith
5/CONCLUSIONS and OUTLOOK	Jakub Kolarik, Gabriel Rojas

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Annex 68 guide - overview

		Design			Construction, Comissioning & Operation	
Chapter	Case studie	Assessment methods	Assessing ventilation concepts	Novel ventilation solutions	Quality assurance	Assessing in-use performance
3.1	Alternative ducting options for balanced mechanical ventilation systems in multifamily housing					
3.2	Ambient air filtration in highly energy efficient dwellings with mechanical ventilation					
3.3	Development of a compact ventilation system for facade integration					
3.4	VOC exposure due to Floor heating systems versus Radiator heating					
3.5	Control strategies for mechanical ventilation in Danish low-energy apartment buildings					
3.6	Response of commercially available Metal Oxide Semiconductor Sensors under air polluting activities typical for residences					
3.7	Impact of multi zone air leakage modelling on ventilation performance and indoor air quality assessment in low-energy houses					
3.8	Towards a better integration of indoor air quality and health issues in low-energy dwellings					
3.9	List of key pollutants for design and operation of ventilation in low-energy housing					
3.10	Definition of a Reference Residential Building Prototype for Evaluating IAQ and Energy Efficiency Strategies					
3.11	Temperature dependent emissions of Volatile Organic Compounds from building materials					
3.12	Detailed modelling of IAQ to improve ventilation design in low energy houses					
3.13	Mechanical ventilation system in deep energy renovation of a multi-story building with prefabricated modular panels					
3.14	Simplifying MVHR systems: Assessing the extended cascade ventilation and active overflow concept					
3.15	Design of room-based ventilaiton systems in renovated appartments					
4.1	House owners' experience and satisfaction with Danish Low-energy houses - focus on ventilation					
4.2	Development and test of quality management approach for ventilation and indoor air quality in single-family buildings					
4.3	Applications of the Promevent protocol for ventilation systems inspection in French regulation and certification programs					
4.4	Long-term durability of humidity-based demand-controlled ventilation: results of a ten years monitoring in residential buildings					
4.5	Practical use of the Annex68 IAQ Dashboard					
4.6	Performance evaluation of Mechanical Extract Ventilation (MEV) systems in three 'low-energy' dwellings in the UK					
4.7	Indoor air quality in low energy dwellings: performance evaluation of two apartment blocks in East London, UK					

Addressed topics:
- Health & Comfort
- Spatial requirements
- Cost & Energy consumption
- Refurbishment
- Comissioning
- Quality of installation
- Maintenance
- User satisfaction

- 40 contributors
- 22 case studies
- Available in spring 2020

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Annex 68 guide - overview

Each case study is presented using a fixed structure comprising of:

- **Objectives, description and methods** – briefly presents background, aim and main methodology used in the case.
- **Main results and findings** – this section documents how the objectives were fulfilled.
- **Conclusions and lessons learned** – represents a direct connection between the case study and practice.
- **Further reading** – a simplified reference section. Presents one, most important source for further reading providing additional information regarding the case study.

Annex 68 guide – an appetizer

Following presentations in this session represent examples of individual “chapters” in the guide

Thank you for your attention

http://www.iea-ebc-annex68.org/

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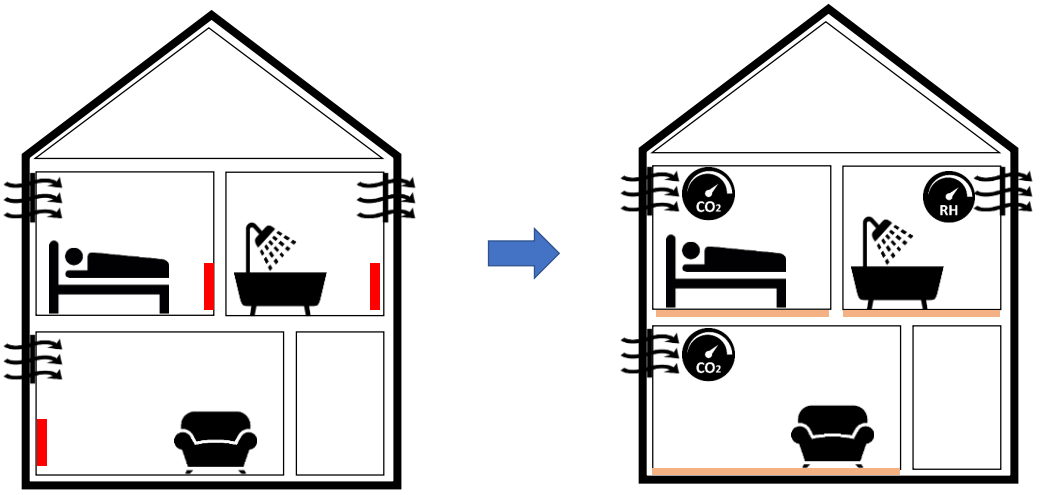
HVAC and VOCs: interaction between building systems and indoor VOC concentrations

Ir. Arch. Klaas De Jonge / 15-16.10.2019 / AIVC-TightVent-Venticool Conference

GHENT UNIVERSITY fwo

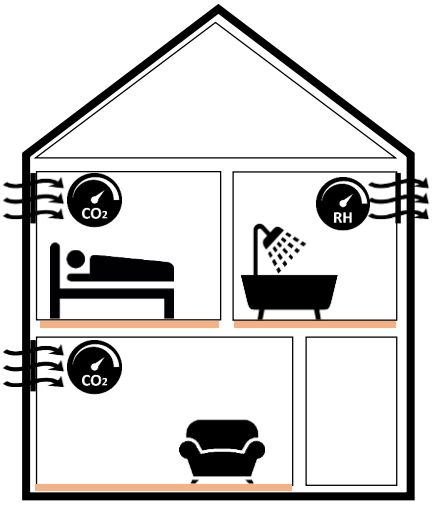
1



Radiator Heating (High T)
Continuous Ventilation

Floor Heating (Low T)
Demand Controlled Ventilation

2



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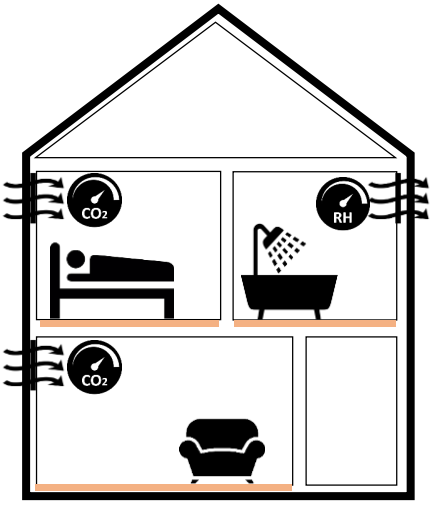



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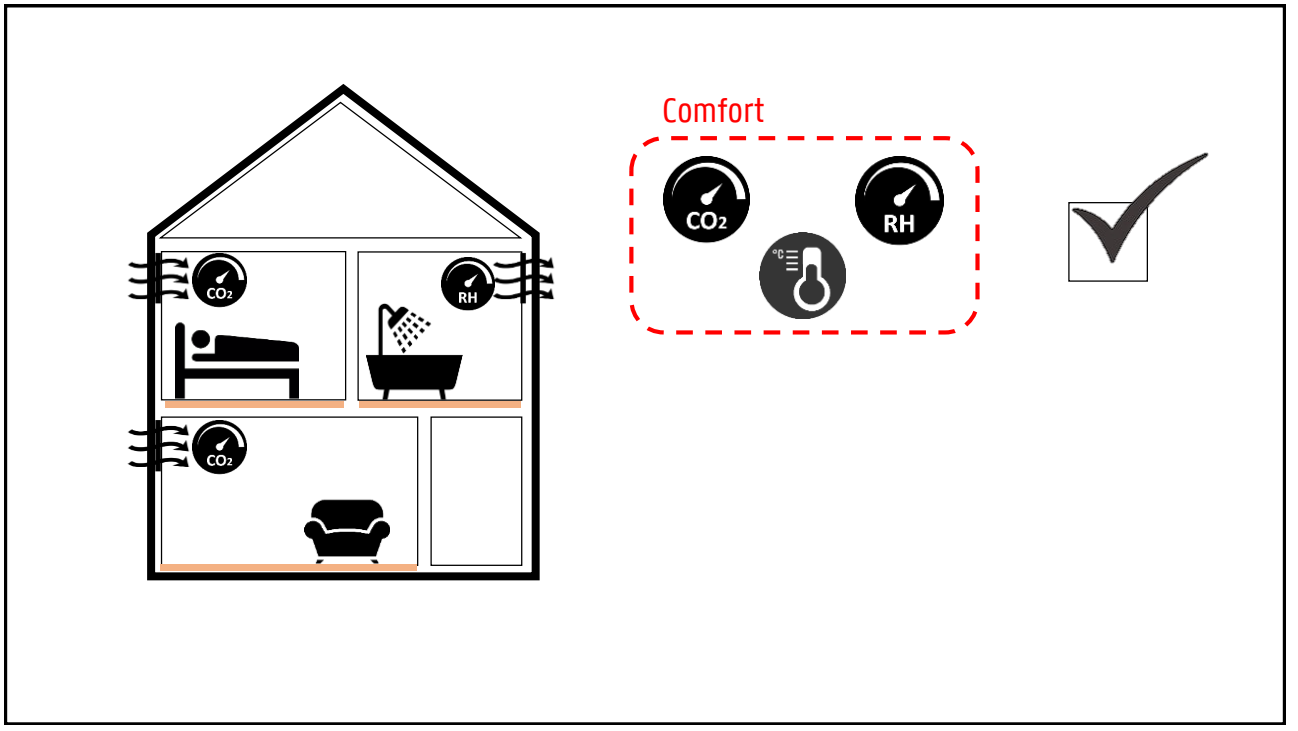
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Comfort

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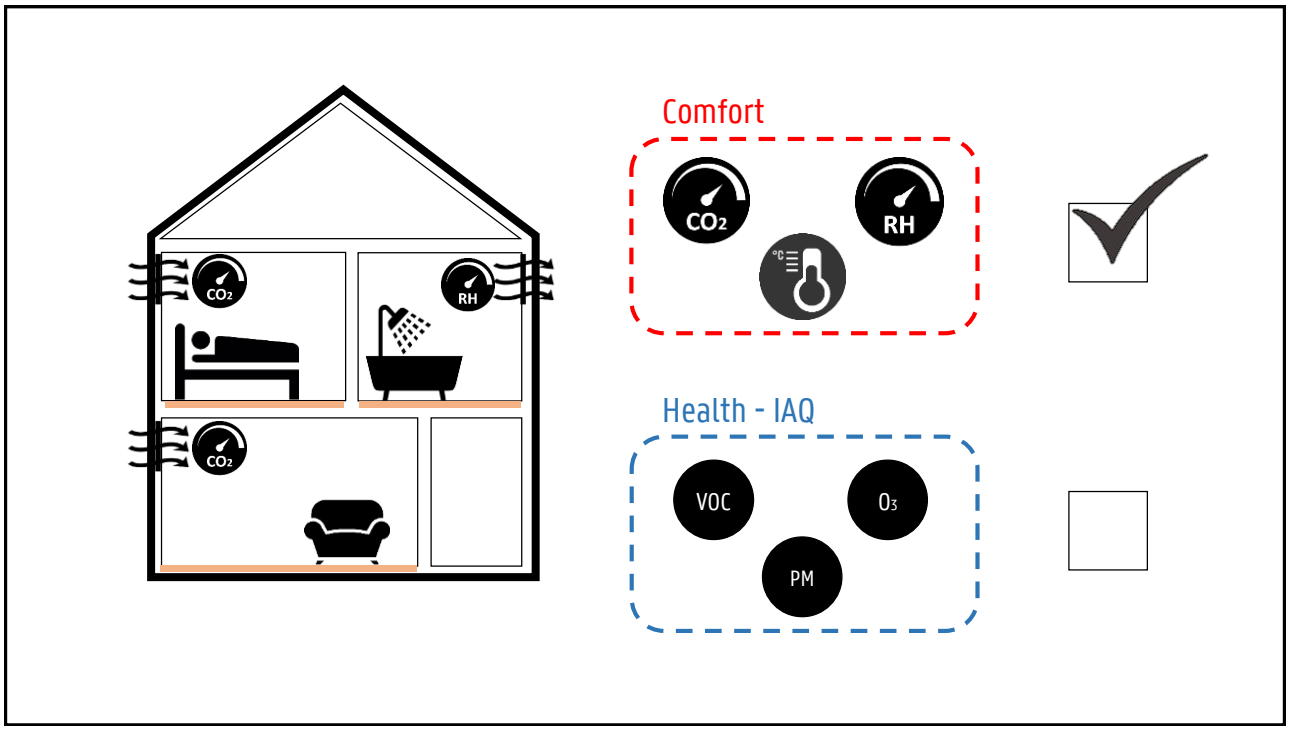
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Health - IAQ
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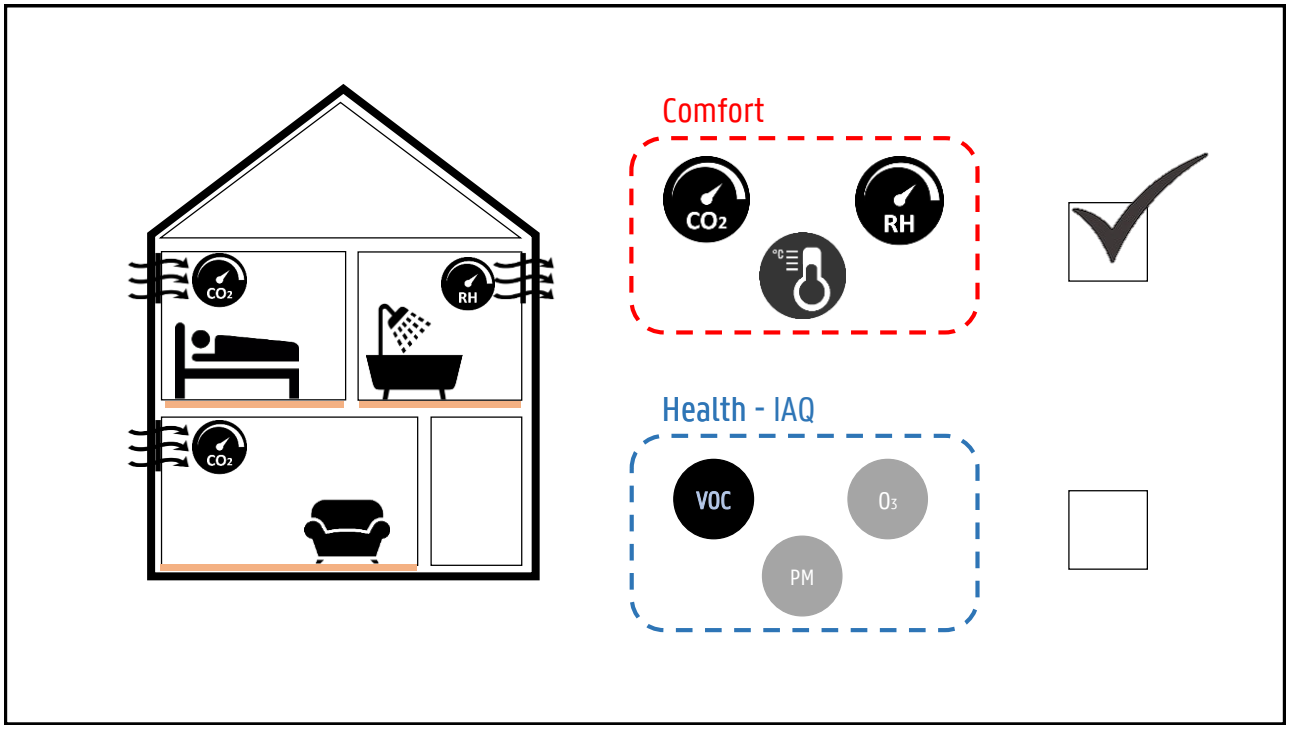
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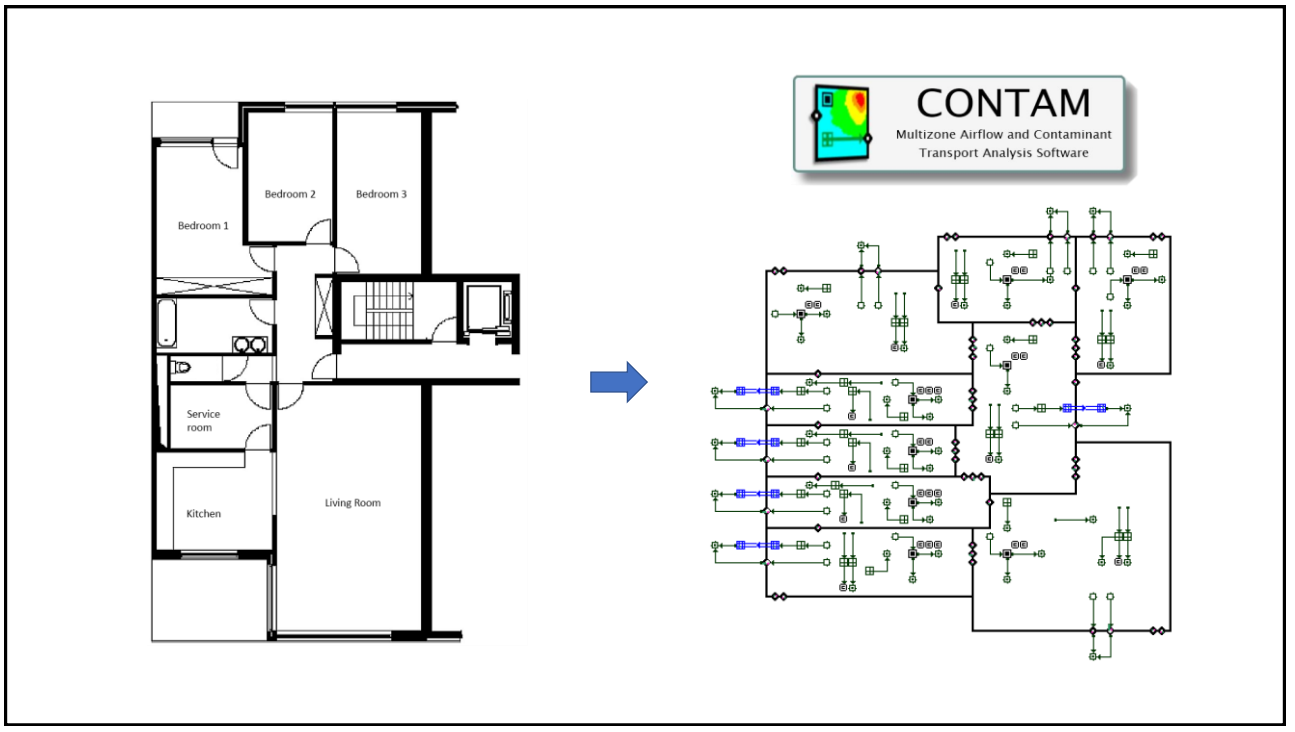
Bedroom 1
Bedroom 2
Bedroom 3
Service room
Kitchen
Living Room
CONTAM
Multizone Airflow and Contaminant Transport Analysis Software

8

VOC emission model

$$E(t) = 2.1 \frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right]\left[(1+C_1 AH) C_2 T^{-0.5} e^{\frac{-C_3}{T}}\right]}{\delta} e^{-2.36 \frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right] t}{\delta^2}}$$

E(t)	[mg/m²/h]	Emission rate
T	[K]	Material temperature
AH	[g/kg]	Absolute humidity
δ	[m]	Material thickness
t	[h]	Time since start of emissions
d_1, d_2	[varies]	Diffusivity material constants for VOC-material system
C_1, C_2, C_3	[varies]	Initial concentration material constants for VOC-material system

9

Dm(T)* C0(T,AH)* Dm(T)

$$E(t) = 2.1 \frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right]\left[(1+C_1 AH) C_2 T^{-0.5} e^{\frac{-C_3}{T}}\right]}{\delta} e^{-2.36 \frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right] t}{\delta^2}}$$

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C_1, C_2, C_3	[varies]	Initial concentration material constants for VOC-material system

J. Xiong, W. Wei, S. Huang, and Y. Zhang, 2013.; Q. Deng, X. Yang, and J. Zhang, 2009.; W. Liang, M. Lv, and X. Yang, 2016. and K. De Jonge, J. Laverge, 2019.

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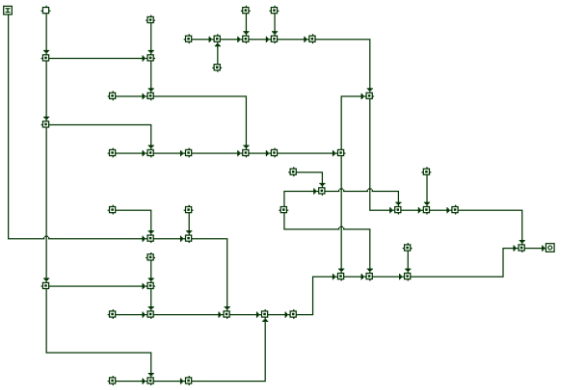


11

Radiator heating ⟷ Floor heating



12

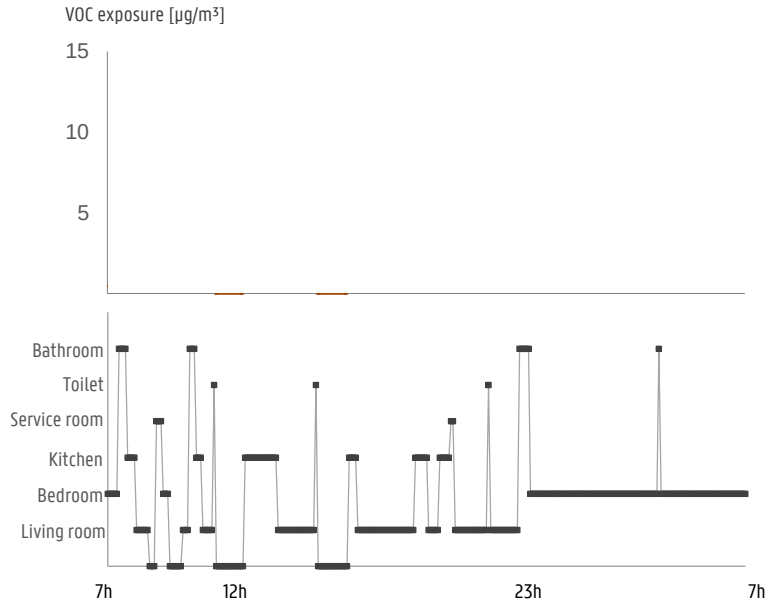
Radiator heating ⟷ Floor heating



Continuous ventilation ⟷ Demand controlled ventilation



13



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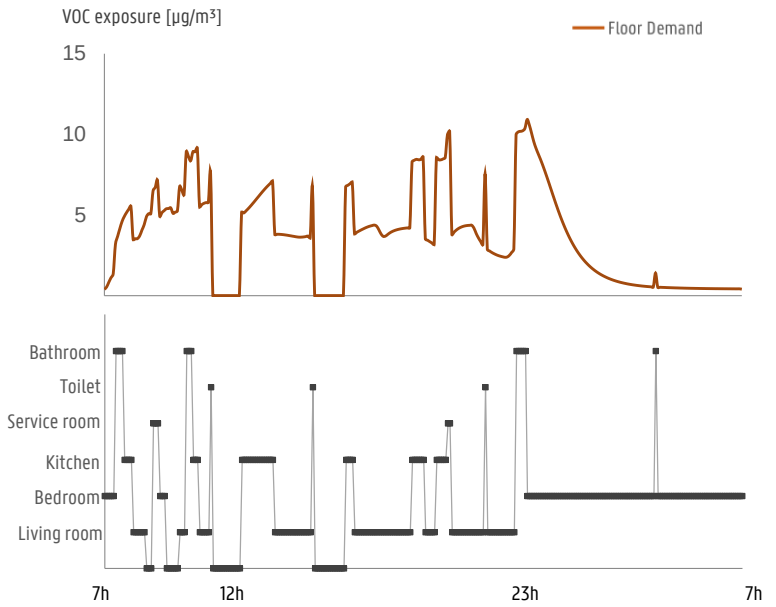
VOC exposure [µg/m³]
Floor Demand
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Bathroom
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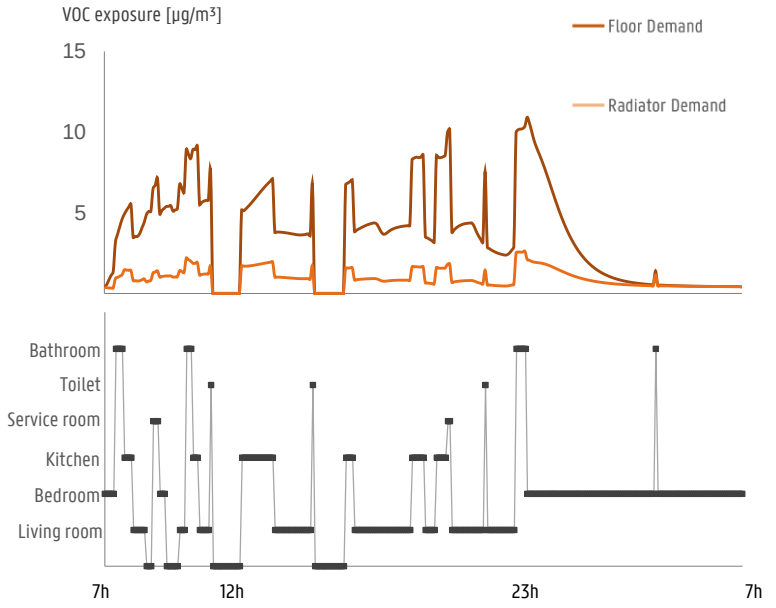
VOC exposure [µg/m³]
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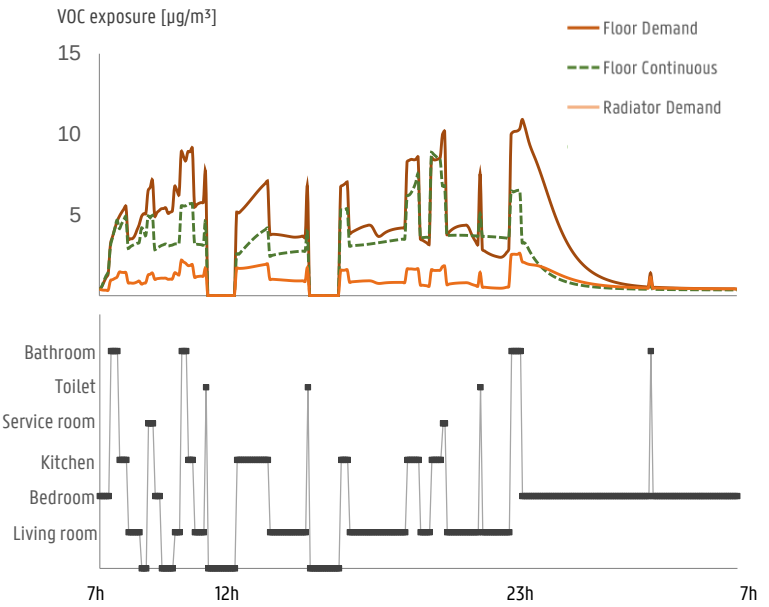
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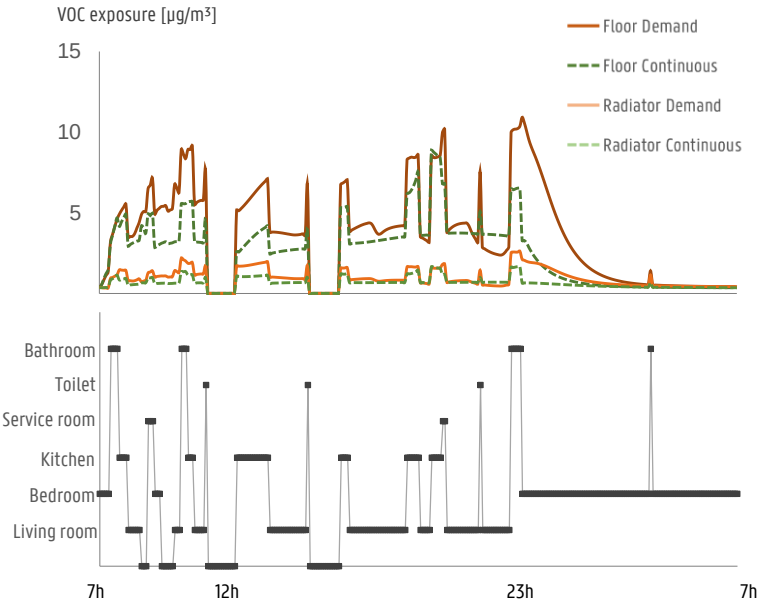
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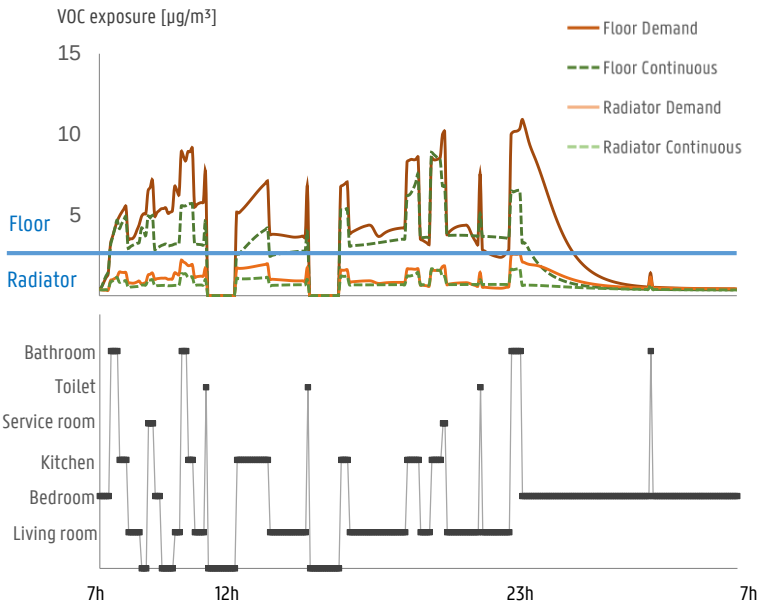
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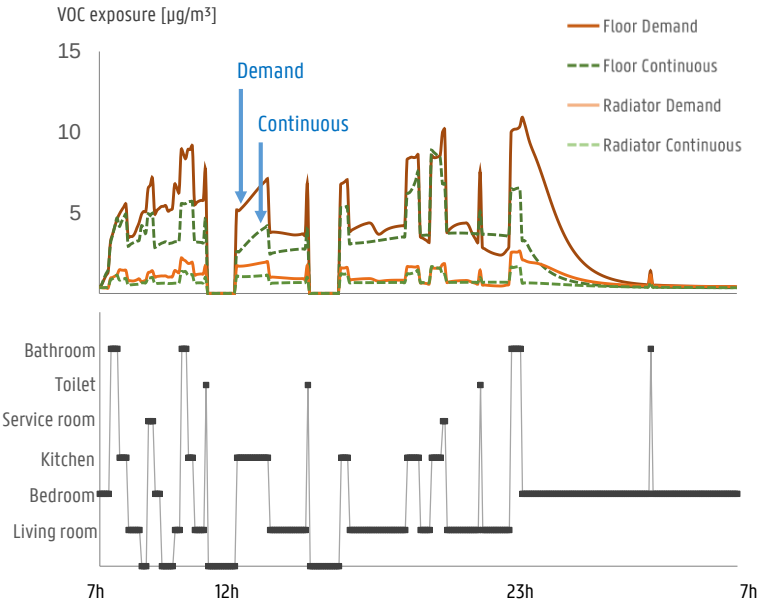
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Floor Demand
Floor Continuous
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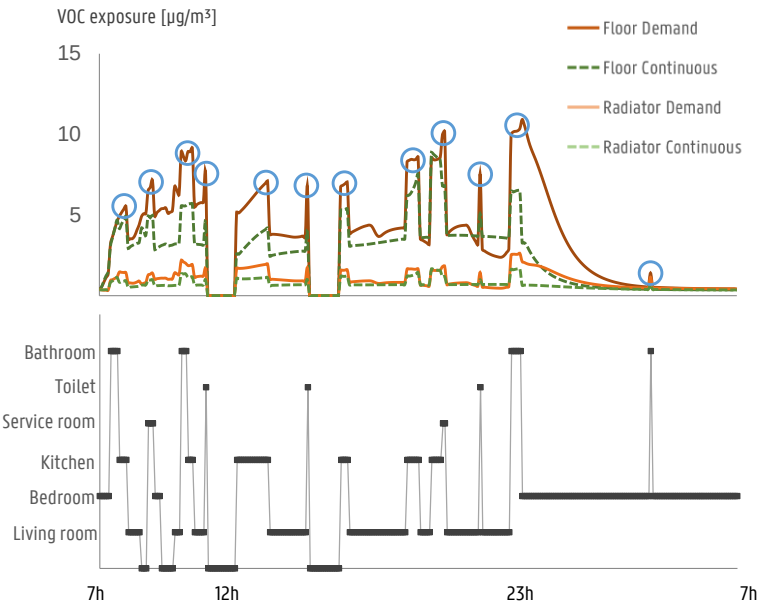
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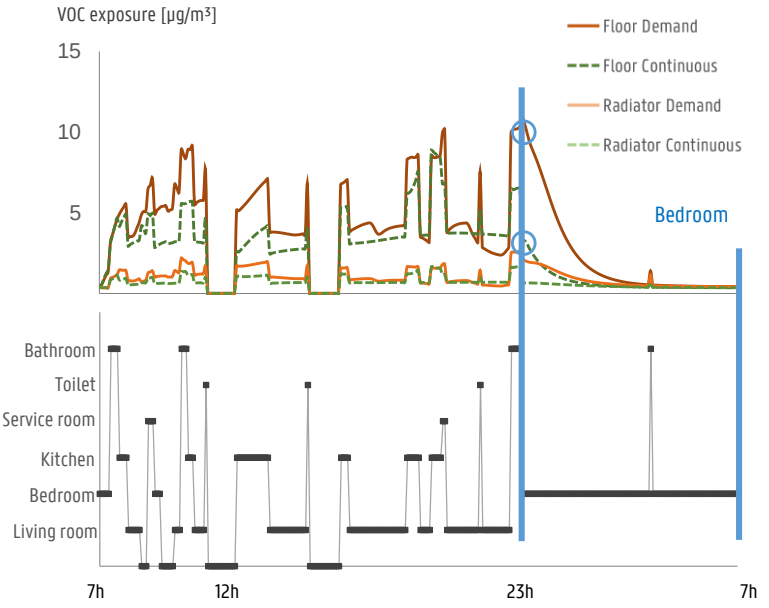
VOC exposure [µg/m³]
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Floor Demand
Floor Continuous
Radiator Demand
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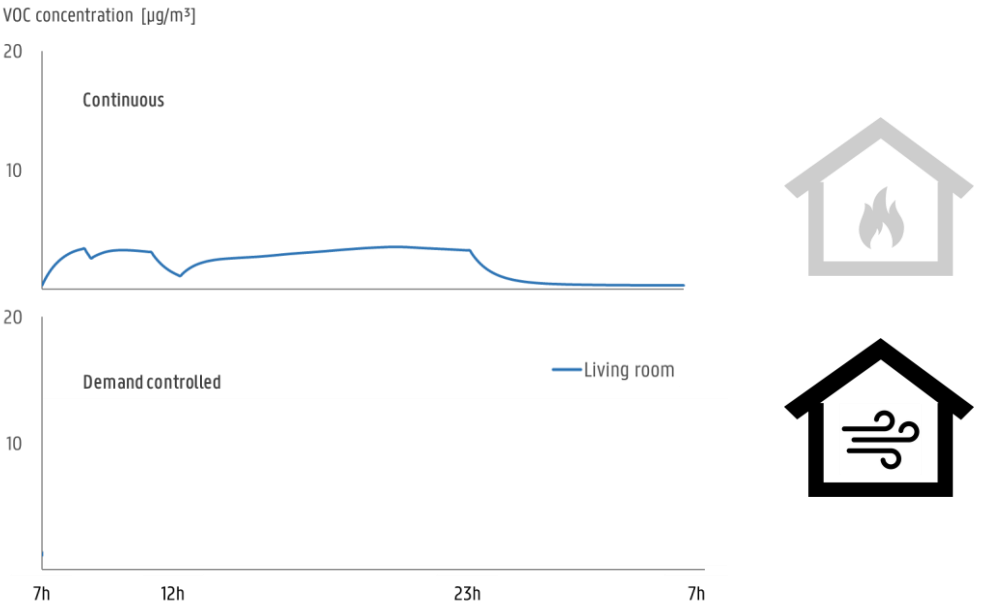
VOC concentration [µg/m³]
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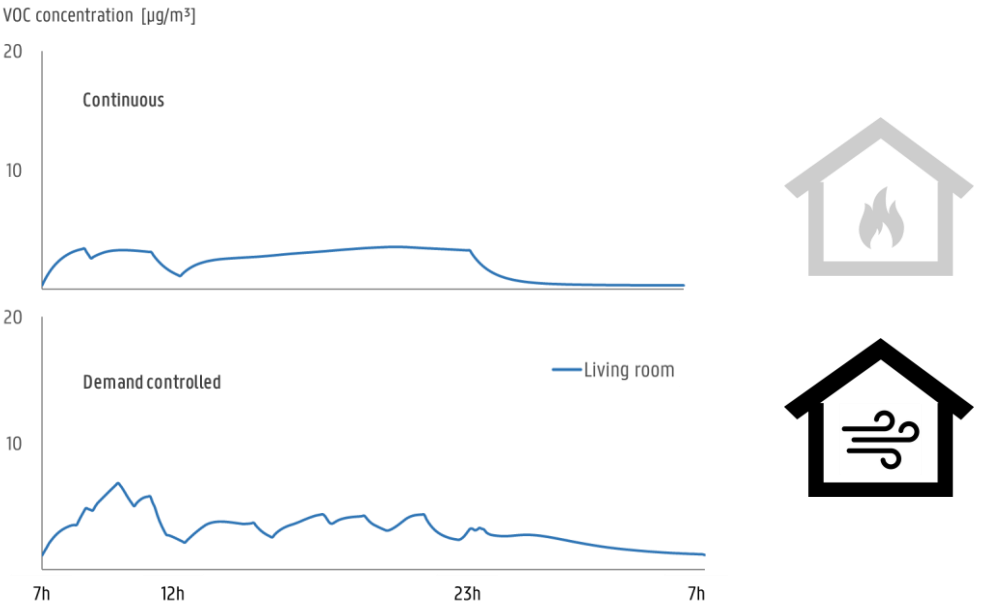
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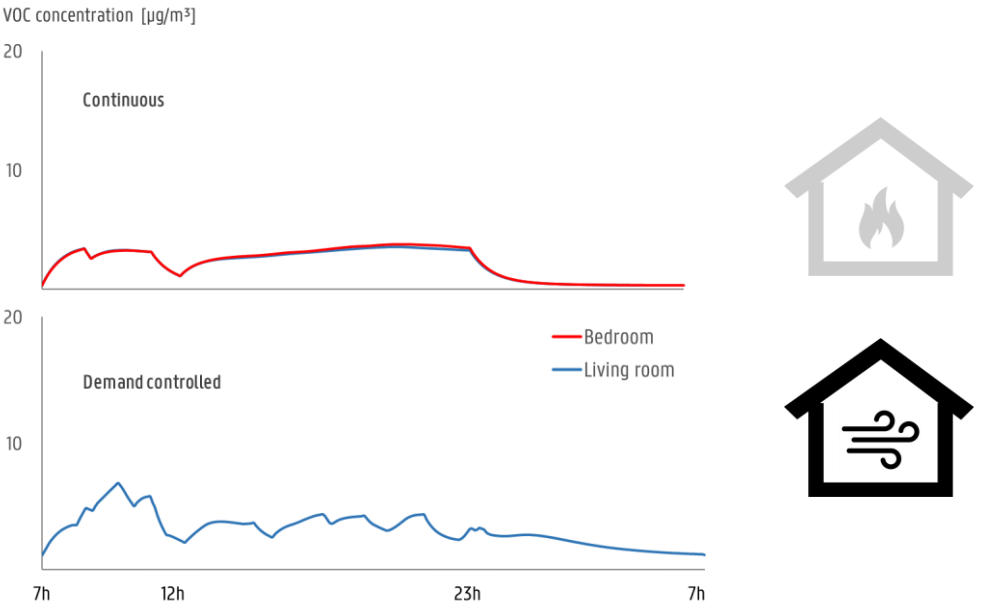
VOC concentration [µg/m³]
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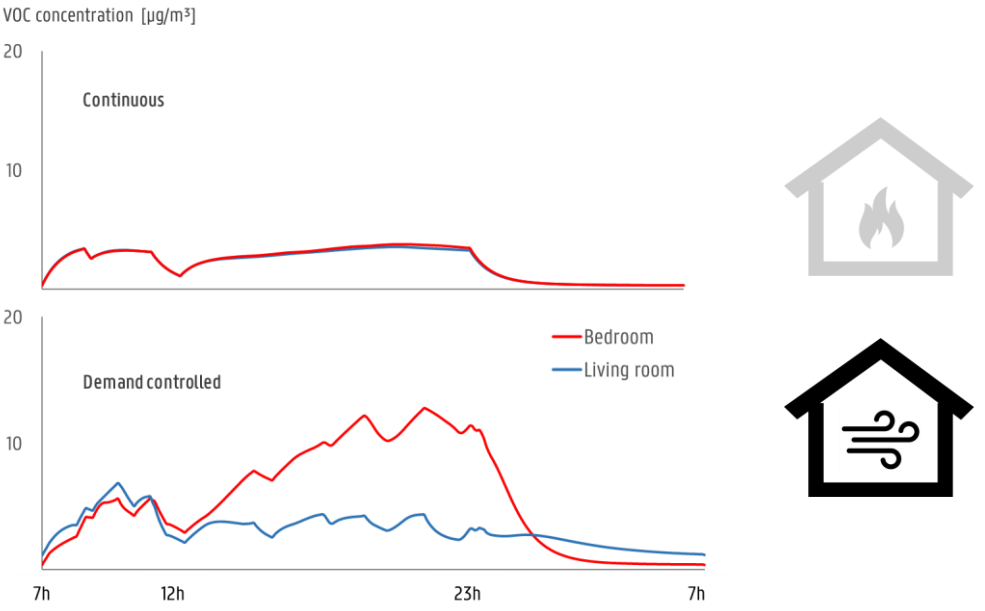
VOC concentration [µg/m³]
20
Continuous
10
20
Demand controlled
10
Bedroom
Living room
7h
12h
23h
7h

26

Conclusion

1. New HVAC developments pose new Challenges for IAQ
2. Health aspect should be (re)introduced when assessing/developing ventilation systems
3. Extra caution should be taken for choosing flooring materials when floor heating is being used.

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FACULTY OF ENGINEERING AND ARCHITECTURE

Ir. Arch Klaas De Jonge
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Project reference 1SA7619N

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Arbeitsbereich für
Energieeffizientes Bauen



Alternative ducting options for balanced mechanical ventilation systems in multifamily housing

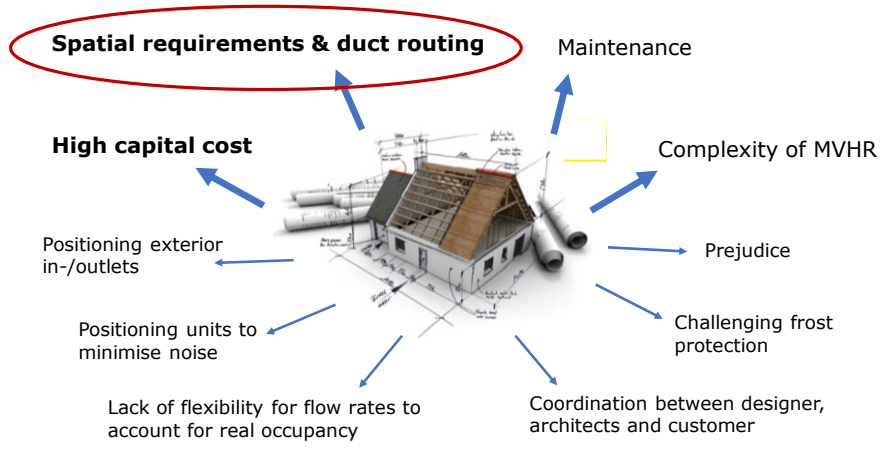
Gabriel Rojas, Universität Innsbruck, Unit for Energy Efficient Buildings

October 15th, AIVC 2019

EBC Bundesministerium Verkehr, Innovation und Technologie IEA FORSCHUNGS KOOPERATION FFG Forschung wirkt.

1

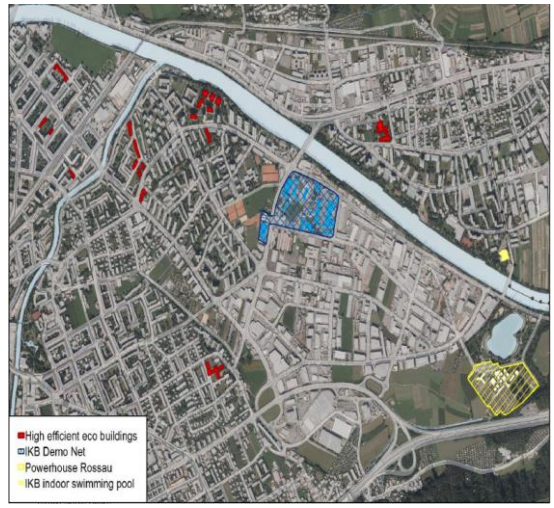
Barriers for MVHR implementation



-> in particular refurbishments

2

Sinfonia project: many refurbishment projects with MVHR



Sinfonia

Highest Energy Efficient Retrofit of Residential Buildings with 678 Appartments in Social Housings with total Heated Floor Area of 57,000 m²

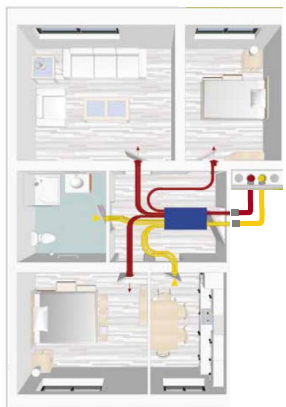
Year of construction 1940 – 1980

70 – 80 % Reduction of Total Energy Demand

http://sinfonia-smartcities.eu/

Standard approach: installation in false ceiling

Installation while occupied: „5-day programm“



Central (unit in attic/cellar)

Source: Ventilation concepts for energy retrofit - Component Award 2016; Ed: K. Bräunlich et.at., Passive House Institute, 2016





Day 4-5:
Painting
Installing lights, covers, etc

Source: Neue Heimat Tirol

Alternative approach: integrate ducts in ext. wall



- 84 apartments
  5200m² net floor area
- 70 apartments
  conneceted to central MVHR
- Heating demand
  from: 135kWh/m²a
  to: 24 kWh/m²a

Sinfonia NHT

Source: Neue Heimat Tirol

6

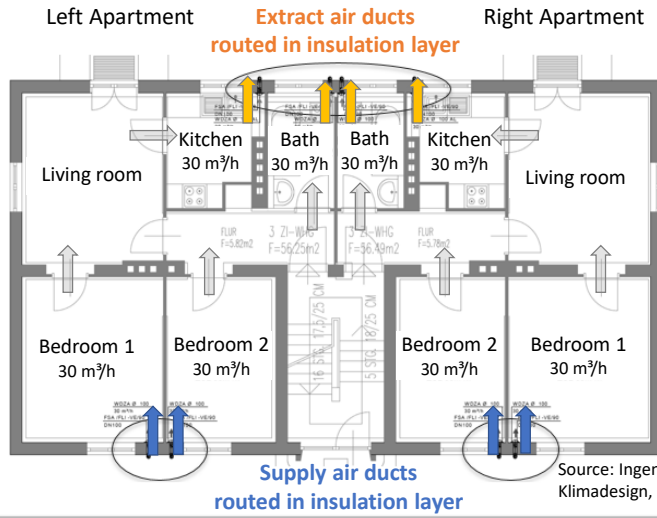
Integrate ducting in external insulation layer



Source: Ingenieurbüro Alpsolar Klimadesign, Innsbruck

7

Integrate ducting in external insulation layer



Source: Ingenieurbüro Alpsolar Klimadesign, Innsbruck

8

Integrate ducting in external insulation layer



Dampers and silencers



MVHR unit in fire protected housing

Source: Ingenieurbüro Alpsolar Klimadesign, Innsbruck

9

Integrate ducting in external insulation layer

Advantages

» no spatial requirement for ducting within apartment

» minimal disturbance for occupants („only“ core hole drilling)

To consider:

» Coordination with insulation work (different trade)

» Fire protection measures / requirements

universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen



Thank you!

EBC
Bundesministerium Verkehr, Innovation und Technologie
IEA FORSCHUNGSKOOPERATION c.at
FFG Forschung wirkt.

Lessons learned from a ten-year monitoring in residential buildings equipped with humidity-based demand controlled ventilation in France

Gaëlle Guyot, PhD
BPE Research team, Cerema, France
Research fellow at Univ. Savoie Mont Blanc, LOCIE

1

Outline

- Regulatory and technological context
- What we know about energy & IAQ performances
- First Feedbacks on robustness and durability after prolonged in situ operation
- Perspectives with the Performance 2 project

2

Regulatory context

- The EP regulation (RT2012) generalizes low energy dwellings (~50 $kWh_{ep}/m^2/y$)
  - Envelope airtightness requirement for single-family dwellings:
    - $q_{a4} \leq 0.6\ m^3/h/m^2 \cong n_{50} \leq 2.3\ h^{-1}$
    - Justification : measurement or quality management approach
- Dwellings ventilation is concerned by another 30 year-old regulation (1982-1983)
  - Compulsory general layouts of ventilation installation : location of inlets and outlets, doors undercut,
  - Required exhausted airflows in each humid room
    - Depending on the number of humid and main rooms of the dwelling
    - => 6 – 9 L/s/pers in a 4 bedroom-dwelling
    - Can be reduced in case of DCV systems
  - No compulsory procedure at commissioning

⇒ **A prescriptive approach except for DCV systems**

3

Regulatory context

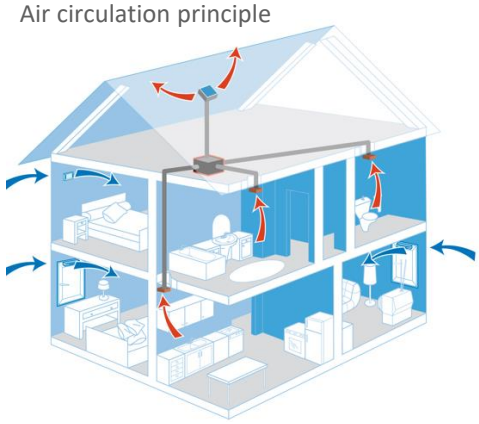
- Humidity-based DCV is a reference in France
  - > 30 years of experience
  - Well rewarded in the EP calculation
  - > 25 DCV systems with agreements (mostly RH controlled)
  - > 92% of residential buildings built after 2008 (Mélois et al. 2019*)
- An agreement procedure for each DCV system (Guyot, Walker, and Sherman 2018*)
  - Asked by the manufacturer
  - Based on a multizone modelling using conventional entry data
    - Weather data, homes geometries, airleakage distribution, occupancy schedules, emission scenarios…
  - Calculated performance indicators (by room, over the heating period)
    - CO_2 cumulative exposure indicator E_{2000} < 400.000 ppm.h
    - Number of hours $T_{RH>75\%}$ < 600 h in kitchen, 1000 h in bathrooms, 100 h in other rooms

4

Technological context

- Description of the humidity DCV systems used in France

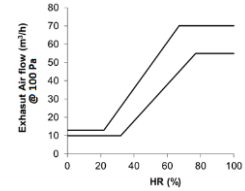
Air circulation principle



Source : Jardinier et al, 2018

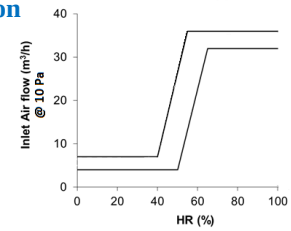
Exhaust : air flow





Inlet : air distribution





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Outline

- Regulatory and technological context
- What we know about energy & IAQ performances
- First Feedbacks on robustness and durability after prolonged in situ operation
- Perspectives with the Performance 2 project

6

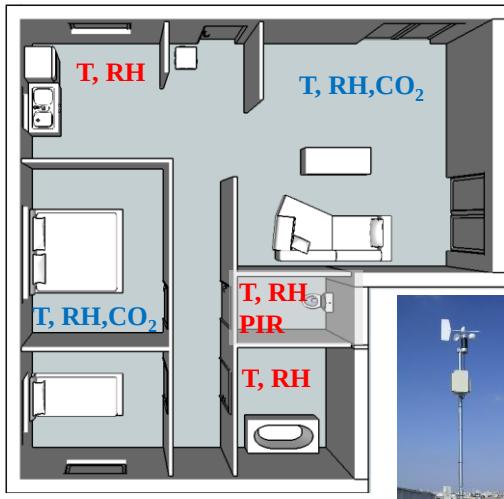
Energy and IAQ performances

- Feedbacks from the « Performance » Project (Bernard, 2009)
- 29 new dwellings in 2 multi-family residential buildings (social housing)
- 2007-2009 monitoring including two heating seasons



7

Energy and IAQ performances



T, RH, CO_2
Wind



Unit	Aperture	ΔP	Air flow
Inlet	Measured	/	Computed @ 10 Pa
Exhaust	Measured	Measured	Computed

8

Energy and IAQ performances

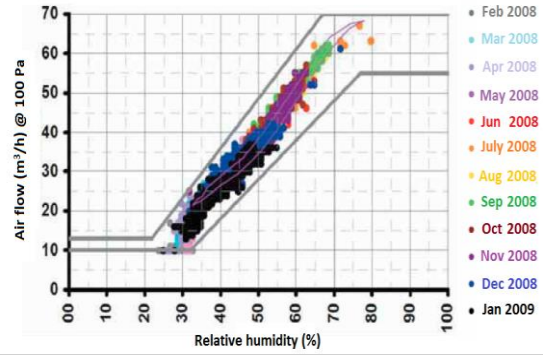
- Expected level of IAQ despite over occupation (> 4 adults) : CO_2 < 1500 ppm ; low condensation risk
- IAQ better in bedrooms during nights than with fixed air inlets

- Average ventilation airflow was measured at approximately 30% lower than with fixed ventilation rates
- Energy savings on ventilation motor consumption was estimated at between 35% and 50% in comparison with fixed airflow

=> 55% energy savings on heat losses on the statistical French occupation

- In-situ operation in accordance with « factory » characteristics.

Source : Bernard, 2009



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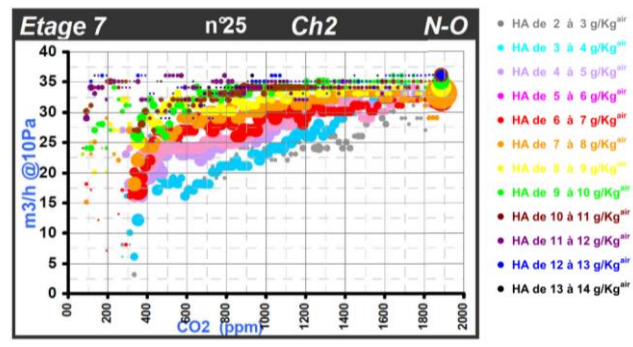
Energy and IAQ performances

- A clear correlation between degree of inlet opening and concentration of CO_2 in bedrooms
  - Quantified plotting the average degree of opening of humidity-controlled air inlets for each 20ppm-range of CO_2 concentrations between 300 ppm and 2000 ppm
  - At "constant" outdoor absolute humidity (HA)
  - Over a year

Exemple of the average opening of a trickle ventilator in a bedroom of a 6 occupant-dwelling.
Source : Bernard, 2009



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Energy and IAQ performances

Is humidity a good tracer for other pollutants in the literature ?

- NO !
  - A poor relationship between relative humidity and occupant load in a room : Anon 1983; Barthez and Soupault 1984; Sheltair Scientific, Ltd. 1988; Parekh and Riley 1991.
  - Other residential pollutants are not correlated with humidity : Fisk and De Almeida (1998)
  - No correlation between the value given by an RH sensor and a mixed gas sensor in the living room during a two-week monitoring study of a house reported by Mansson (1993)
- YES !
  - From 26 apartments equipped with humidity-controlled ventilation in France, Belgium, and the Netherlands, good correlation RH/CO_2 (Mansson 1993).
  - Moffat, et al. (1991): in one house CO_2 levels and relative humidity tend to track each other, but CO_2 peaks occurred 3 hours later. Confirmed by research by Parekh and Riley (1991).
  - Raatschen and Trepte (1987) conclude that the need for ventilation in occupied rooms is dominated by moisture.
- Correlation between absolute humidity and CO_2 stronger than the correlation between relative humidity and CO_2; however, it has a lag time due to sorption characteristics of the building materials and furniture in the home (Moffat, et al. 1991; Savin and Jardinier 2009)
- More details in Guyot et al, 2017 (LBNL Report)
- **Not a simple question … climate, influence of DCV, level of airflows, moisture buffering effect …**

Outline

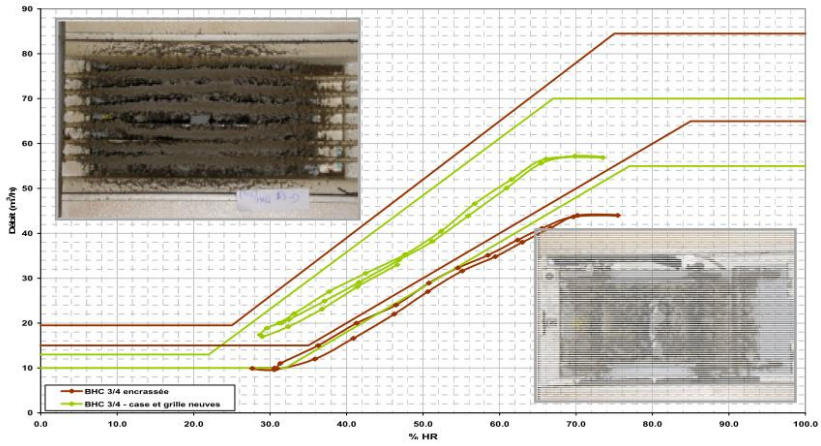
- Regulatory and technological context
- What we know about energy & IAQ performances
- First Feedbacks on robustness and durability after prolonged in situ operation
- Perspectives with the Performance 2 project

First Feedbacks on robustness and durability after prolonged in situ operation

- Selection of 21 social housings in the Parisian suburb by the COSTIC laboratory, and collection of 57 exhaust units after 6 years of in-situ functioning (Berthin and Parsy, 2018*)

- First on-site observations :
  - 14 % of the units suffered damage, either due to voluntary modifications by the occupants (e.g. blocking of the shutter), or to bad re-assembly after maintenance.
    - In 1/3 dwellings, at least one device with such defects.
  - 75 % of the units showed an absence of sufficient maintenance (dusting), when 58 % visually exhibited clogging of the canal.

First Feedbacks on robustness and durability after prolonged in situ operation



Source : Berthin and Parsy, 2018

First Feedbacks on robustness and durability after prolonged in situ operation

- First characterized on a laboratory test bench as-collected (i.e. still soiled).
  - 100 % of the non-damaged exhaust units : conform hygroscopic behavior or slight shift of their characteristic when still soiled
  - 46 % of the kitchen units complied with factory specifications despite the absence of maintenance
  - 100 % of the bathroom exhaust units showed an airflow reduced by 5 m^3/h
- After cleaning and properly re-assembling
  - 75 % of the units complied with factory specifications after cleaning
  - Among the other 25 %, the kitchen elements showed an increase of volume flow < 3 m^3/h
  - While bathroom units exhibited a decrease lower < 2 m^3/h

Outline

- Regulatory and technological context
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Perspectives with the Performance 2 project

- Ten years later : Performance 2 project on the same buildings
  - 6 partners : LOCIE (Univ. Savoie Mont-Blanc), Cerema, Anjos, Aereco, Paris Habitat, Lyon Metropole habitat
- Paris' building (AERECO) - Preliminary results (Jardinier et al, 2018*)
  - At start-up, more than 80 % of the metrology is still in working conditions
  - Using this rough data, the average in-situ drift of the hygroscopic devices after 9 years of operation is estimated below ± 1.5 %RH and is lower than the announced accuracy of the electronical humidity sensors at installation (± 1.8 %RH).
  - The observed drift of volume flows on some of the exhaust units is typical of an absence of maintenance.
  - The battery of the presence-based toilet exhaust is very often (90 %) discharged.

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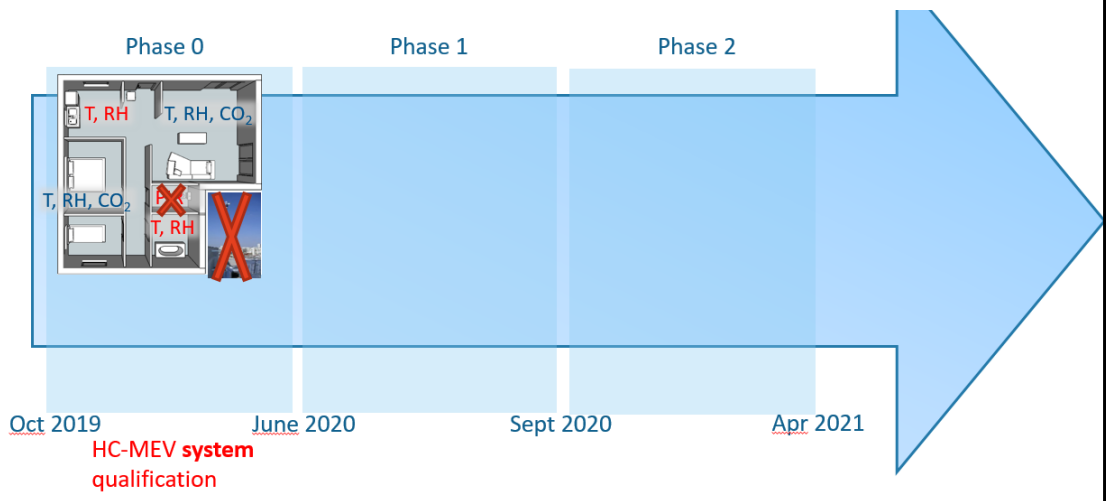
Perspectives with the Performance 2 project



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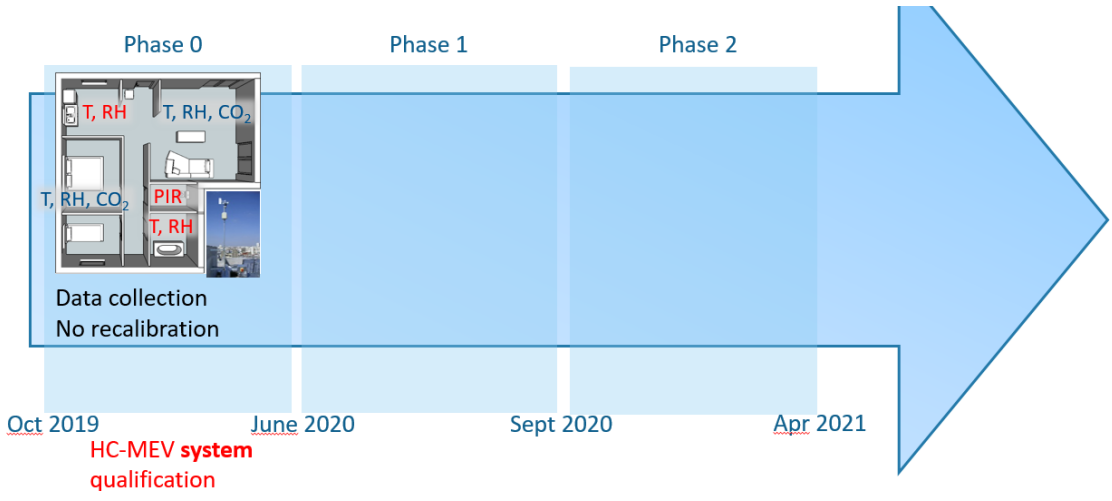
Perspectives with the Performance 2 project



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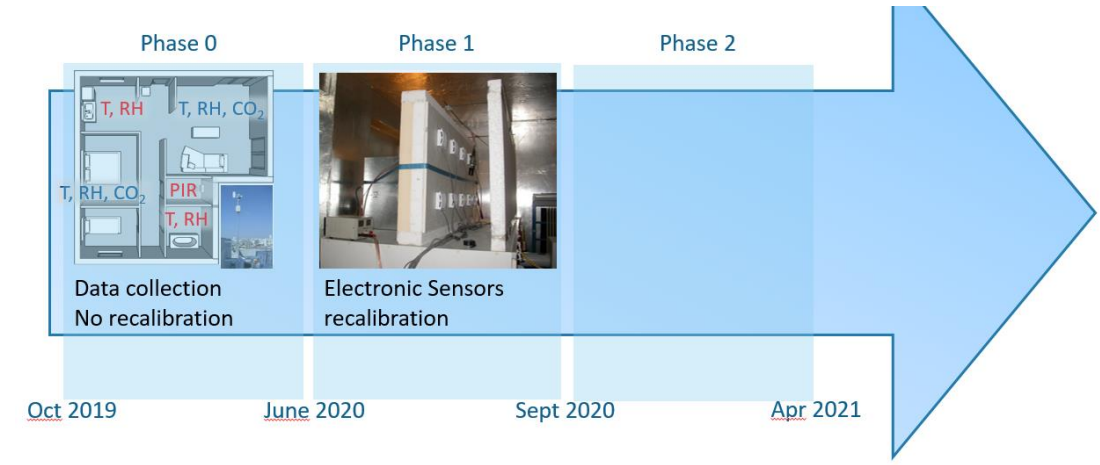
Perspectives with the Performance 2 project



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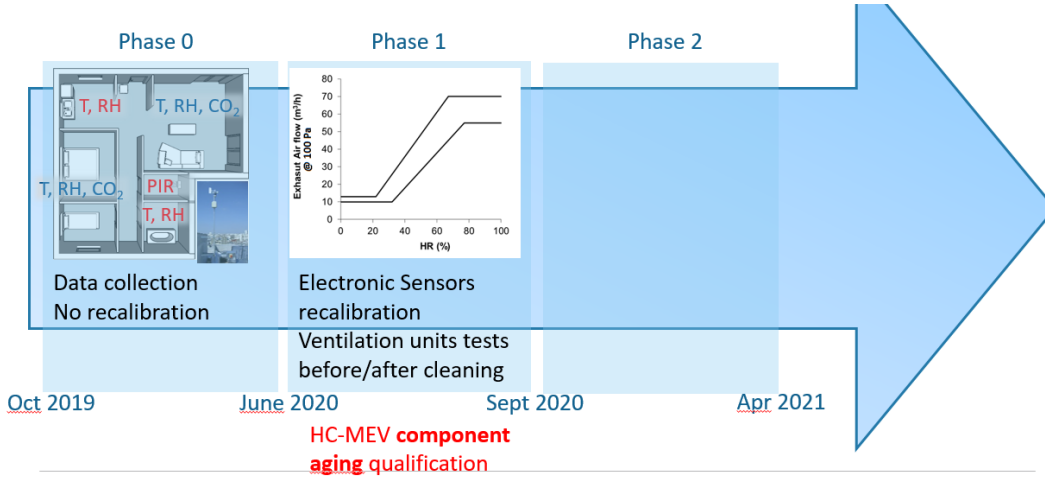
Perspectives with the Performance 2 project



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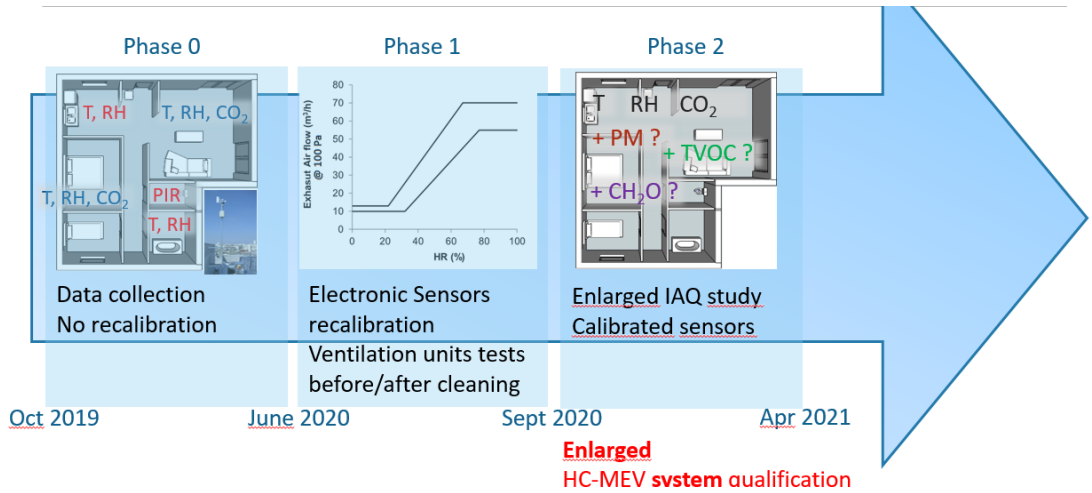
Perspectives with the Performance 2 project



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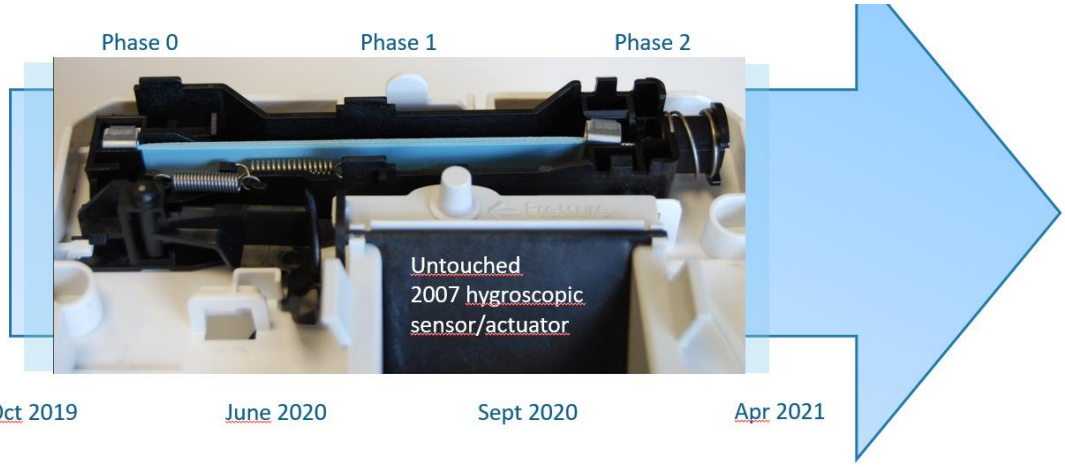
Perspectives with the Performance 2 project



Conclusion

- Humidity based DCV systems used in France offer interesting performances (humidity, energy, CO_2)
- Promising results on durability of these performances
  - Even with a strog lack of clean and maintenance …
- See you in 2020 for the Performance 2 results !
  - Durability of the technology ?
  - Robustness to occupant behavior ?
  - Reaction to other pollutants (PM, formaldehyde) ?

Cerema

Thank you for your attention !

***References**

Bernard, Anne-Marie. 2009. Performance de La Ventilation et Du Bâti - Phase 3 - Performance Énergétique et QAI Des Systèmes Hygroréglables. Projet PREBAT ADEME.

Berthin, S, and F Parsy. 2018. "Feedback on Installation, Maintenance, and Aging of Mechanical Humidity-Controlled Ventilation Exhaust Units." In Smart Ventilation for Buildings. Juan les Pins, France.

Guyot, G., I.S. Walker, and M.H. Sherman. 2018. "Performance Based Approaches in Standards and Regulations for Smart Ventilation in Residential Buildings: A Summary Review." International Journal of Ventilation 0 (0): 1–17. doi:10.1080/14733315.2018.1435025.

Guyot, Gaelle, Iain S. Walker, Max Sherman, and Jordan Clark. 2017. Residential Smart Ventilation: A Review. LBNL-2001056. LBNL Report. https://eta.lbl.gov/sites/default/files/publications/lbnl-2001056.pdf.

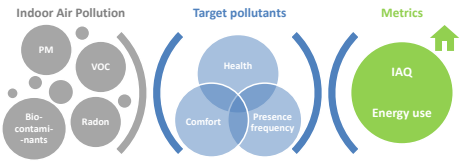
Jardinier, E, F Parsy, G Guyot, S Berthin, and S Berthin. 2018. "Durability of Humidity-Based Demand-Controlled Ventilation Performance: Results of a 10 Years Monitoring in Residential Buildings." In *Smart Ventilation for Buildings*. Juan les Pins, France.

Mélois, Adeline Bailly, Bassam Moujalled, Gaëlle Guyot, and Valérie Leprince. 2019. "Improving Building Envelope Knowledge from Analysis of 219,000 Certified on-Site Air Leakage Measurements in France." Building and Environment, May. doi:10.1016/j.buildenv.2019.05.023.

Practical use of the Annex 68 Indoor Air Quality Dashboard

Marc Abadie

LaSIE - University of La Rochelle (ULR), La Rochelle, France



AIVC2019 40th AIVC - 8th TightVent & 6th venticool Conference From energy crisis to sustainable indoor climate
40 years of AIVC, 15-16 October 2019, Ghent, Belgium

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Contents

- ❑ Subtask 1 – Defining the metrics
- ❑ Case Study
- ❑ Results
- ❑ Conclusion

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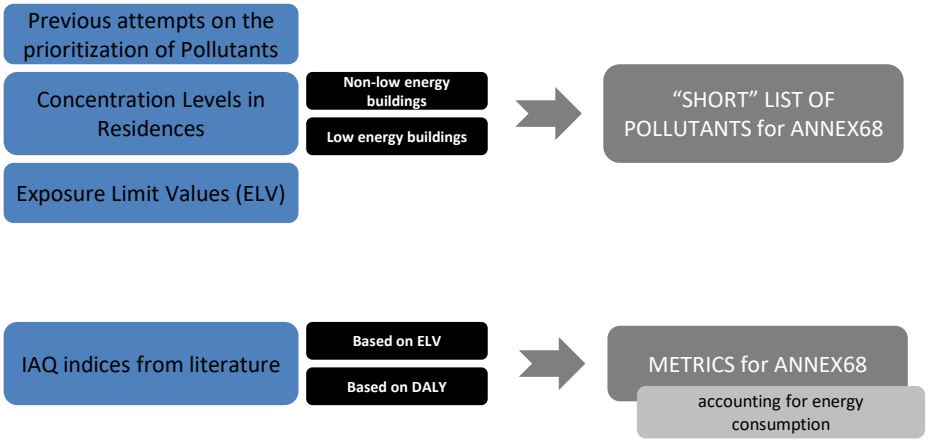
Subtask1 – Defining the metrics



3

3

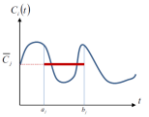
List of pollutants of concern for Annex68

	Long-term Exposure			Short-term Exposure		
	ELV	Averaging period	Source	ELV	Averaging period	Source
Acetaldehyde	48	1 year	Japan	-	-	-
Acrolein	0.35	1 year	USA-California	6.9	1 h	France
α-pinene	200	1 year	Germany	-	-	-
Benzene	0.2	whole life (carcinogenic risk level: 10^{-6})	France	-	-	-
Carbon dioxide	-	-	-	1250	8 h	Portugal
Formaldehyde	9	1 year	USA-California	123	1 h	Canada
Naphthalene	2	1 year	Germany	-	-	-
Nitrogen dioxide	20	1 year	France, Canada	470	1 h	USA-California
PM10	20	1 year	WHO	50	24 h	WHO
PM2.5	10	1 year	WHO	25	24 h	WHO
Radon	200	1 year	Austria, Canada, Hong-Kong	400	8 h	Austria, China, Portugal
Styrene	30	1 year	Germany	-	-	-
Toluene	250	1 year	Portugal	-	-	-
Trichloroethylene	2	whole life (carcinogenic risk level: 10^{-6})	France	-	-	-
TVOC	-	-		600	8 h	China, Hong-Kong, Portugal
Mold	200	1 year	EU	-	-	-

4

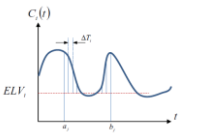
4

Metrics for Annex68 – Dashboard

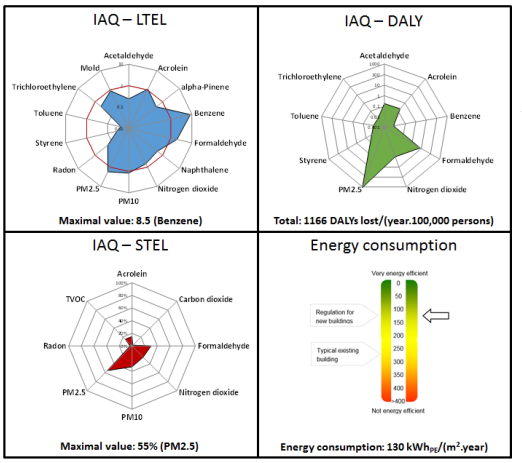


$$\overline{C_i} = \frac{1}{n}\sum_{n=1}^{n}\left[\frac{1}{b_j - a_j}\int_{a_j}^{b_j} C_i(t)dt\right]$$

$$I_p = \frac{\overline{C_p}}{ELV_p}$$



$$I_i = \frac{\sum_{j=1}^{n}(b_j - a_j)\times f_j(C_i(t) \geq ELV_i \text{ over } \Delta t_i)}{\sum_{j=1}^{n}(b_j - a_j)}$$



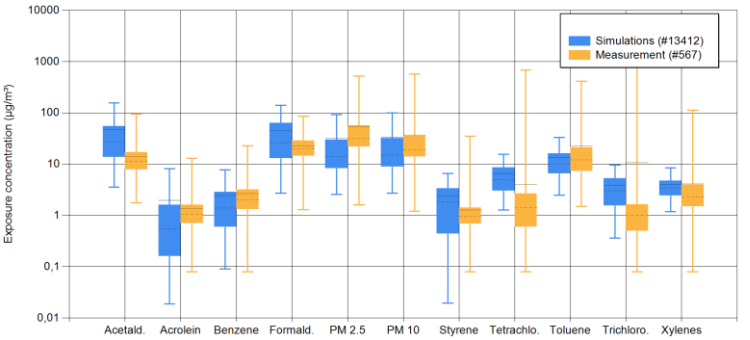
Data represented here are just for display and do not represent actual situation

$$DALY^{p} = \sum_{j=1}^{n_{hours}} DALY_j = \sum_{j=1}^{n_{hours}} f_j(\overline{C_i})$$

- **Energy** needed **to condition the outdoor air** i.e. heat, cool, humidify or dehumidify.
- **Energy to power the systems** like fans or air cleaning devices (electrostatic precipitation, plasma or photocatalytic oxidation)

Case Study

- Numerical evaluation of exposure concentration with **TRNSYS – CONTAM coupling**
- **Prototypical house** + **scenarios** regarding ventilation systems, pollutant source strengths, outdoor pollution, occupants' activities…
- **Validation** against French survey from **567 houses and apartments** (Kirchner et al., 2006)

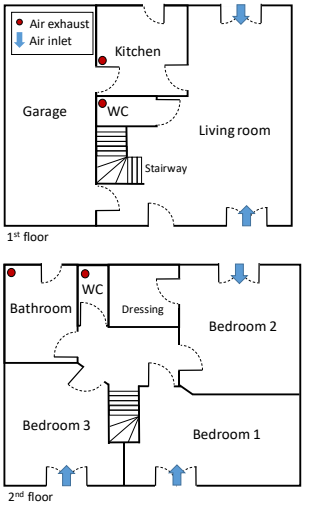


- Louis Cony-Renaud-Salis: PhD Thesis to be defended in beginning of 2020

Kirchner S, Arene JF, Cochet C, Derbez M, Duboudin C, Elias P, Gregoire A, Jedor B, Lucas JP, Pasquier N, Pigneret M, Ramalho O. 2006a. Campagne nationale logements: état de la pollution dans les logements français. Report, CSTB/DDD/SB – 2006-57, 165 pages.

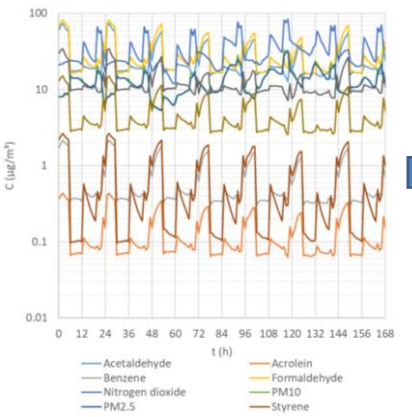
Case Study

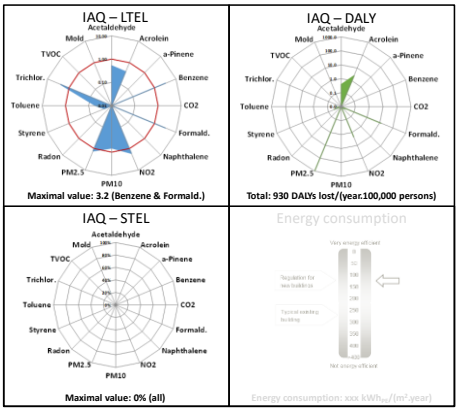
- Two-storey house : 1 living room and 3 bedrooms
- Location : La Rochelle (small city, low pollution), France
- Envelope, furniture, occupant activity : “standard” see Cony-Renaud-Salis et al (2018 and 2019) for details.
- Ventilation rates (French standards):
  - 180 m^3/h during 30 min. at noon and 19:30
  - 105 m^3/h otherwise
- Ventilation systems :
  - Natural ventilation using vertical ducts for extraction (NAT)
  - Pressure-controlled exhaust ventilation (EXH)
  - Balanced mechanical ventilation (BAL)
- Occupants: Sedentary people (always at home)
- Considered pollutants (9/16 ST1 target pollutants): acetaldehyde, acrolein, benzene, formaldehyde, nitrogen dioxide, particulate matter (PM2.5, PM10), styrene and toluene.
- Simulation: 1 week, timestep = 5 min.



Cony-Renaud-Salis, L., Ramalho, O., Abadie, M. (2018). Development of a Numerical Methodology to Assess Indoor Air Quality in Residential Buildings, Proceedings of the 15th Conference of the International Society of Indoor Air Quality & Climate (ISIAQ), July 22 to 27, Philadelphia, USA.
Cony-Renaud-Salis, L., Belhaj, N., Ramalho, O., Abadie, M. (2019). Analysis of the need of detailed modelling for the assessment of indoor air quality in residential buildings. Proceedings of 13th REHVA World Congress CLIMA 2019, May 26 to 29, Bucharest, Romania.

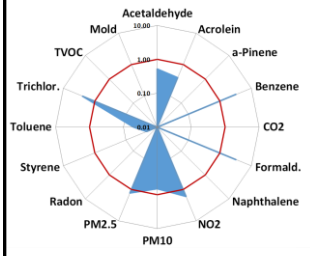
Results – example for Natural Ventilation



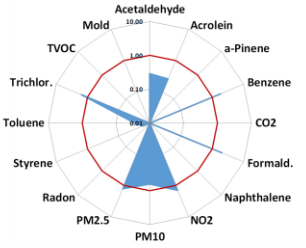


Results – comparison

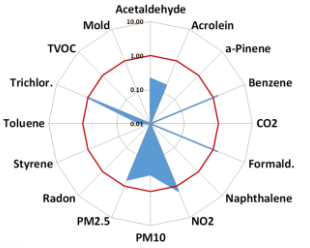
NAT



EXH



BAL



	NAT	EXH	BAL
LTEL	3.2	2.3	1.4
Target Pollutant	Benzene and Formaldehyde	Benzene, Formaldehyde	Benzene, Formaldehyde and NO2
DALY	930	900	494
Target Pollutant	98.1% (PM2.5)	98.7% (PM2.5)	98.3% (PM2.5)

Conclusion

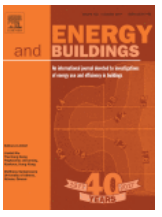
- ***AIVC Contributed Report***

EBC
Energy in Buildings and Communities Programme

AIVC



- Energy and Buildings Special Issue for EBC Annexes:



ELSEVIER

Energy and Buildings
Volume 152, 1 October 2017, Pages 492-502



Towards the definition of indicators for assessment of indoor air quality and energy performance in low-energy residential buildings

Louis Cony Renaud Salis [a], Marc Abadie [a], Pawel Wargocki [b], Carsten Rode [b]



Thanks to the financial supports of:

IEA EBC Annex 68 - Indoor Air Quality Design and Control in Low Energy Residential Buildings

Energy in Buildings and Communities Programme

Subtask 4 - Strategies for design and control of buildings

TOPICAL SESSION: "Ventilation design and control in residences - current challenges, innovative solutions and case studies gathered by IEA-EBC Annex 68"

Lessons learned from design and operation of ventilation systems in low-energy dwellings in the UK

40th AIVC conference, Ghent, Belgium

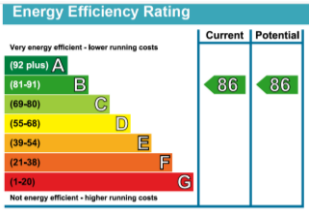
Dr Esfand Burman
UCL Institute for Environmental Design and Engineering

Case Study: MVHR System

Energy in Buildings and Communities Programme

- Completed in 2015 (approx. 7900 m²)
- 98 flats and maisonettes
- Mixed tenure: rent, leasehold, shared ownership
- Low air permeability: 2-3 m³/hr/m² at 50 Pa
- Mechanical Ventilation with Heat Recovery (MVHR)
- Communal heating (CHP led) managed by an ESCO





Energy & IAQ monitoring



Energy (heating demand & electricity): 1 year



T/RH/CO_2: 1 year



Outdoor site data



Passive sampling (VOCs, O_3, NO_2)
Weekly blocks in winter & summer

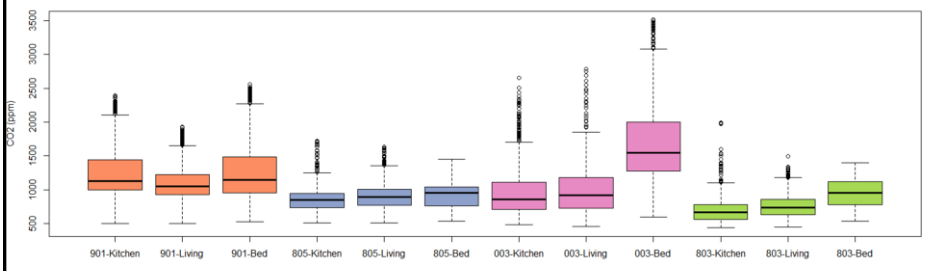


Active monitoring (PM1-10, NO_2, TVOC, CO)
Weekly blocks in winter & summer



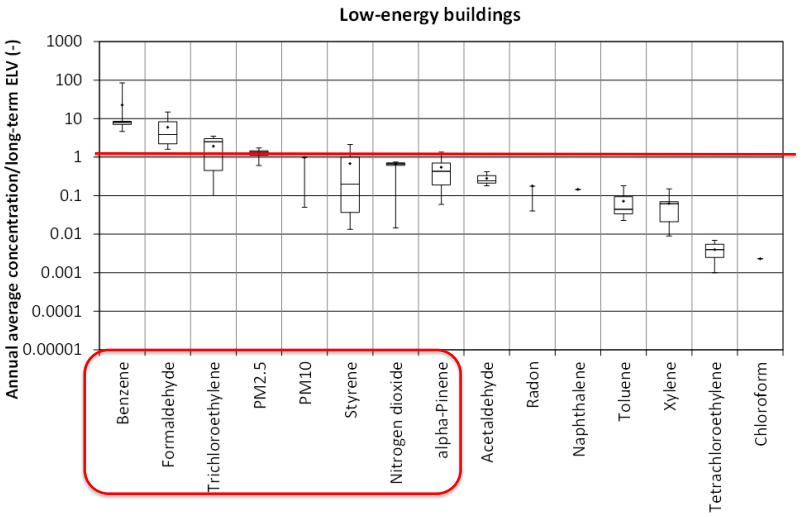
PFT measurements (air change rates)
Weekly blocks in winter & summer

CO_2 measurements (heating season)



- Median concentration levels between 800-1600 ppm in heating season
- Peaks of up to 3400 ppm
- PerFluorocarbon Tracer (PFT) method used to infer the ventilation rates

Pollutants covered



Source: Abadie et al., 2016. IEA EBC Annex 68 – Indoor Air Quality Design and Control in Low-energy Residential Buildings, SUBTASK 1: Defining the metrics

Passive sampling of VOCs (heating season)

VOC concentration (µg/m³) & Air Change rates per Hour for each zone	APT. 3 (Block A, 9th Floor)			APT. 4 (Block B, Ground Floor)			IEA EBC Annex 68 Long Term ELV
	Living room	Kitchen	Sample bedroom	Living room	Kitchen	Sample bedroom	
Benzene	**1.3**	**1.0**	**1.2**	**1.5**	**2.1**	**1.6**	0.2
Formaldehyde	**29.25**	**26.87**	**29.53**	**21.23**	**31.35**	**27.44**	9
Trichloroethylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	2
Styrene	1.5	2.2	3.0	0.8	0.7	1.7	30
Naphthalene	**5.4**	**5.4**	**5.0**	0.9	0.9	1.3	2
Toluene	2.7	2.9	3.1	2.2	2.6	2.4	250
Tetrachloroethylene	0.6	<0.6	<0.6	1.5	1.2	1.8	100
ACH (PFT measurements)	0.50	0.52	0.76	1.02	1.14	0.6	n/a

Concentration levels of benzene and formaldehyde are higher than best practice long-term/chronic exposure limit values (ELVs) in both apartments 3 years after completion.

Maintenance of MVHR systems: Who is responsible?!



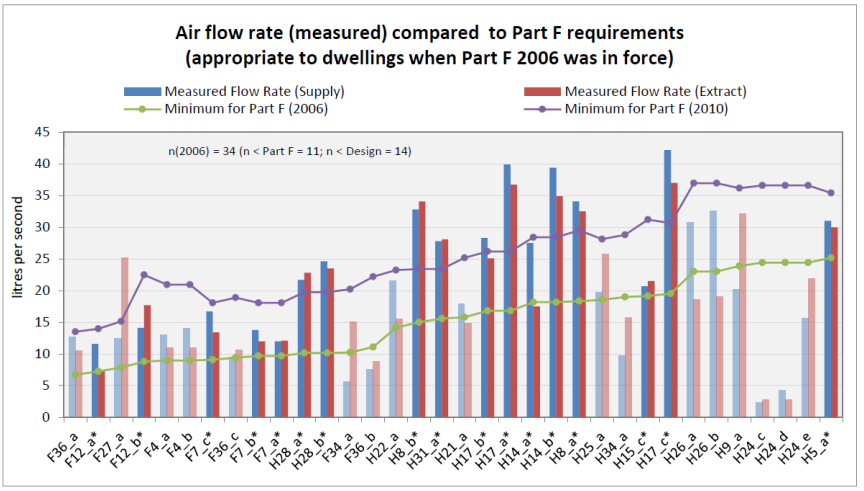
MVHR system installed in case study dwellings



Air filter (after cleaning!)

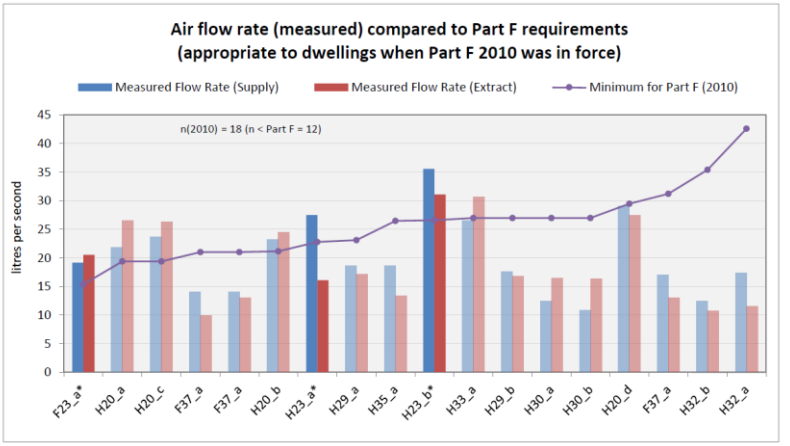
- Provision of training and adequate information to users is critical and often missing!
- *There might be a case to make Landlords and housing associations responsible in rented accommodation (analogy with gas safety/annual inspection of heating systems).*

Measured air flows in MVHR systems



Source: Sharpe T., et al., 2016. Characteristics and performance of MVHR systems

Measured air flows in MVHR systems



Source: Sharpe T., et al., 2016. Characteristics and performance of MVHR systems

Conclusions

- Internal sources of pollution become more relevant in dwellings (ACH<1 in heating season).
- Better source control measures and enhanced ventilation through MVHR systems could help.
- Commissioning and maintenance issues often mean actual ventilation rates are lower than design intent.
- Provision of training and adequate information to building users is critical and often missing.



Contact: esfand.burman@ucl.ac.uk

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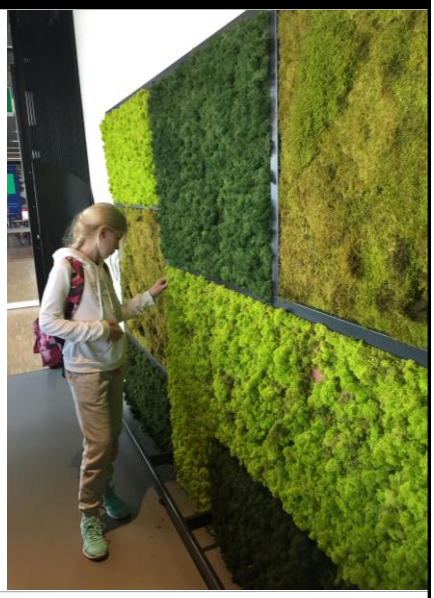
Moisture in indoor air: Findings of 40 years

Paula Wahlgren
Chalmers University of Technology
Sweden



Schiphol airport, Netherlands

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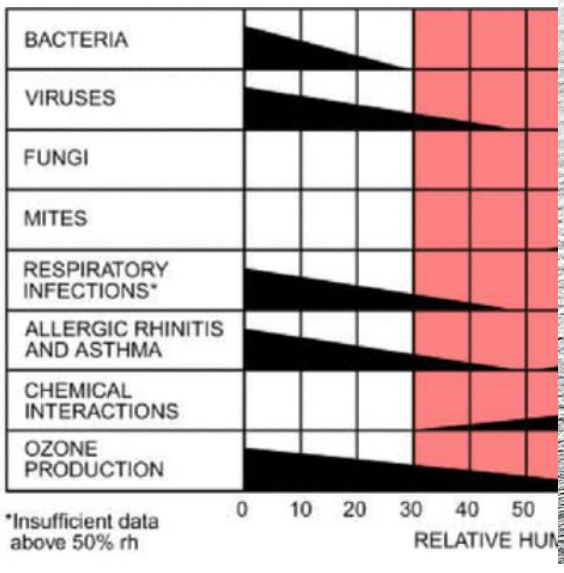
What levels are good?





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Too much moisture in the air?





3

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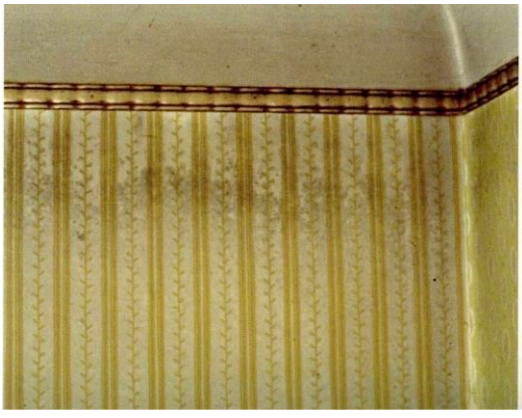
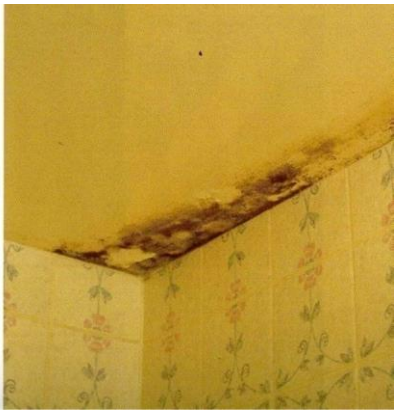
Aesthetics and mould





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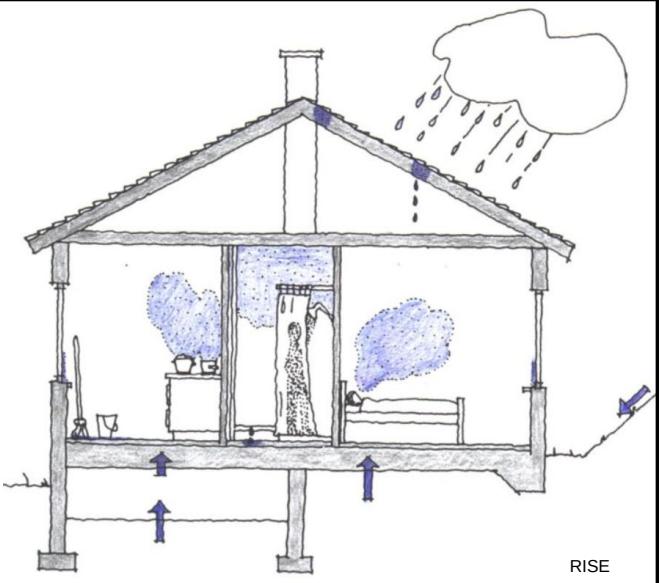
Moisture sources

- Occupants, activities
- Construction moisture
- Ground moisture
- Storage of moisture
- Leakages (rain, building services)



RISE

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Example of mold growth due to leakages



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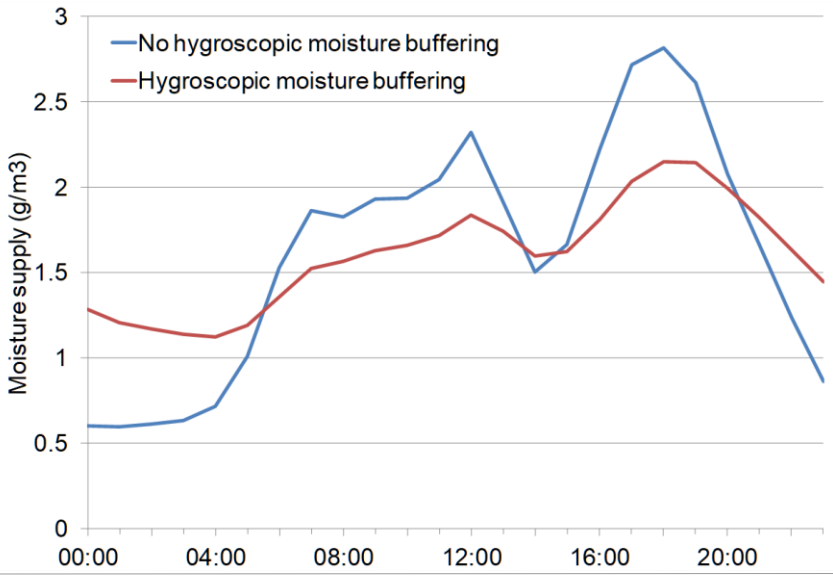
Moisture storage



Johansson, 2011

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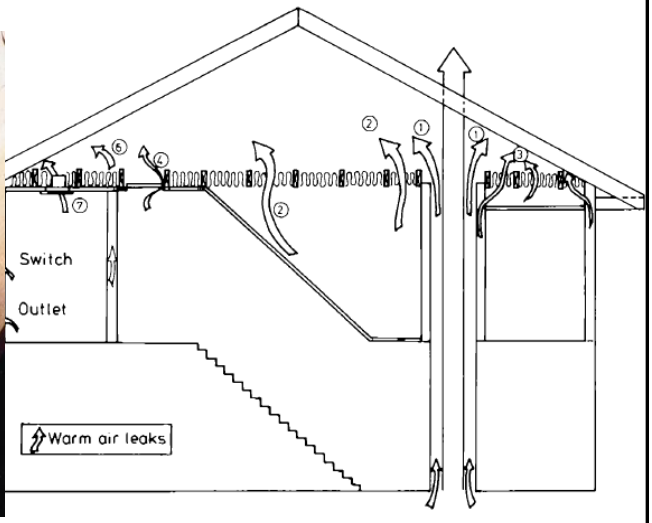
Infiltration and exfiltration





Sikander et al. 2008

Elmroth et al. 1981

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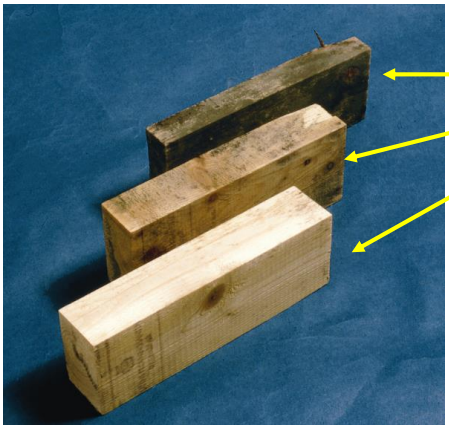
Mould and emissions





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Common places for moisture damage



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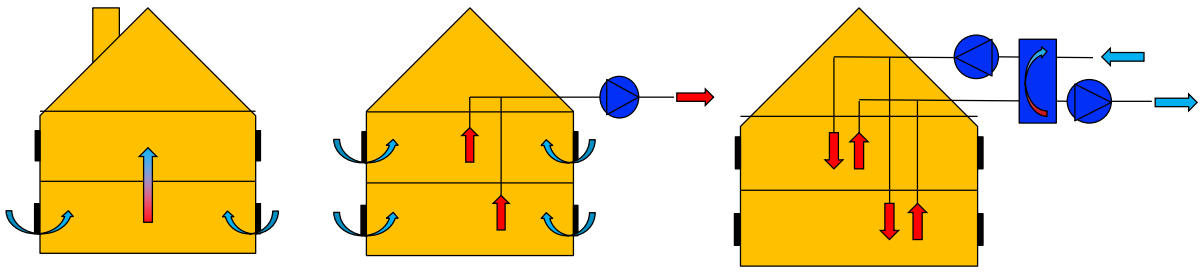
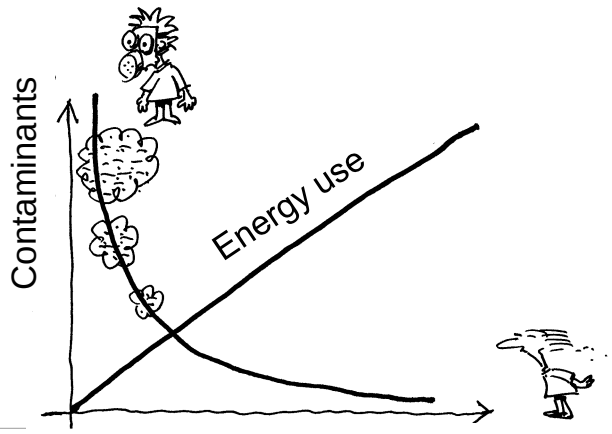
Ventilation



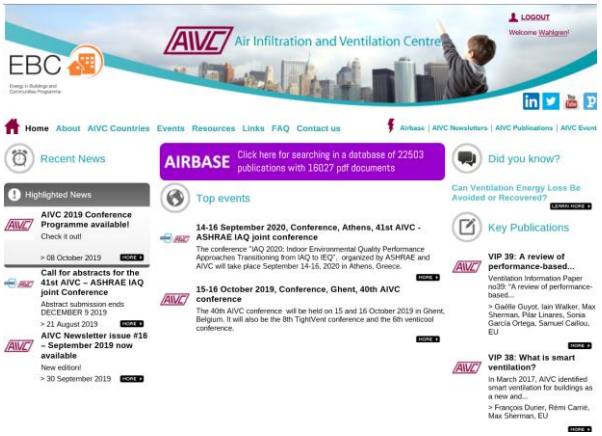
Natural Exhaust Balanced (heat recovery)

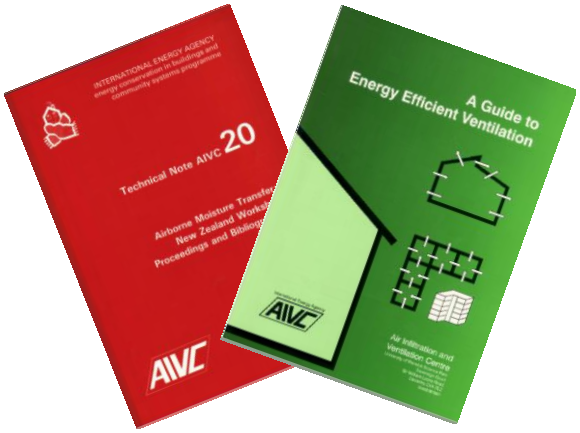
Air leakages and energy use



Build tight-
Ventilate right

Airbase database, www.AIVC.org





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AVANCEZ 1829

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40th AIVC - 8th TightVent & 6th venticool Conference
University Gent, Ghent, Belgium
Oct. 15 &16, 2019

Issues on humidity environment and health problems in Japan

Hiroshi Yoshino
Emeritus Professor, Tohoku University,
Sendai, Japan
Distinguished Professor, Chongqing University,
China
Kenichi Hasegawa
Professor, Alita Prefectural University

TOHOKU UNIVERSITY

Introduction

1. The climatic conditions of Japan are characterized by high temperature and high humidity in summer, and low temperature and low humidity in winter.
2. Summer has a situation where mold is easy to grow, and the issue of mold damage is commonly found in many houses.
3. In winter, indoor is often maintained at a relatively high level, and this also causes the mold damage.
4. On the other hand, the problem of being too dry in well-insulated houses has been pointed out.

In this presentation, based on the research conducted by the current authors, discussed are 1) Indoor humidity environment in Japan, 2) Dampness and health problems, 3) Dry feeling and health issues, 4) Subjects of humidity control.

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2. Indoor temperature/humidity environments of houses

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4. Dry feeling and the health effect of dryness
5. Conclusion

3

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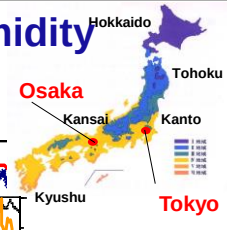
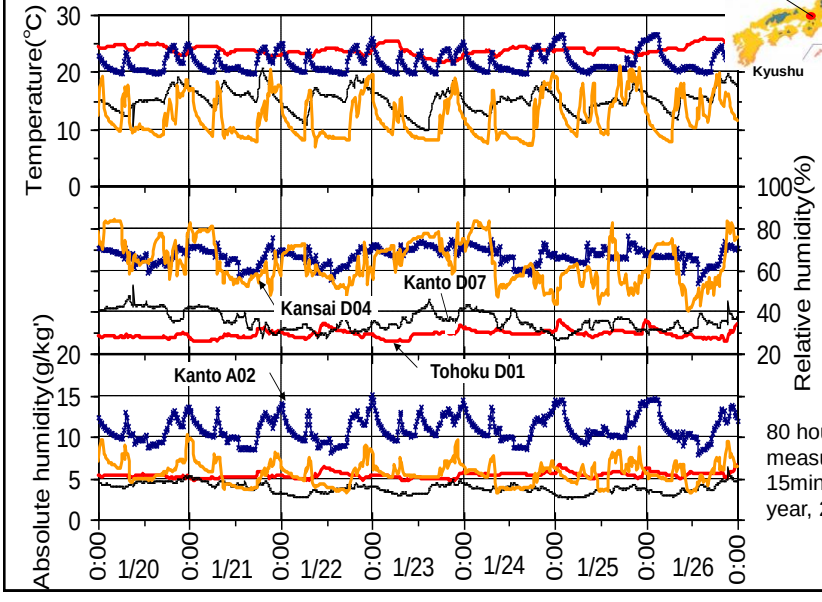
Change of living room temp. and humidity of four houses during the winter





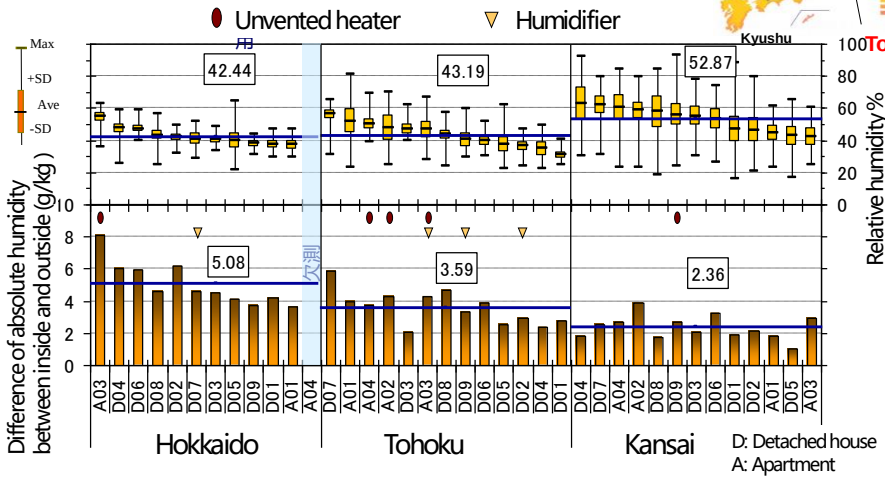
80 houses measured every 15minutes for one year, 2003

4

4

Humidity of 37 houses in Jan. and Feb.





In Hokkaido and Tohoku Districts, relative humidity of 40% houses is less than 40%

5

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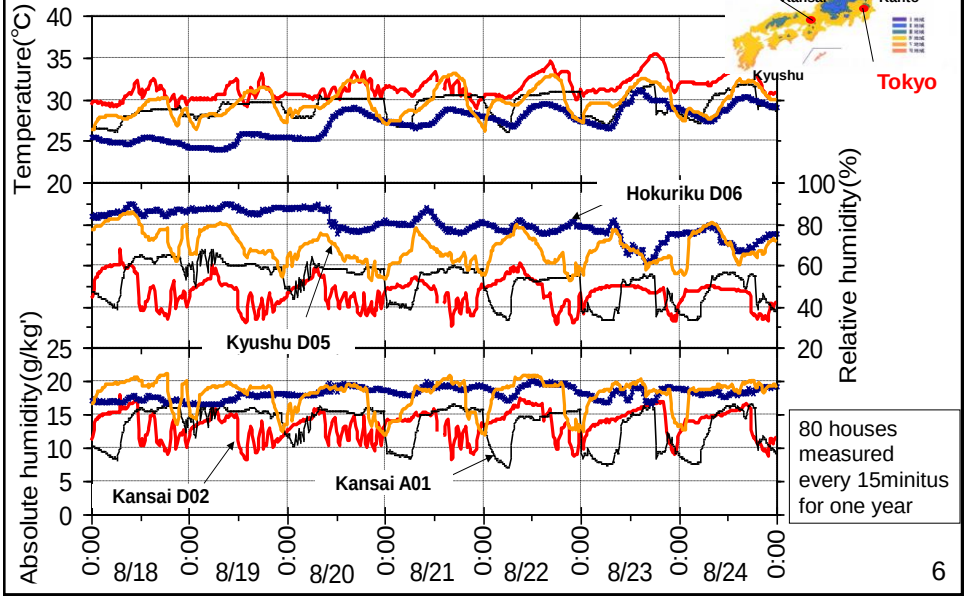
Change of living room temp. and humidity of four houses during the summer





80 houses measured every 15minitus for one year

6

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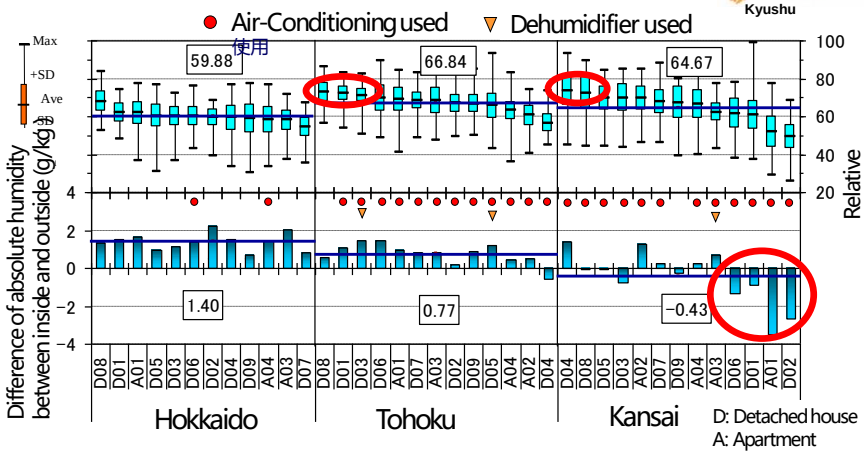
Humidity of 38 houses in Jul. and Aug.





Hokkaido: around 60%, Tohoku/Kansai: around 65%

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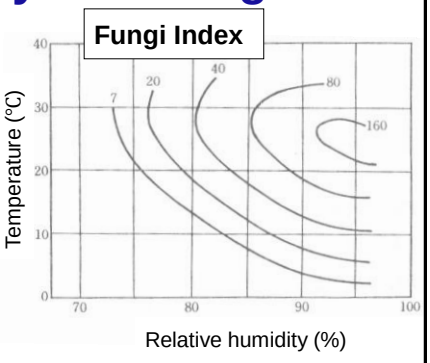
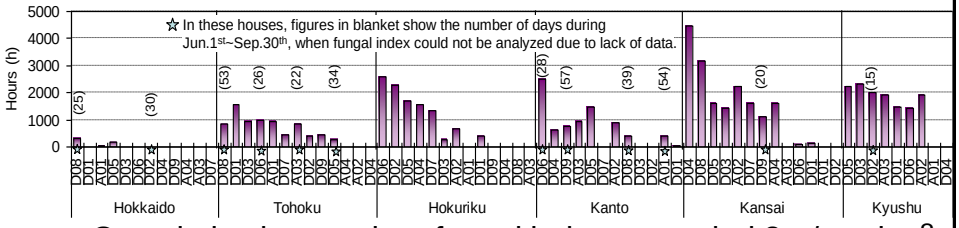
Prediction of possibility of mold growth

Fungi Index: Biologic sensors based on measurement of hyphae length grown under certain temperature and humidity for a week developed by Dr. Abe. Under the environment with more than 3 ru/week, the possibility of mold growth is high.





Keiko Abe: A prevention strategy against fungal attack for the conservation of cultural assets using a fungal index. International Biodeterioration & Biodegradation 88: 91–96 (2014)



Cumulative hours when fungal index exceeded 3ru/week

8

8

Prediction of possibility of mold growth

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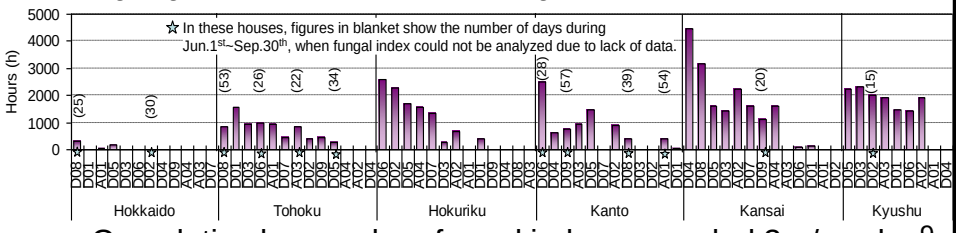

Cumulative hours when fungal index exceeded 3ru/week

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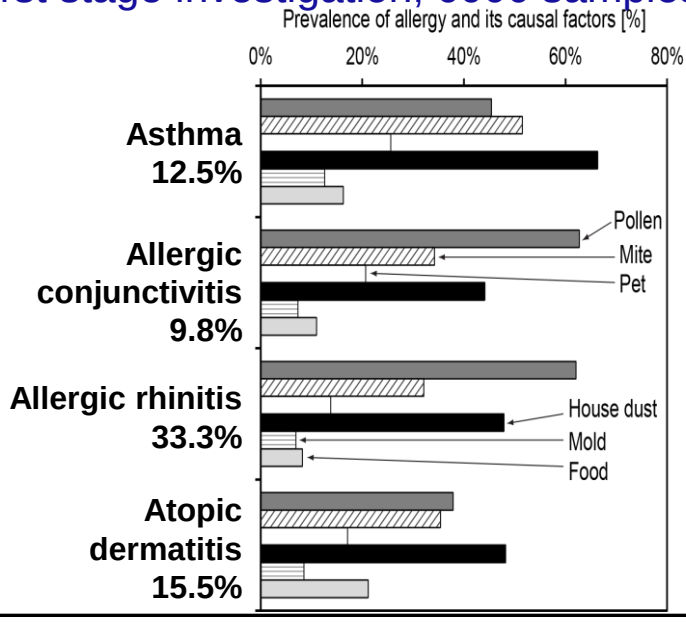
Prevalence of allergy and its causes

(First stage investigation, 6000 samples, 2009)



Condensation and mold

(Second stage investigation, 1800 samples, 2010)

Item		Hokaido (%) freq.	Tohoku et al. (%) freq.	Kanto (%) freq.	Tokai (%) freq.
Vapor condensation in a living room (M.A.)	Wall	2	42	53	3
	Floor	0	21	14	3
	Ceiling	1	8	13	1
	Openings	25	325	680	58
	Closet	4	36	36	4
	No occurrence	5	122	163	16
	No idea	0	7	5	0
Mold growth in a living room (M.A.)	Wall	1	45	61	4
	Floor	0	11	14	1
	Ceiling	0	6	9	1
	Openings	12	169	305	24
	Closet	2	27	26	3
	No occurrence	17	225	454	33
	No idea	0	36	76	15

Item		Kansai et al. (%) freq.	Kyusyu et al. (%) freq.	Total (%) freq.
Vapor condensation in a living room (M.A.)	Wall	3	3	106
	Floor	1	0	39
	Ceiling	1	1	25
	Openings	89	49	1226
	Closet	2	1	83
	No occurrence	20	11	337
	No idea	2	1	15
Mold growth in a living room (M.A.)	Wall	2	2	115
	Floor	2	1	29
	Ceiling	0	0	16
	Openings	34	25	569
	Closet	3	2	63
	No occurrence	65	36	830
	No idea	14	4	145

- Condensation occurs in 70% houses
- Mold growth occurs in 40% on sashes and in 10% on walls

Univariate analysis between indoor environment and symptoms

		At least one allergic symptoms at present	Asthma (including similar symptoms)	Hyperesthesia of airway	Hey fever (including similar symptoms)
Dampness in a living room	Yes/No	1.01	1.10	**1.52***	1.04
Dryness in a living room	Yes/No	1.11	1.34	0.94	1.06
Dampness in a child room	Yes/No	1.22	1.41	**1.47***	1.17
Dryness in a child room	Yes/No	1.31	1.08	0.89	1.26
Vapor condensation	Observed / Not	**1.56*****	1.10	1.36	**1.54***
Mold growth in a living room	Observed / Not	**1.44****	1.58	**1.44***	**1.43***
Mold growth in a child room	Observed / Not	**1.49*****	1.43	**1.48***	**1.46****
Damp stain in a living room	Observed / Not	**1.40***	2.01	**1.89****	1.31
Damp stain in a child room	Observed / Not	**1.43****	**2.17***	**2.30*****	**1.36****

* p<0.05, ** p<0.01, ***p<0.001

- Odd's ratio of dampness in a child room is more than 1.0 in various symptoms.
- Odd's ratio of vapor condensation, mold growth and damp stain are more than 1.0 in all symptoms.

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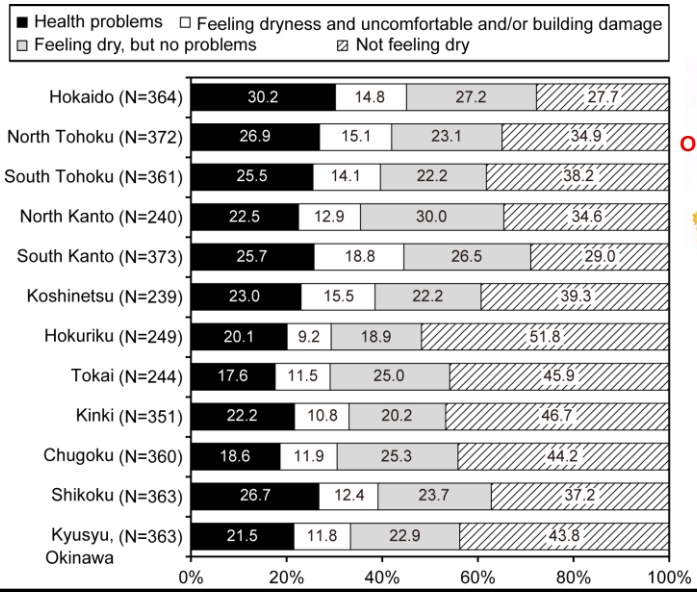
Dry feeling, health problems, building damage during the winter





Sample size: 3600
Survey: 2011

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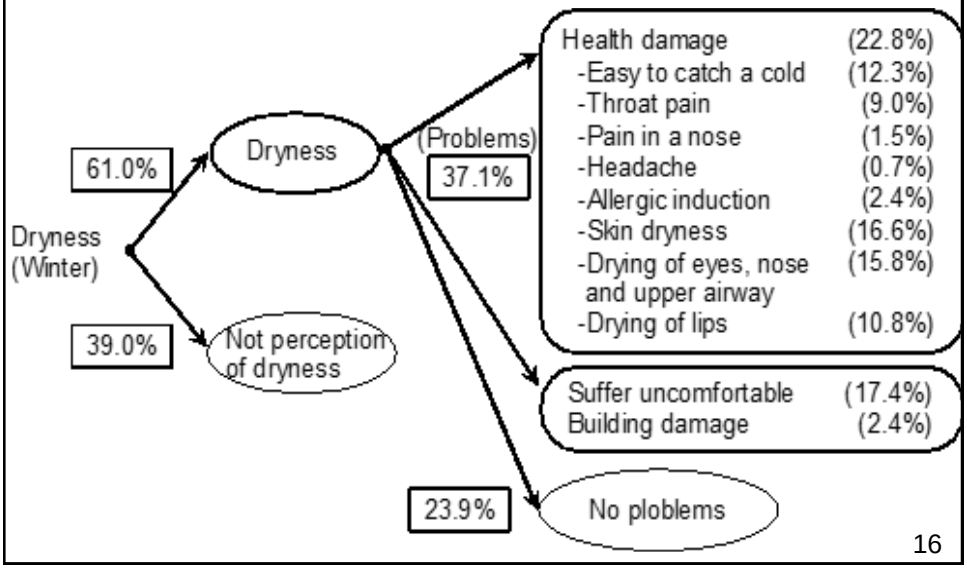
Ratio of dryness perception and claims of health problems



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Conclusions

1. The conditions are quite different from the north to the south in Japan. The characteristics of the indoor temperature and humidity vary greatly depending on the heating and cooling conditions, and also on the location.

2. There is a large variation in dampness among houses, it is found that dampness may be related to allergic diseases to children. On the other hand, dry feeling and health problems are serious in well insulated houses.

3. It is necessary to keep an environment away from high and low relative humidity by the humidity control strategies, such as ventilation operation, appropriate use of humidity control materials, proper installation of the dehumidifier.

4. Design methods for humidity control and recommendation of occupant's behavior should be established.

Thank you!

KU LEUVEN

UNIVERSITEIT GENT

FACULTY OF BIOSCIENCE ENGINEERING

Fungal growth on timber frame houses

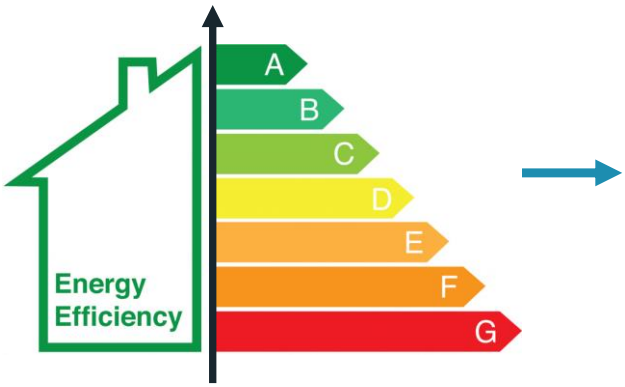
Michiel Vanpachtenbeke

AIVC 2019 Conference 15/10/2019

Topical session ‘Controlling moisture for improved IAQ’

1

Problem statement





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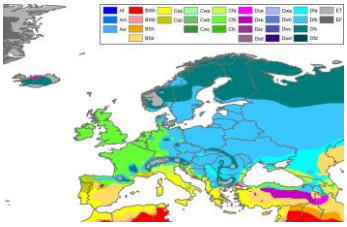
Problem statement

Indoor & outdoor climate



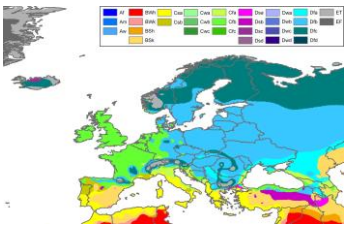
Composition



Hygrothermal performance
- **RH**
- **interstitial condensation**
- **…**

Problem statement

Indoor & outdoor climate



Composition



Hygrothermal performance
- **RH**
- **interstitial condensation**
- **…**



Problem statement

risk of fungal growth ?



Moisture threshold for wood decay ?

State-of-the-art: Wood Decay

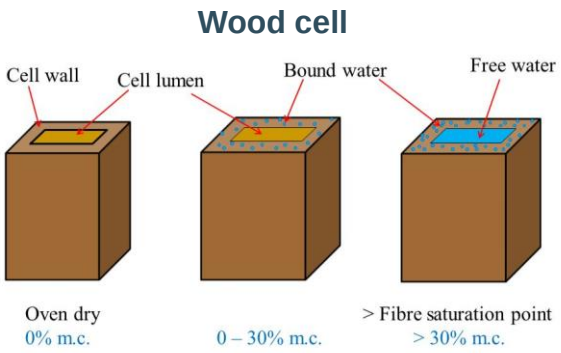
20% MC

State-of-the-art: Wood Decay

20% MC

Fibre saturation point (FSP)

critical level ?

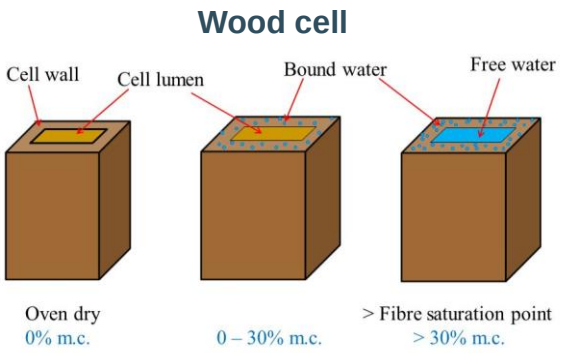


State-of-the-art: Wood Decay

20% MC → safe and conservative approach

Fibre saturation point (FSP)

critical level ?

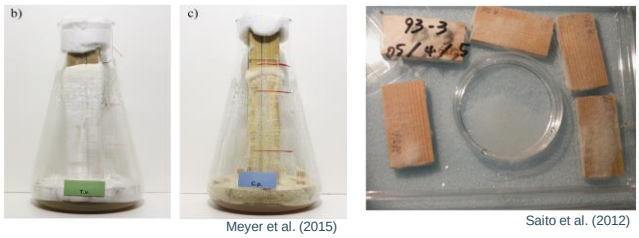


State-of-the-art: Wood Decay

Laboratory tests

Liquid water source
< FSP

No liquid water source
≥ FSP



Meyer et al. (2015)

Saito et al. (2012)

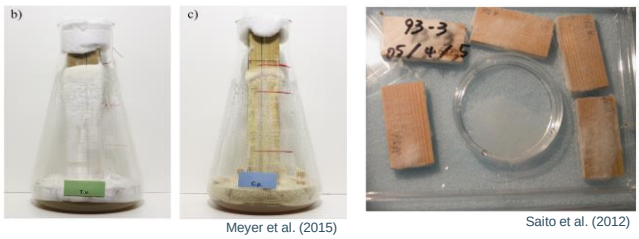
State-of-the-art: Wood Decay

Laboratory tests

Liquid water source
< FSP

No liquid water source
≥ FSP

Inoculation and sterilization — **PROGRESS**



Meyer et al. (2015)

Saito et al. (2012)

State-of-the-art: Wood Decay

No inoculation and sterilization **ONSET**

Laboratory tests

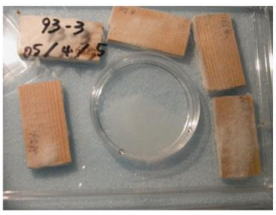
Liquid water source **< FSP**

No liquid water source **≥ FSP**

Inoculation and sterilization **PROGRESS**



Meyer et al. (2015)



Saito et al. (2012)

State-of-the-art: Wood Decay

Field tests

Conditions not representative for timber frame building components

No inoculation and sterilization **ONSET**

Laboratory tests

Liquid water source **< FSP**

No liquid water source **≥ FSP**

Inoculation and sterilization **PROGRESS**



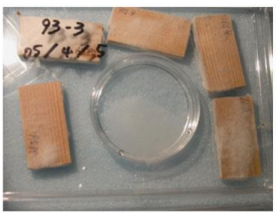
Sciencedirect.com



Scion



Meyer et al. (2015)



Saito et al. (2012)

Research objective

Performance of wood and wood-based building materials in timber frame building components

FCU – Fungal Control Unit

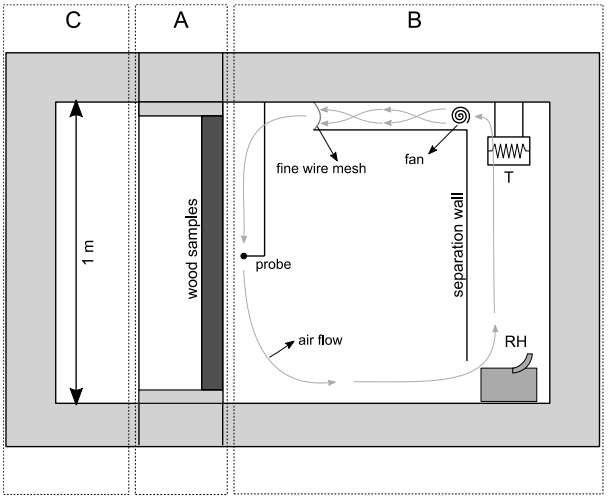
A



B



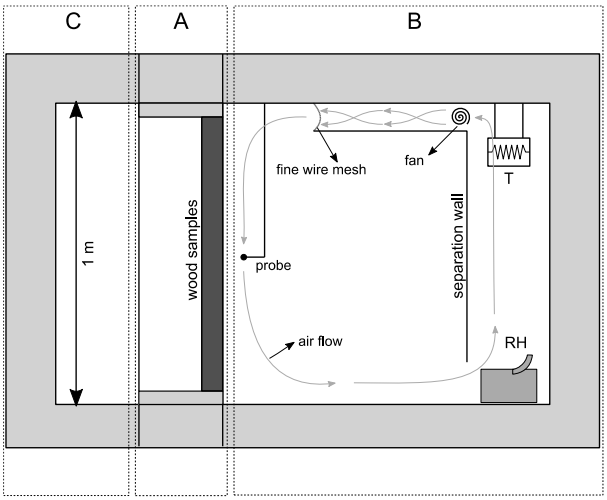




FCU – Fungal Control Unit

Evaluation

- visual inspection
- mass loss
- stiffness
- moisture content
  - gravimetrical
  - Electrical resistance



FCU – test 1

High RH

No liquid water source

FCU – test 1

Materials

- Scots pine
- Norway spruce
- OSB

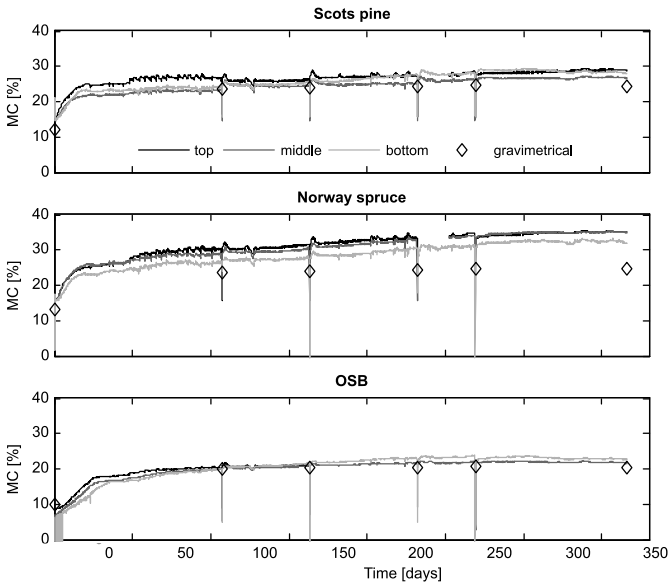


Climate

- T: 25°C
- RH: 97%

≤ FSP





≥ 25%

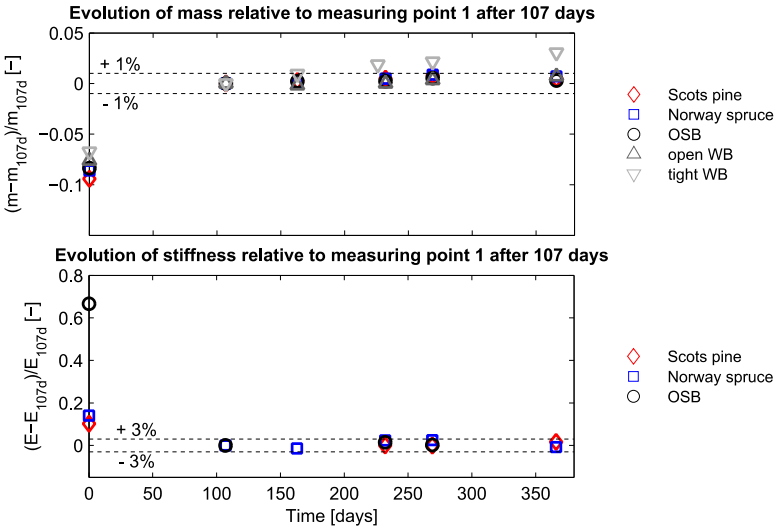
≥ 25%

+/- 20%

Moisture content

1 year exposure





Mass loss

1 year exposure

Stiffness loss

1 year exposure

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UGent, Department of Environment, Laboratory of Wood Technology (Woodlab-UGent)

FCU – test 2

liquid water source: condensation

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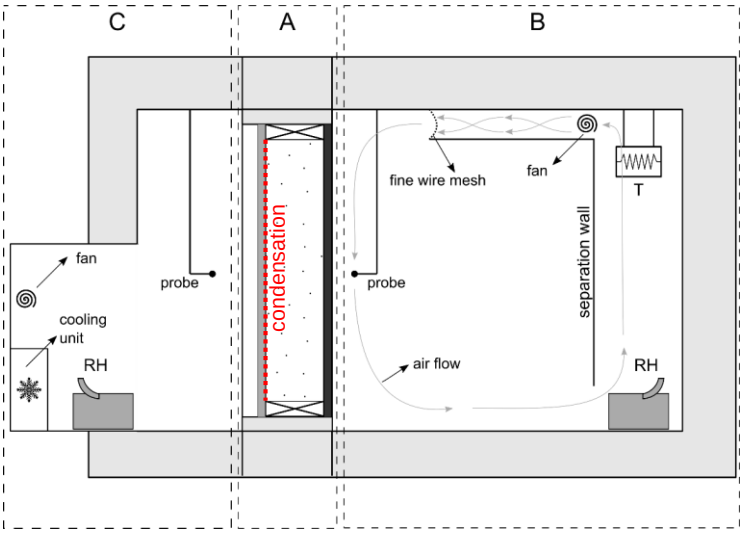
FCU – test 2

Materials

Timber frame wall

Climate

25 °C & 65% RH
vs.
5°C & 80% RH
→ **condensation (>FSP)**



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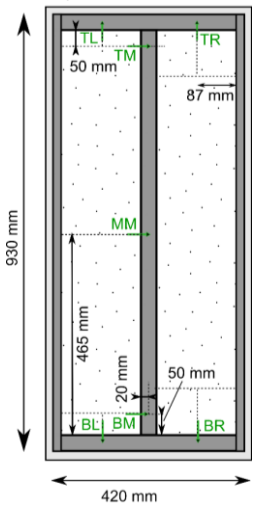
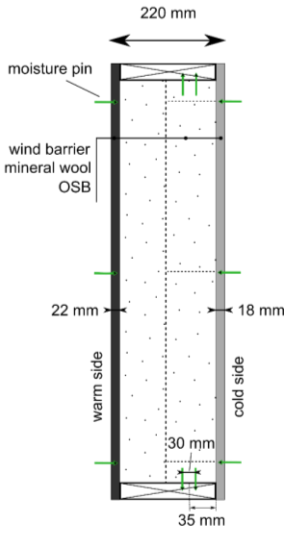
FCU – test 2

moisture content measurements

Front view



Side view



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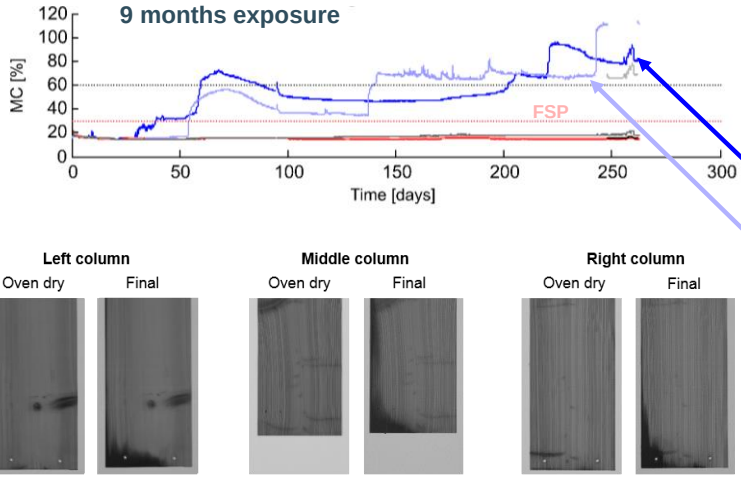
FCU – test 2

Moisture content





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FCU – test 2

Stiffness

9 months exposure	Stiffness (N/mm²)	
	initial	final
Top plate	7261	7264 (-0.0%)
Bottom plate	10261	9886 (-3.7%)
Left column	10952	10962 (+0.1%)
Middle column	11669	11540 (-1.1%)
Right column	11925	11512 (-3.5%)



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Conclusion

- **Performance of wood and wood-based building materials**
- **High RH, no condensation**
  - **No wood decay after 1 year of exposure**
- **High RH, condensation**
  - **No clear signs of wood decay after 9 months of exposure**

Future work

- **Tests over multiple years**
- **Dynamic conditions**

25

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FACULTY OF BIOSCIENCE ENGINEERING

Fungal growth on timber frame houses

Michiel Vanpachtenbeke

AIVC 2019 Conference 15/10/2019

Topical session ‘Controlling moisture for improved IAQ’

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1

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AND ARCHITECTURE

DEPARTMENT OF ARCHITECTURE AND URBAN PLANNING
BUILDING PHYSICS, CONSTRUCTION AND SERVICES RESEARCH GROUP

9 MONTHS OF IN SITU-MEASUREMENTS ON
SMART VENTILATION SYSTEMS IN BELGIUM :

BIG HUMIDITY DATA

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2

The Context:
IoT connected AHU

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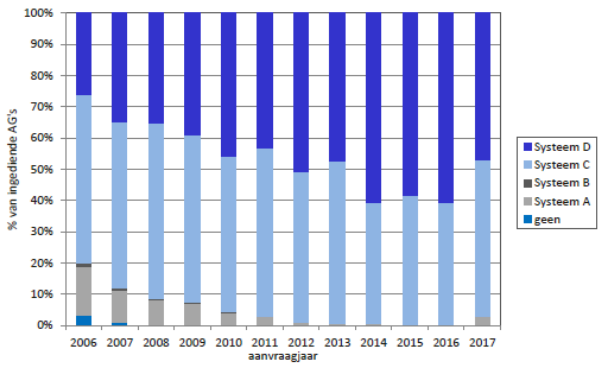
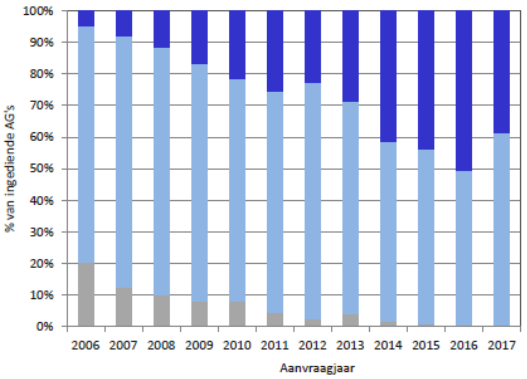
3

DCV IN THE BELGIAN MARKET





EPB cijferrraport: procedures, resultaten en energetische karakteristieken van het Vlaamse gebouwenbestand – periode 2006-2018

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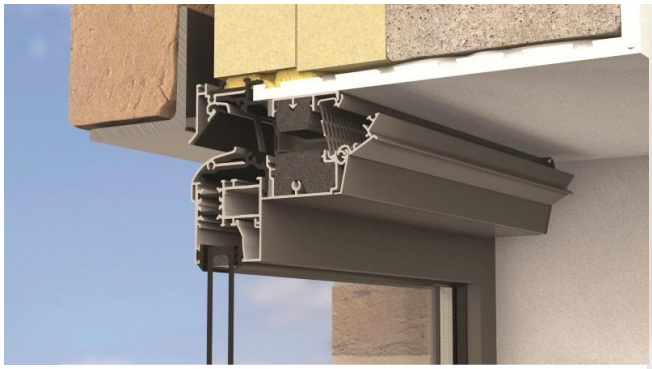
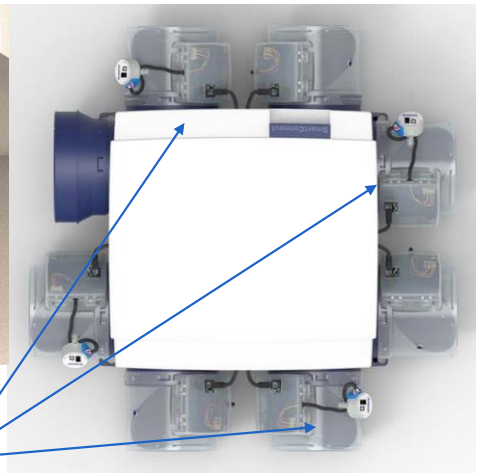
4

DCV IN THE BELGIAN MARKET





Room type	Measured parameters
Laundry room/ Shower/ Bathroom without toilet	T&RH
Bathroom/ Toilet/ Storage	T&RH + VOC
Kitchen (open/closed), Bedroom, Living room, Office	T&RH + CO_2

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DCV IN THE BELGIAN MARKET





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The Research Objective

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RESEARCH OBJECTIVE

Use the recorded big data to verify our assumptions of ‘normal’ conditions in modern dwellings

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The Case Study

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THE SAMPLE

Valve type	May	June	July	August	September	October	November	December	January
BathRoom	113	151	192	268	374	454	534	682	789
BathRoomWithoutToilet	7	7	8	10	11	14	14	17	19
BedRoom	122	151	181	247	336	412	496	657	775
ClosedKitchen	2	2	2	2	5	7	7	10	9
Kitchen	92	122	152	205	285	350	418	535	632
LaundryRoom	92	123	150	191	258	320	400	502	589
LivingRoom	1	1	2	3	3	4	3	2	4
Office	4	4	6	6	7	10	9	10	10
Shower	6	6	9	11	10	11	13	12	9
Storage	0	0	0	0	0	1	4	6	6
Toilet	135	171	219	296	400	496	575	741	880

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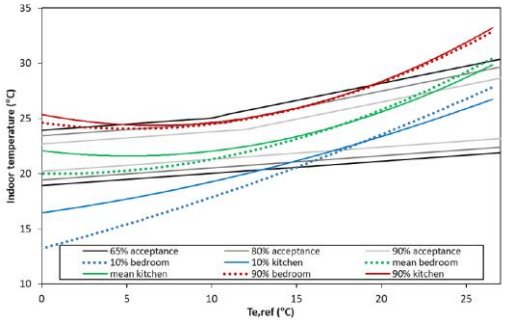

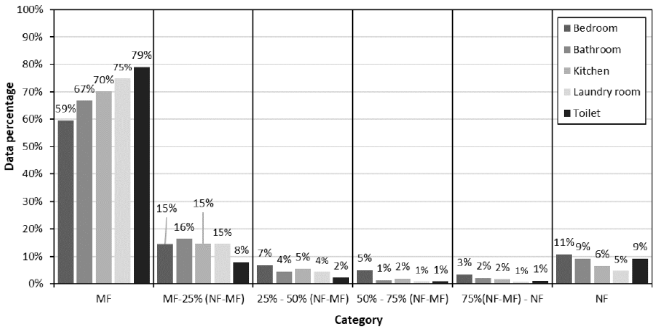

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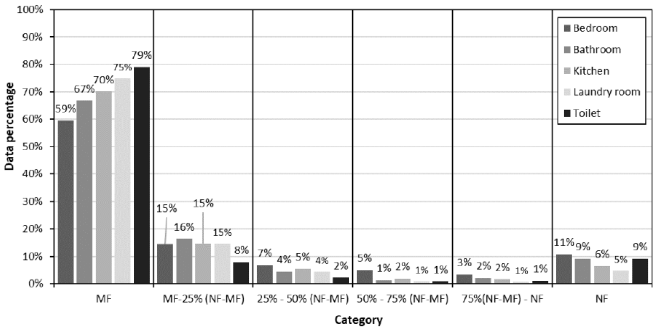
Roomtype	Area of the room	Air inlet	Air outlet to the outside
Bedroom, office, playroom, ...	less than 7 m²	25 m³/h	
	between 7 and 20 m²	3,6 m³/h.m²	
	more than 20 m²	72 m³/h	
Living room, salon, dining room, ...	less than 21 m²	75 m³/h	
	between 21 and 42 m²	3,6 m³/h.m²	
	more than 42 m²	150 m³/h	
Toilet			25 m³/h
Kitchen (closed), bathroom, laundry room,...	less than 14 m²		50 m³/h
	between 14 and 21 m²		3,6 m³/h.m²
	more than 21 m²		75 m³/h
Open kitchen			75 m³/h



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The Results

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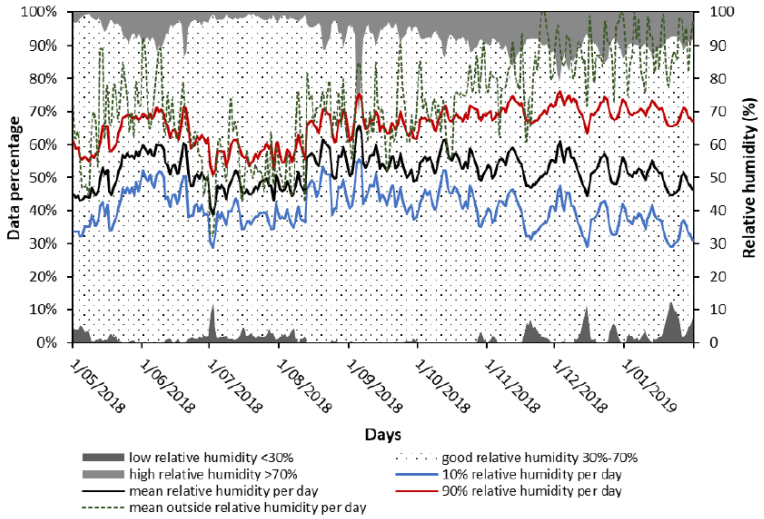

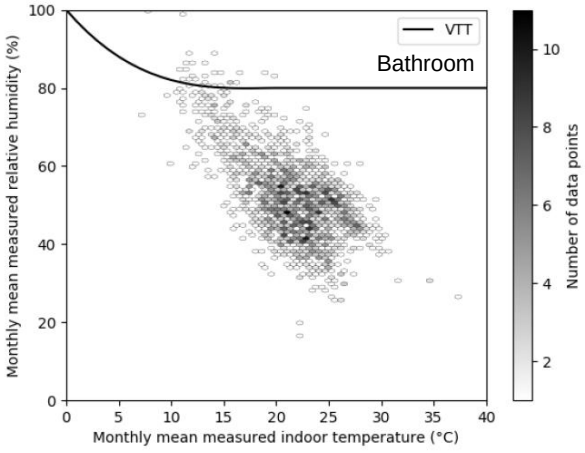

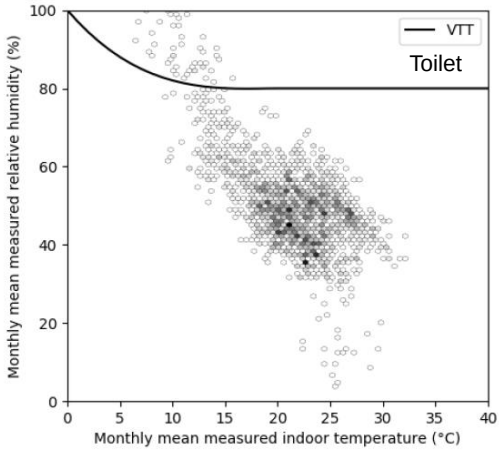

	Bedroom	Kitchen	Bathroom	Laundry room	Toilet
Risk of mould growth	1.15%	0.63%	1.14%	0.52%	2.39%

15

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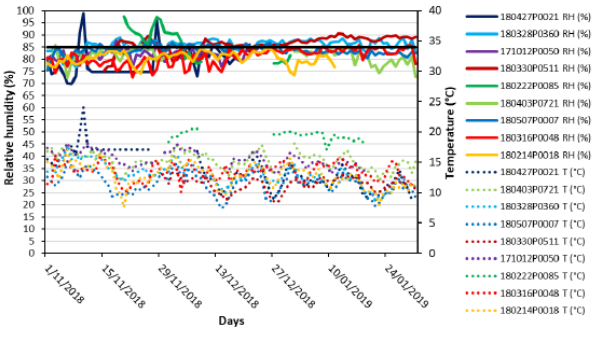
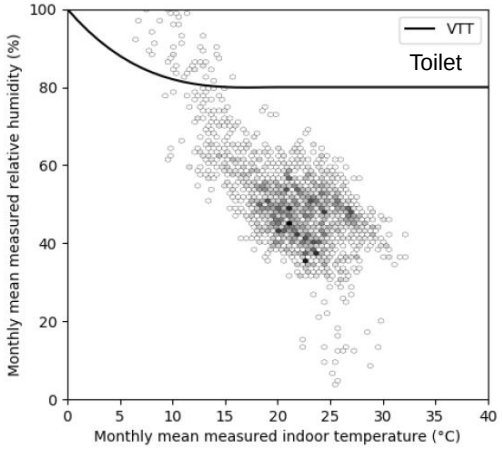
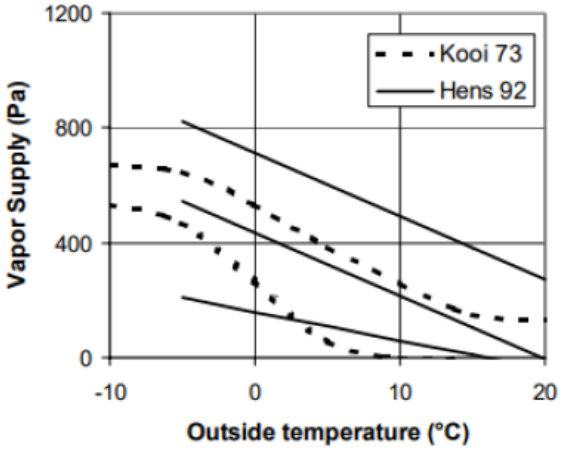




	Bedroom	Kitchen	Bathroom	Laundry room	Toilet
Risk of mould growth	1.15%	0.63%	1.14%	0.52%	2.39%

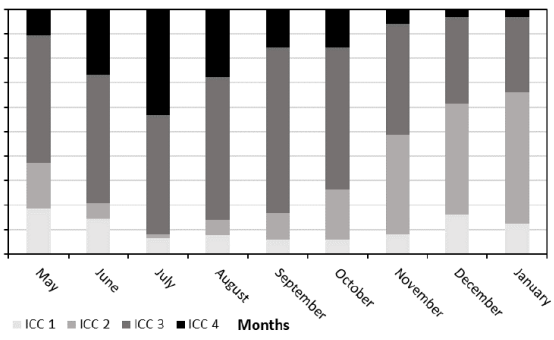
16

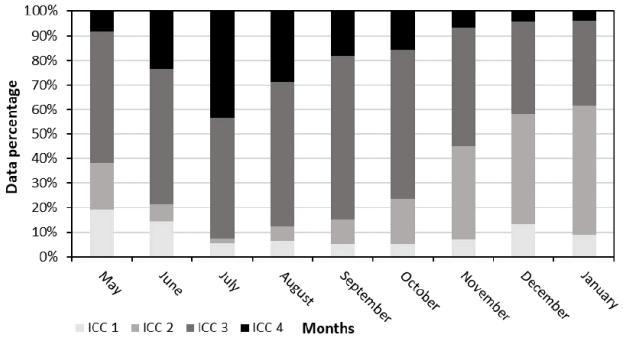
16



ICC	Hens 1992 (355 weekly mean data, r^2 = 0,25)	
	Limit $P_i - P_e$ (Pa)	Description
1	$<159 - 10\theta_e$	5% of dwellings less humid
2	$<436 - 22\theta_e$	50% of dwellings less humid
3	$<713 - 22\theta_e$	95% of dwellings less humid
4	$>713 - 22\theta_e$	5% of dwellings more humid

17

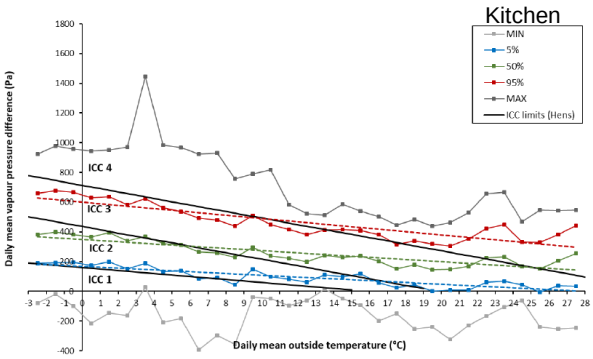


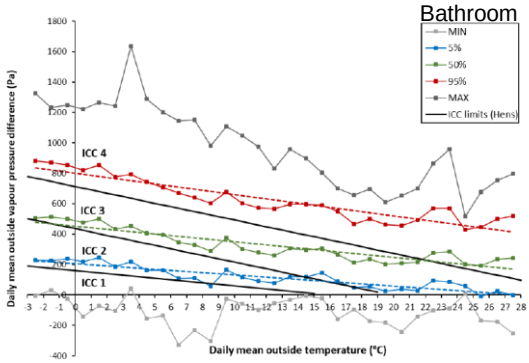


ICC	Model of Hens with short-term measurements	
	$P_i - P_e$ (Pa)	Description
1	<159 - 10 θ_e	Buildings with a low moist production
2	<436 -22 θ_e	Buildings with a small moist production or sufficient ventilation system
3	<713 - 22 θ_e	Buildings with a considerable moist production or moderate ventilation
4	>713 -22 θ_e	Buildings with a high moist production or poor ventilation

18

18

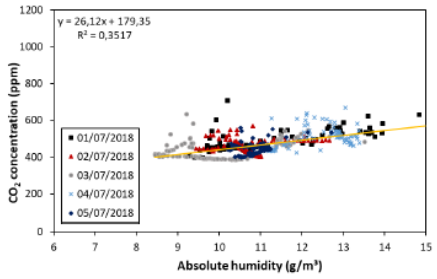




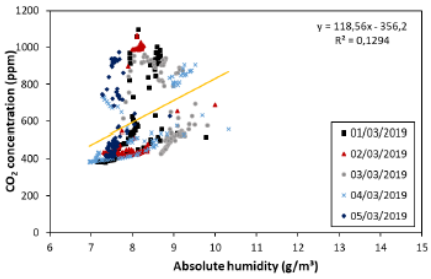
ICC	Bedroom		Kitchen		Bathroom		Toilet		Laundry room	
	Limit $P_i - P_e$ (Pa)	R^2	Limit $P_i - P_e$ (Pa)	R^2	Limit $P_i - P_e$ (Pa)	R^2	Limit $P_i - P_e$ (Pa)	R^2	Limit $P_i - P_e$ (Pa)	R^2
1	$<148{,}73 - 6{,}02\theta_e$	0,77	$<168{,}76 - 6{,}08\theta_e$	0,77	$<205{,}85 - 7{,}38\theta_e$	0,80	$<178{,}37 - 6{,}74\theta_e$	0,80	$<167{,}69 - 5{,}21\theta_e$	0,74
2	$<341{,}65 - 7{,}63\theta_e$	0,75	$<349{,}07 - 7{,}50\theta_e$	0,73	$<452{,}80 - 10{,}34x$	0,83	$<382{,}11 - 7{,}48\theta_e$	0,69	$<385{,}35 - 8{,}16\theta_e$	0,75
3	$<597{,}42 - 11{,}33\theta_e$	0,80	$<600{,}87 - 11{,}03\theta_e$	0,74	$<800{,}30 - 14{,}04\theta_e$	0,85	$<648{,}15 - 9{,}13\theta_e$	0,63	$<667{,}72 - 10{,}94\theta_e$	0,69
4	$>597{,}42 - 11{,}33\theta_e$	0,80	$>600{,}87 - 11{,}03\theta_e$	0,74	$>800{,}30 - 14{,}04\theta_e$	0,85	$>648{,}15 - 9{,}13\theta_e$	0,63	$>667{,}72 - 10{,}94\theta_e$	0,69

19

19



(a) *1 to 5 July 2018*



(b) *1 to 5 December 2018*

20

20

Mean [1-5/03/2018] [quarterly measurements]						
180219P0050	Bedroom	Bedroom	Bedroom	Laundry room	Bathroom	Kitchen
Bedroom	1,00					
Bedroom	0,68	1,00				
Bedroom	0,29	0,27	1,00			
Laundry room	0,25	0,35	0,69	1,00		
Bathroom	0,24	0,33	0,40	0,49	1,00	
Kitchen	0,34	0,49	0,46	0,43	0,32	1,00
Mean correlation coeff. dry and wet rooms						0,39

Mean [1-5/03/2018] [quarterly measurements]						
180219P0060	Bedroom	Bedroom	Living room	Office	Kitchen	Bathroom
Bedroom	1,00					
Bedroom	0,78	1,00				
Living room	0,44	0,53	1,00			
Office	0,93	0,62	0,28	1,00		
Kitchen	0,62	0,68	0,27	0,55	1,00	
Bathroom	0,91	0,61	0,29	0,94	0,50	1,00
Mean correlation coeff. dry and wet rooms						0,61

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DEPARTMENT OF ARCHITECTURE AND URBAN PLANNING
BUILDING PHYSICS, CONSTRUCTION AND SERVICES RESEARCH GROUP

9 MONTHS OF IN SITU-MEASUREMENTS ON SMART VENTILATION SYSTEMS IN BELGIUM :

BIG HUMIDITY DATA

AIVC 2019

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ByggaF

A Method to Include Moisture Safety in the Construction Process

Kristina Mjörnell, RISE



1

Introduction

Many buildings suffer from moisture related problems, with negative consequences for health, comfort and well-being

This causes extensive costs for refurbishment and lost confidence in the building sector

The cost for defects and damage is 5 billion Euros per year in the Swedish building sector and moisture damages are dominating



2

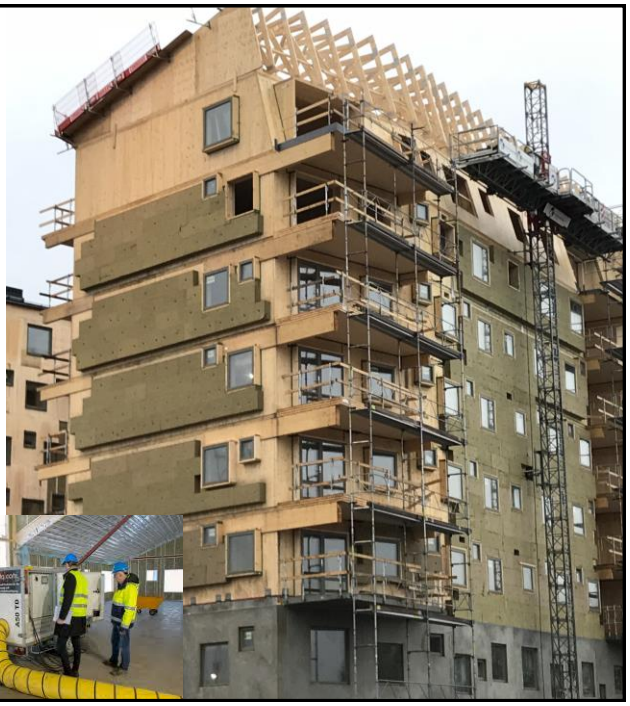
Introduction

Increased interest for construction in wood to decrease the environmental impact.

Wood is sensitive to moisture and must be handled with care during construction.

Moisture damages causes an environmental impact, since materials have to be demolished, replaced with new or dried out and decontaminated.

These problems could have been avoided if moisture safety had been included in the building process.



Introduction

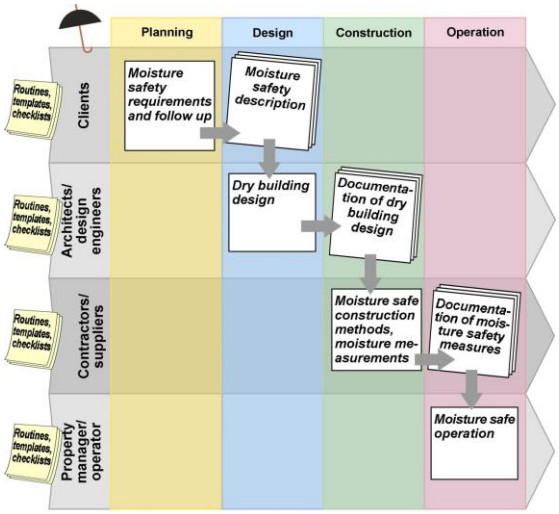
Since 2006 the Swedish building regulations have been more distinct regarding moisture safety.

The first version of ByggaF was introduced in 2007.

After a few years use, the building sector asked for a more standardized method for moisture safety.

The industry standard ByggaF was developed and published in 2013.





ByggaF

A method for all actors involved to ensure, document and communicate moisture safety in the entire building process, from planning through design, construction, operation and management.

5

Industry standard ByggaF

- The industry standard is structured based on "requirements" that must be met.
- In addition, "guidance text" that can clarify, explain or give examples of what the requirement means. The guidance may also contain advice.



6

The property owner/developer is responsible

- To carry out planning, design, construction or renovation work in accordance with the laws and regulations and
- appoint appropriate qualifications for the tasks.
- To appoint a moisture expert.





Organisation of the moisture safety work











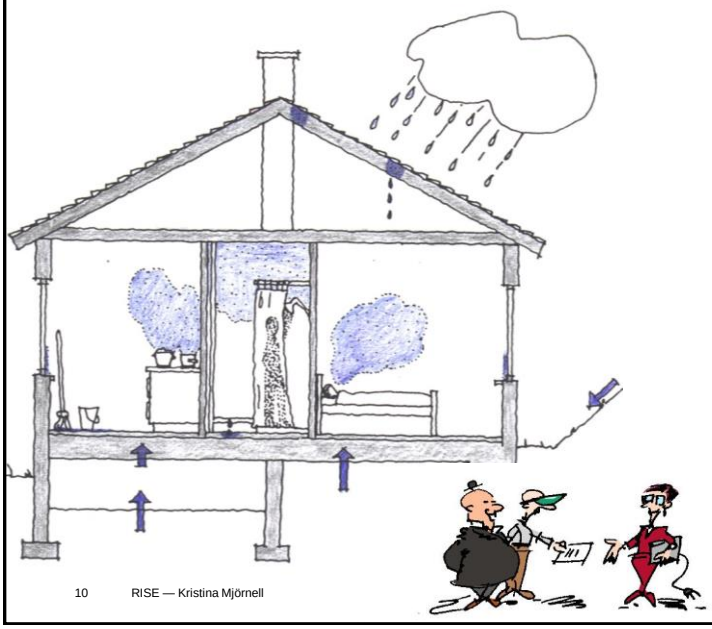
Programme stage

- Appoint a moisture expert
- Early moisture risk analysis
- Decide on the developer's moisture safety requirements
- Decide on measures in cases of non conformance
- Decide on procedures for monitoring
- Formulate moisture requirements and requirements for activities in the contract documents







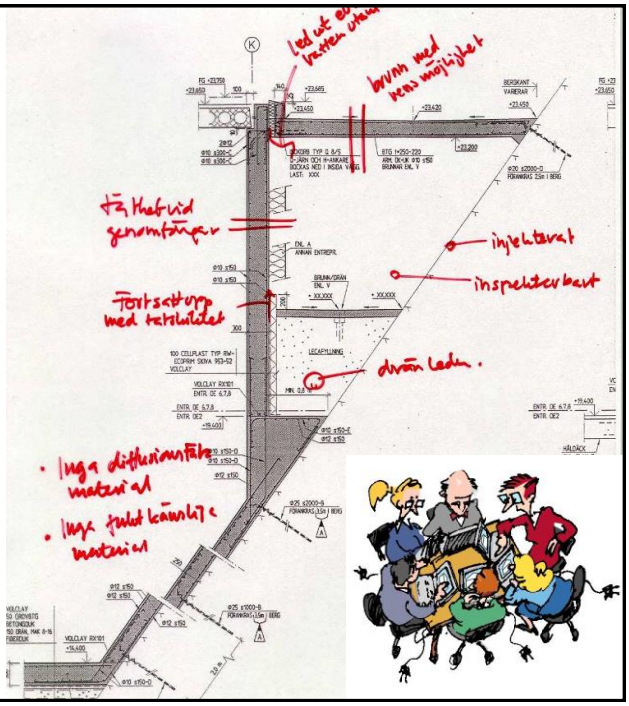


System planning stage

- Information to planners about the developer's moisture safety requirements and methods for monitoring
- Appoint a moisture safety officer for planning
- Present a procedure for moisture safety planning
- Moisture safety planning
- Moisture risk analysis
- Inspection and documentation of system selections for moisture safety
- Decision on specific moisture safety requirements in the production stage
- Moisture safety specification

Detailed design stage

- Information to designers about the developer's moisture safety requirements and methods for monitoring
- Appoint a moisture safety officer for design
- Procedure for moisture safety design
- Follow-up meetings with designers
- Review of moisture safety design
- Collect supporting data for moisture safety documentation









Production stage

- The results of moisture safety design are communicated to production
- Information to contractors and suppliers about the developer's moisture safety requirements
- Appoint a moisture safety officer for production
- Identify moisture-sensitive elements, structures and installations
- Prepare a moisture safety plan
- Developers' follow-up meetings with contractors and suppliers
- Moisture inspection rounds
- Measurement and inspections
- Document non-conformance in relation to the moisture safety plan

End of production stage

- Collect and establish supporting data for operation and maintenance instructions for moisture safety
- Collect supporting data for moisture safety documentation
- Handling over to the property owners organisation







Operation and management

- Follow-up and monitoring
- Moisture inspection rounds in the management stage

Supporting documents and templates

- ByggaF industry standard
- Risk identification and evaluation at early stage
- Moisture Inventory of existing building
- The developer's moisture safety requirements and activities
- Job description for moisture expert
- Moisture Safety Description (template)
- Moisture Safety Design and Risk Management (template)
- Moisture Plan (template)
- Moisture Round Protocol (template)
- Deviation Report (template)
- Content for moisture safety documentation (template)

All material can be downloaded from:
www.fuktcentrum.se

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ByggaF is a requirement in Miljöbyggnad 3.0

- A diploma moisture expert must be engaged by the building owner to participate in the project (gold and silver level)
- ByggaF:s templates should be used or similar
- Moisture safety design, moisture safety inspection rounds and moisture plans are required
- Moisture safety work must be documented according to ByggaF:s templates or similar

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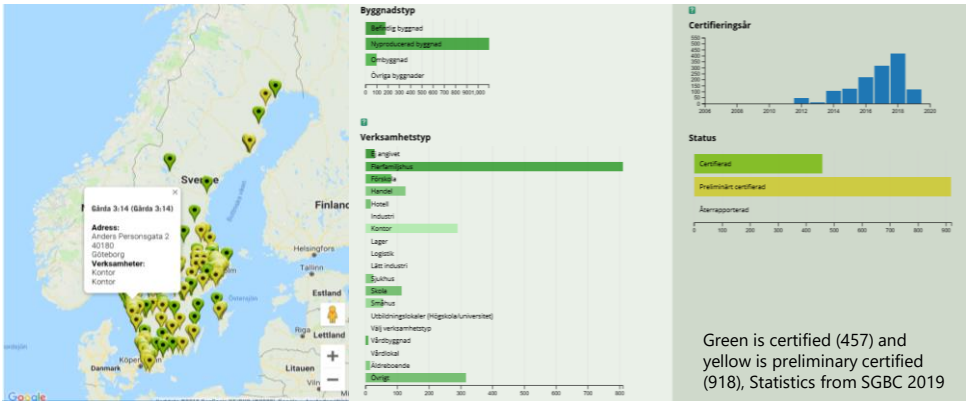
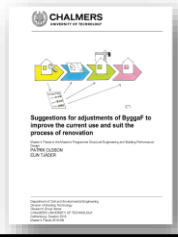
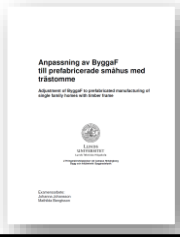
1375 certified buildings at silver or gold level



Developing new versions of ByggaF

- 2 master theses have adapted ByggaF to suit specific needs such as
  - construction of prefabricated single family houses and
  - renovation of multifamily houses







Conclusions

- ByggaF - A method for including moisture safety in the construction process has been developed and successfully adopted by the Swedish construction industry and transferred into an industry standard.
- The wide implementation is a result of an advise in the Swedish Building Regulations to use ByggaF and a requirement in the Swedish environmental assessment system Miljöbyggnad to follow ByggaF to reach silver and gold levels.
- According to Miljöbyggnad, ByggaF has been used in the construction or renovation of 1375 buildings.
- It is possible to use ByggaF in other countries, but national conditions and regulations have to be implemented.
- Two versions of ByggaF have been developed to better suit specific applications such as renovation and construction of prefabricated single-family homes with timber frame.
- There are great development opportunities to digitize ByggaF.



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Analysis of the Effects of Ventilation Method on Indoor Humidity Distribution and Condensation by CFD method

Reporter: Kitakyushu University
Ryu Lab
Zhang Fangyuan

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Analysis of the Effects of Ventilation Method on Indoor Humidity Distribution and Condensation by CFD method

01 Introduction
02 The summary of CFD simulation
03 Simulation results and analysis
04 Conclusion & Summary

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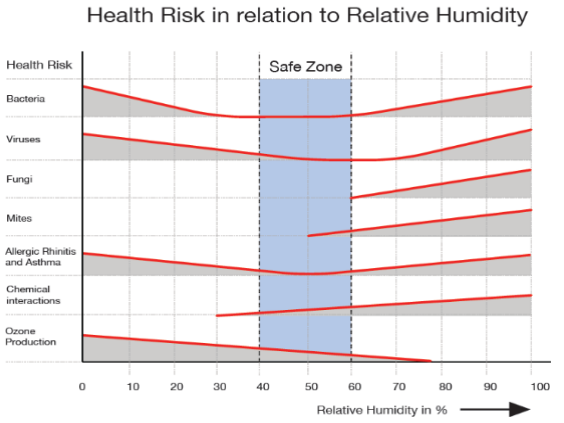
Introduction

The effect of air humidity on the health

In a person's life, 70% -90% of the time is spent indoors, and indoor air quality and the health of the human body has a close relationship. With the advent of society, user comfort requirements for thermal environment is rising. Humidity is an important indicator of indoor air parameters, for human, not only related to human comfort, but also to the healthy. The optimum relative humidity for the human body is 40 to 60 percent.



* https://www.smartdry.co.uk/damp-info/

The condensation on walls, floors and ceilings is likewise a serious problem for buildings. When the moisture content of the air near the wall exceeds the saturated water content of the wall surface, the wall will condense, causing the wall to fall off, and the mold will cause corrosion of the outer casing structure and reduce the life of the building.

Introduction

There are two ways to reduce the risk of condensation on the construction in the engineering field. In ordinary rooms, the wall is attached to insulation materials to improve the dew point temperature of the inner surface of the enclosure structure; Ventilation and air conditioning rooms reduce the possibility of condensation of wet air on the wall by controlling the temperature of the room and the humidity of the indoor air.

Compared with the two methods, the use of mechanical ventilation cannot only reduce the risk of condensation on the building, but also adjust the indoor temperature and humidity environment,

CFD is one of the most important research fields in the world. HVAC refrigeration industry is one of the important areas of CFD technology applications . Airpak was previously used to simulate indoor pollutant distribution. Because of the similarity between pollutants and water vapor, we consider using it to simulate indoor humidity distribution.In recent years, with the development of large capacity, high speed of computer, CFD technology has been used to simulate air flow organization. It is possible to simulate the airflow organization, temperature and humidity of the building air conditioning system by using CFD technology.

ANSYS FLUENT & Airpak

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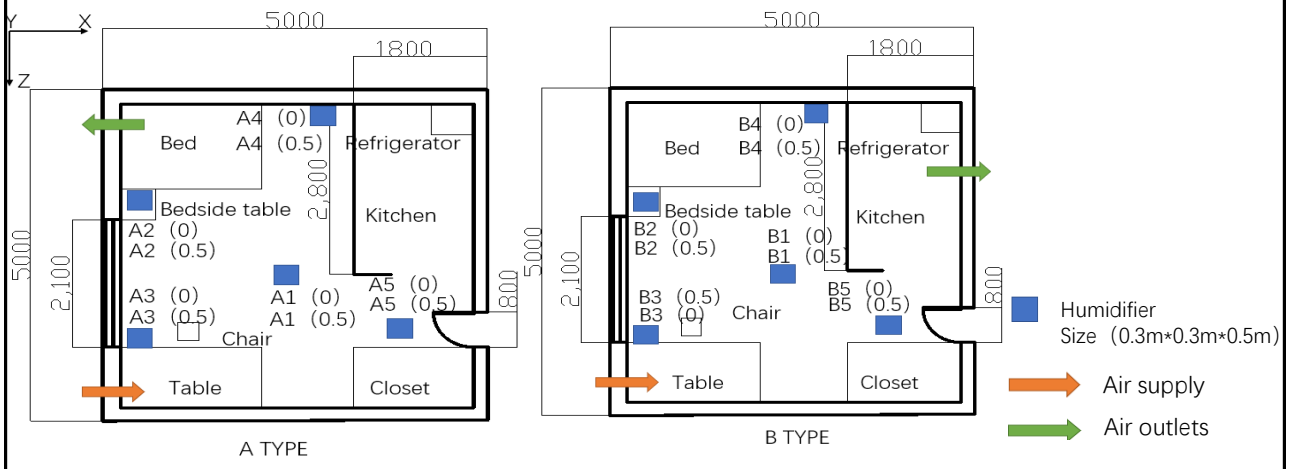
The Summary Of CFD Simulation



(0) indicate that the humidifier is placed on the ground (0.5) placed at the height of 0.5 m from the ground.

In the model the wall on the side of window are made by concrete with overall heat transfer coefficient of 1.74W/m^2 · K. The heat transfer coefficient of the window is 0.63 W/m^2 · K. The other walls are insulated and desiccated.

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The Summary Of CFD Simulation

Model Boundary Condition

Boundary	*Parameter Setting*
Air supply	Air volume ： 216m^3/h, Temp.： 30℃， Relative Humidity：20%
Air Outlet	Outflow
Wall	On the side of window are made by concrete with overall heat transfer coefficient of 1.74W/m^2 · K. The other walls are insulated and desiccated. Outdoor temperature 5 ℃
Ceiling and Floor	Insulation
window	heat transfer coefficient 0.63W / (m^2 • K)
Initial environment	Temp. 23℃ RH Φ=20%
Penetrating wind	0.2m/s
Humidifier	Amount of moisture 300ml/h

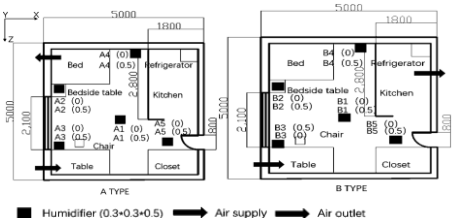


Table 2: Case number and the humidifier position

case 1	no humidifier		
case 2	A1(0)	case 12	B1(0)
case 3	A1(0.5)	case 13	B1(0.5)
case 4	A2(0)	case 14	B2(0)
case 5	A2(0.5)	case 15	B2(0.5)
case 6	A3(0)	case 16	B3(0)
case 7	A3(0.5)	case 17	B3(0.5)
case 8	A4(0)	case 18	B4(0)
case 9	A4(0.5)	case 19	B4(0.5)
case 10	A5(0)	case 20	B5(0)
case 11	A5(0.5)	case 21	B5(0.5)

The Summary Of CFD Simulation

Simplification of the physical model

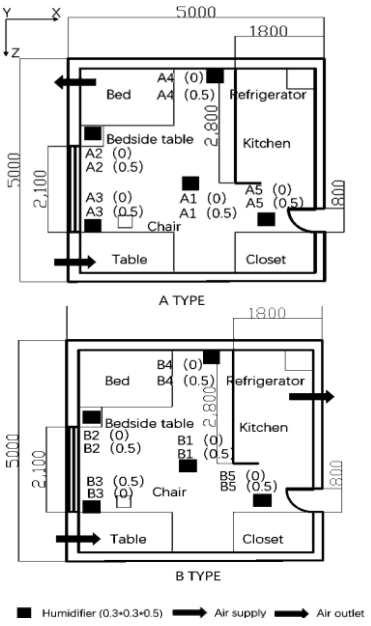
1.The effects of gravity fields on air and water vapors are ignored;

2.Both air and water vapor are considered to be incompressible fluids with a constant density;

3.When the water vapor evaporates from the water surface, only latent heat exchange is performed, and sensible heat exchange is not considered;

4.When water vapor condenses on the wall, the heat release ignored from the phase change process;

5.Wall surfaces moisture absorption capacity is not considered during wall condensation.



Mathematical model

The FLUENT 14.0 turbulence module (Standard k-ε) is used to analyze the flow field characteristics. The component transport module (Species Transport) and the multiphase flow module (Multiphase) simulated the mass transfer phase transition of water vapor in the air. The governing equation is as follows:

$$\frac{\partial(\rho\emptyset)}{\partial\tau} + div(\rho u\emptyset) = div(\Gamma grad\phi) + s$$

Where: $\phi$is a general variable; Γ is a generalized diffusion coefficient; s is a generalized source term

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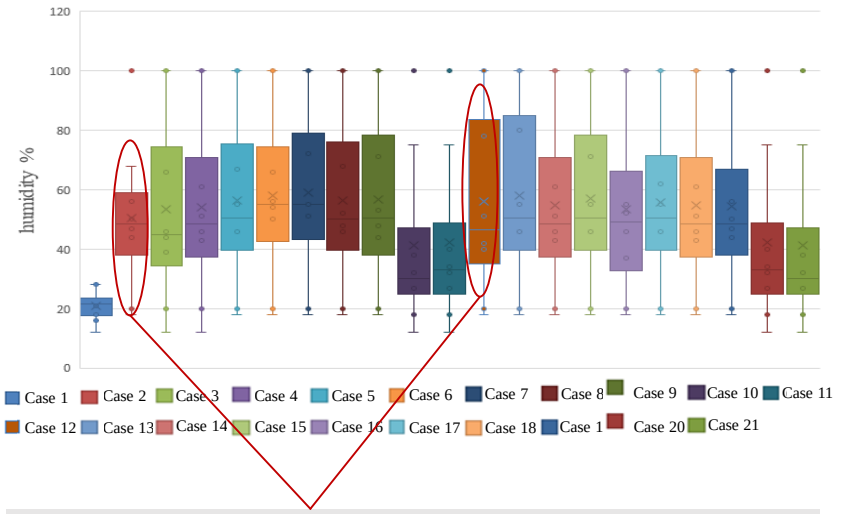
Simulation results and analysis



In Figure it can be seen that the humidity environment of case 2 is very good, between 40% and 60%. However, in case 12 there are many parts of the humidity above the comfort range.

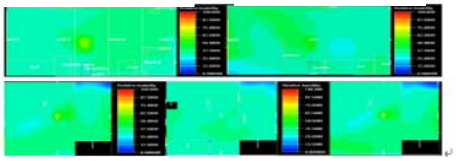
case 1	no humidifier		
case 2	A1(0)	case 12	B1(0)
case 3	A1(0.5)	case 13	B1(0.5)
case 4	A2(0)	case 14	B2(0)
case 5	A2(0.5)	case 15	B2(0.5)
case 6	A3(0)	case 16	B3(0)
case 7	A3(0.5)	case 17	B3(0.5)
case 8	A4(0)	case 18	B4(0)
case 9	A4(0.5)	case 19	B4(0.5)
case 10	A5(0)	case 20	B5(0)
case 11	A5(0.5)	case 21	B5(0.5)

Figure shows the humidity of each simulation case. It can be seen that after using the humidifier, the indoor humidity environment is significantly improved. Under the ventilation mode of B, the indoor humidity is better than the ventilation mode A.

Simulation results and analysis

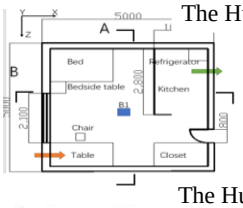


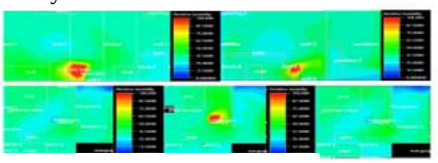
A section B section



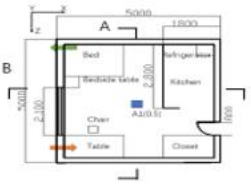
Ground height section 1.2 height section 2.8 height section

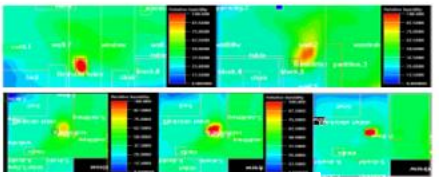
The Humidity Plane Cut of Case 2





The Humidity Plane Cut of Case 12





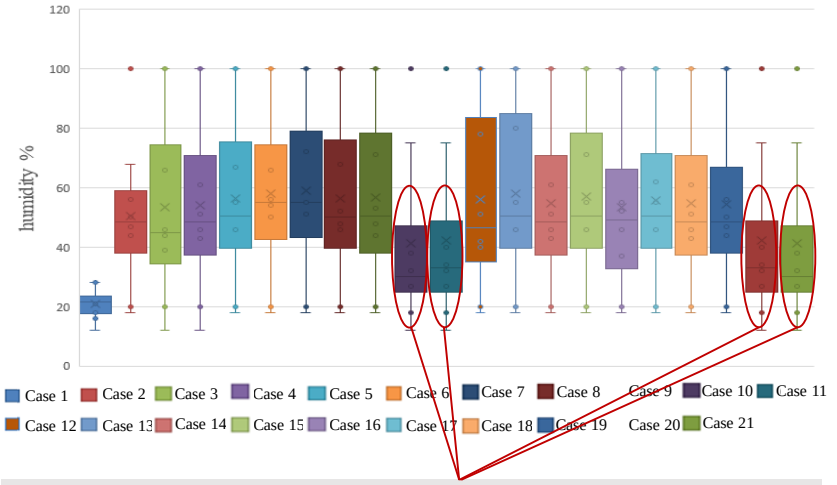
The Humidity Plane Cut of Case 3

Figure shown it is a good illustration of the effect of different ventilation methods on the indoor humidity distribution with the same placement of the humidifier.

In case 2, the indoor humidity is between 40% and 60%. The average humidity is around 50%. No obvious condensation in the room occurred. In case 12, the humidifier position is the same as in case 2, and the ventilation is different. Indoor humidity is mostly distributed between 40% and 60%. However, there is obvious condensation in the area around the humidifier, and the humidity in the centre of the room is high.

It can be concluded that the humidity distribution in the room is related to the ventilation mode

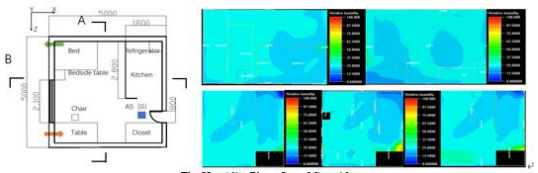
Simulation results and analysis



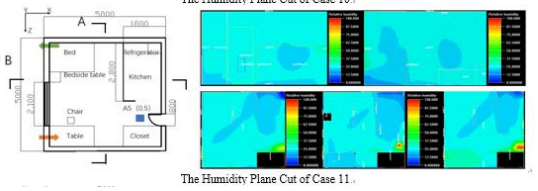
case 1	no humidifier		
case 2	A1(0)	case 12	B1(0)
case 3	A1(0.5)	case 13	B1(0.5)
case 4	A2(0)	case 14	B2(0)
case 5	A2(0.5)	case 15	B2(0.5)
case 6	A3(0)	case 16	B3(0)
case 7	A3(0.5)	case 17	B3(0.5)
case 8	A4(0)	case 18	B4(0)
case 9	A4(0.5)	case 19	B4(0.5)
case 10	A5(0)	case 20	B5(0)
case 11	A5(0.5)	case 21	B5(0.5)

In addition, it can be clearly seen in Figure that these four cases are significantly different from other cases.

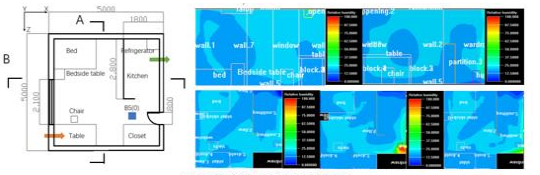
Simulation results and analysis



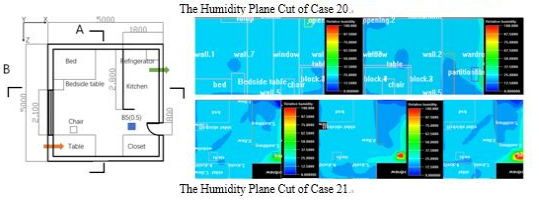
The Humidity Plane Cut of Case 10



The Humidity Plane Cut of Case 11



The Humidity Plane Cut of Case 20



The Humidity Plane Cut of Case 21

As can be seen from Figure, when the humidifier is placed beside the door, the humidifier does not improve the indoor humidity. The humidity in ventilation mode A is higher than the humidity in ventilation mode B. And when the humidifier is placed 0.5 meters above the ground, condensation may occur on the surface of the wardrobe of the room. The reason why the indoor humidity environment is not improved can be considered in the direction of air flow. When the humidifier is placed beside the door, the air at the door of the room is not well mixed. At the same time, the air flow on the refrigerator side is also poor. However, as can be seen from Figure 5, when the humidifier is placed 0.5m from the ground, the humidity of the room is slightly higher than the humidifier placed on the ground.

Conclusion & Summary

Within the scope of the nearby, the air just can hold limited capacity water vapor. The humidifier working efficiency was infected by the different position of humidifiers.

The humidity distribution in the room is related to the ventilation mode, and the flow pattern of the indoor airflow affects the distribution of indoor humidity. The room with the air supply and the return air outlets in the same direction, there is a difference in humidity on both sides of the room, and when the humidifier is used, the humidity on the other side of the room changes little.

The placement height of the humidifier also affects the indoor humidity distribution. When the humidifier is placed in a slightly higher position, the average humidity in the room will increase, and it will be easier to reach a comfortable humidity environment at a sleep height of 0.6 meters. But at the same time, there will be condensation of water near the humidifier.

The placement of the humidifier also has a great influence on the indoor humidity and humidity distribution. when the humidifier is placed beside the door, the humidifier does not improve the indoor humidity. When the humidifier is placed in the centre of the room, the humidity in the room is evenly distributed. When the humidifier is placed close to the wall, condensation occurs near the ground due to the low wall temperature.

Analysis of the Effects of Ventilation Method on Indoor Humidity Distribution and Condensation by CFD method

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Performance of an Advanced Heat Recovery Ventilation System in the Canadian Arctic

Justin Berquist MASc, PEng
Carsen Banister PhD
Dennis Krys

The 40th IAVC Conference
Ghent October 15-16, 2019

National Research Council Canada | Conseil national de recherches Canada

Canada

1

Introduction

- **Northern Canada Housing Challenges**
  - 40% of homes require major repairs[1]
  - 30% are overcrowded[1]
  - 20% contain mould[1]
- **Ventilation Benefits**
  - Can increase indoor air quality
- **Northern Canada Ventilation Challenges**
  - high cost of heating[1]
  - frost prevention challenges
  - lack of maintenance, filters, and parts
  - noise issues[2]
  - occupant interference[2]

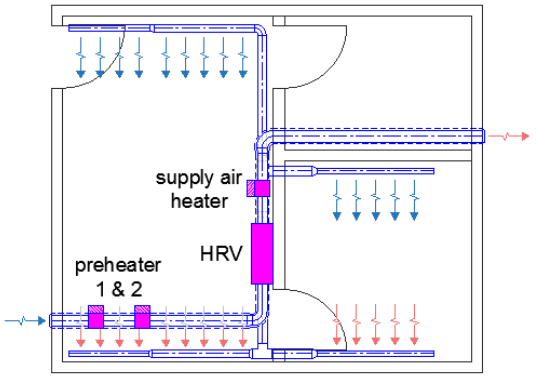


2

Methodology

- **Ventilation System Design**
  - Heat recovery ventilator (HRV), two preheaters, and supply air heater
- **Ventilation System Controls**
  - CO_2-based demand-controlled ventilation strategy
  - Preheater and supply air heater strategy
- **Ventilation System Monitoring**
  - CO_2-based DCV control strategy performance
  - HRV, preheater, and supply air heater performance
  - Ventilation system performance

Ventilation System Design





Ventilation System Controls

- **Demand-controlled ventilation strategy**

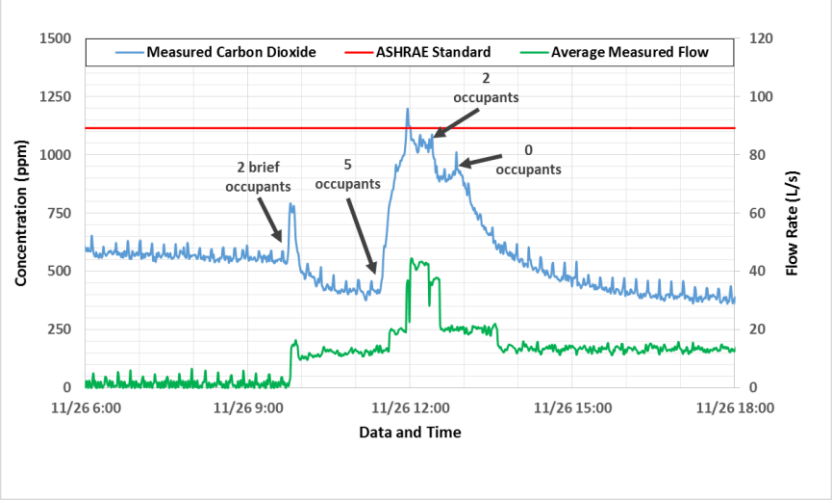
HRV mode	Airflow rate (L/s)	CO_2 concentration thresholds (ppm)	
		When rising	When falling
Fan speed 1	15.5	-	550
Fan speed 2	22.0	700	850
Fan speed 3	40.5	1000	-

- **Preheater and supply air heater strategy**
  - static minimum preheat temperature of -5 °C
    - proportional integral derivative (PID) control
  - static minimum supply air temperature of 18 °C
    - factory supplied thermostat control

Ventilation system monitoring

- **CO_2-based DCV control strategy performance**
  - CO_2 monitoring and manually recording occupancy
- **HRV performance**
  - energy consumption and sensible recovery efficiency monitoring
- **Preheater and supply air heater performance**
  - energy consumption monitoring
- **Ventilation system performance**
  - sensible recovery efficiency monitoring

Results & Discussion
CO_2-based DCV System Monitoring



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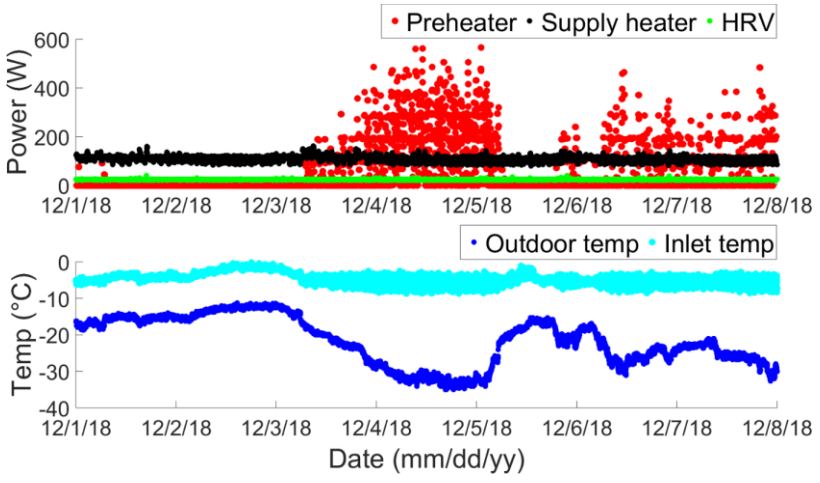
Results & Discussion
Ventilation System Monitoring



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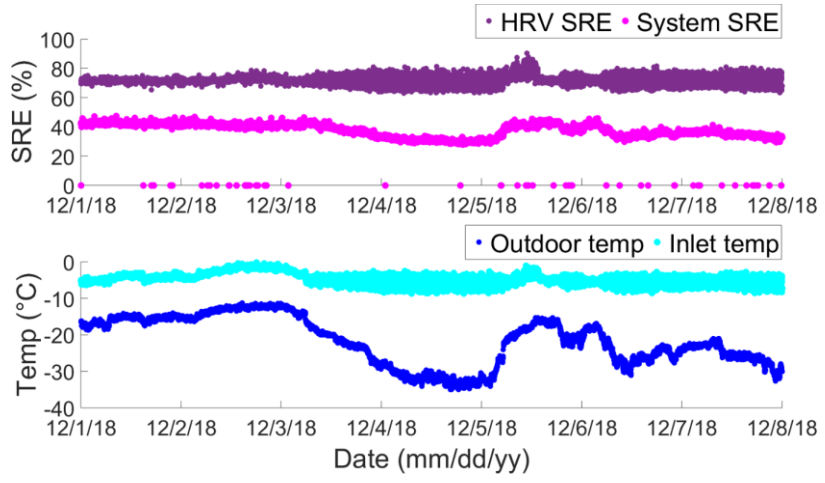
Results & Discussion
Ventilation System Monitoring



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Summary & Conclusion

- **Experimental DCV system design**
  - heat recovery ventilator, two preheaters, a supply air heater, and a carbon dioxide sensor, temperature sensors, and a microcontroller for custom control
- **Experimental DCV system monitoring**
  - thermocouples, and airflow sensors, and current transducers
  - short-term monitoring demonstrated the
    - viability of low-cost residential DCV in the Canadian Arctic
    - capability of preheat as a frost prevention method in the Canadian Arctic
- **Future Work**
  - long-term monitoring is on-going
  - comparison of frost prevention methods: preheat and recirculation

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THANK YOU

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Long-term Performance and Resiliency Testing of a Dual Core Energy Recovery Ventilation System for the Arctic

Boualem Ouazia, Chantal Arsenault, Yunyi Li, Michael Brown, Gerald Kolsteren, Christopher Chisholm

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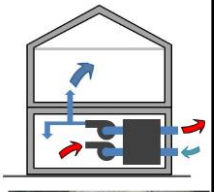
Introduction
Project Motivation

- Conventional HRVs/ERVs are a mature and proven technology for Canadian homes
- Underperform and are plagued with problems when operating in Canada's Far North and Arctic
- Performance achieve to date has been inadequate due to equipment failures (freezing of cores, etc.)
- Frost control strategies often undermine ventilation rate requirement
- Inadequate ventilation contributes to poor IAQ and mold, and to increased cases of serious health issues
- At present, no HRVs/ERVs designed/manufactured, certified to meet rigorous requirements for operation in the Arctic[1]







[1] CMHC's survey of HRV/ERV performance issues in Canada's Near North and Far North (2016)

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Methodology

- Identify novel air ventilation systems for housing in the Arctic
- Lab evaluation using climatic chambers and an HRV/ERV test rig

Heating Mode with	Indoor Conditions	Outdoor T [°C]
Conditions Identified by CSA-C439/HVI	22°C & 40%	0, -10, -20, -30, -35
Identified northern conditions	25°C & 55-65%	0, -10, -20, -30, -35

- Side-by-side testing of novel technology vs. conventional HRV or ERV unit
- Deployment and extended monitoring of novel technology in the Arctic for proven performance and resiliency



Lab Climatic Chambers



CCHT



Triplex Cambridge Bay NU

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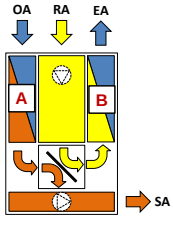
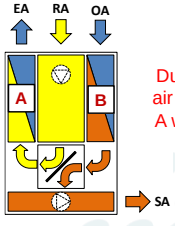
Dual Core Energy Recovery System
Principle of Function

- As one core is defrosting, the other core is used to pre-condition outdoor air (the active core).
- As the active core becomes frosted up, a damper switch the air flow to the core that was defrosting.
- The ventilation flow rate is maintained as the outdoor air directed to each core in turn.

During sequence 1, warm exhaust air (RA) from indoors charges Core B with heat and Core A discharges heat to supply air (SA)





During sequence 2, warm exhaust air (RA) from indoors charges Core A with heat and Core B discharges heat to supply air (SA)

The thermostat 1 in the SA stream is set to 15°C and thermostat 2 in the EA stream is set to 20°C.

- Lower than 20°C - Energy Recovery Mode (cycling every 60s)
- Higher than 20°C and the SAT is higher than 15°C - Free Cooling Mode (cycling every 3 hours); and
- Higher than 20°C and SAT is lower than 15°C - Energy Recovery Mode until the SA T becomes higher than 15°C then it will revert to Free Cooling Mode.

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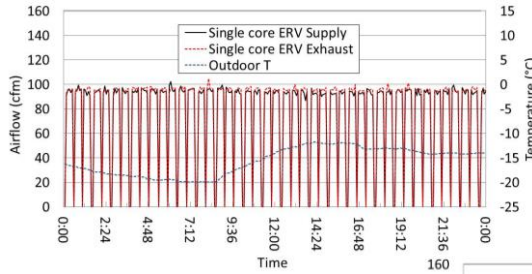
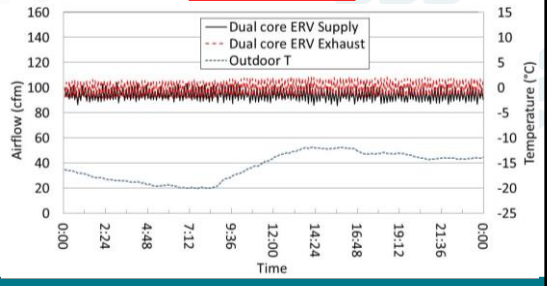
Results from Side-by-side Testing (winter 2019)

Ventilation Rate

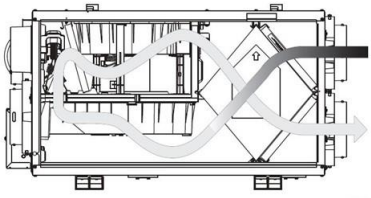


Recirculating exhaust warm air temporarily through the core to melt ice

Dual Core ERV



Single Core ERV



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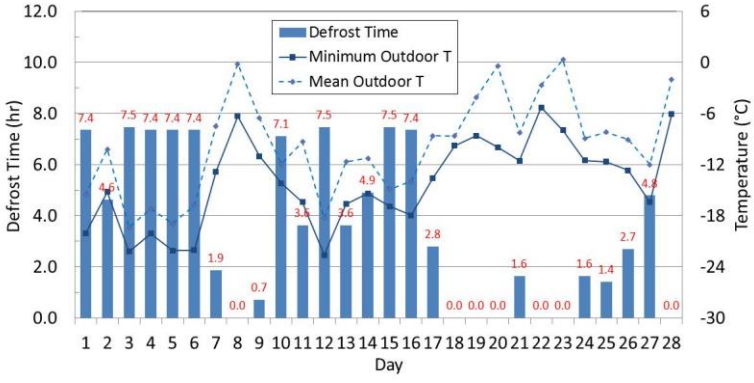
Results from Side-by-side Testing (winter 2019)

Defrost Time of Single Core ERV

Side-by-side Testing Period: January 17th to February 12th, 2019



Single core ERV was 22% of the time (up to 7.5 hours/day) defrosting and not supplying outdoor air to the house

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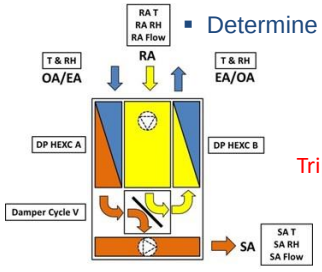
Extended Monitoring in the Arctic

Cambridge Bay (Nunavut)

- Provide operational evidence
- Determine resiliency & durability



Triplex on CHARS Campus in Cambridge Bay











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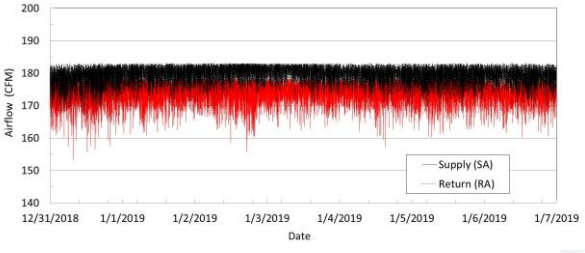
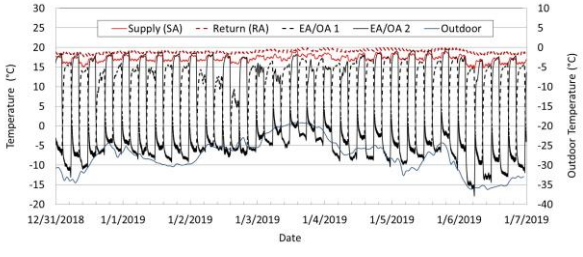
Arctic Monitoring (31/12/2018 to 06/01/2019)

Energy Recovery Mode (cycling every 60 seconds)





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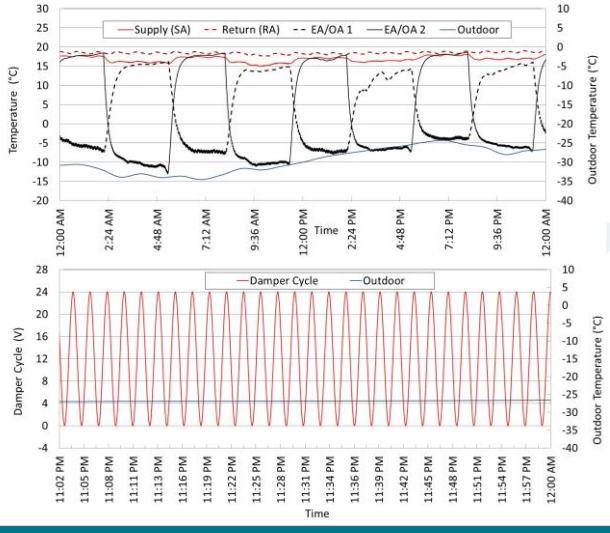
Arctic Monitoring (31/12/2019)

Energy Recovery Mode (cycling every 60 seconds)



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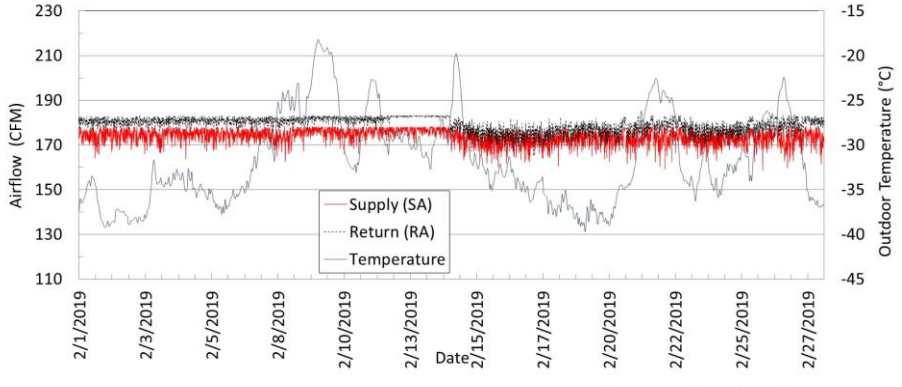
Arctic Monitoring (February 01-28, 2019)

Energy Recovery Mode (cycling every 60 seconds)



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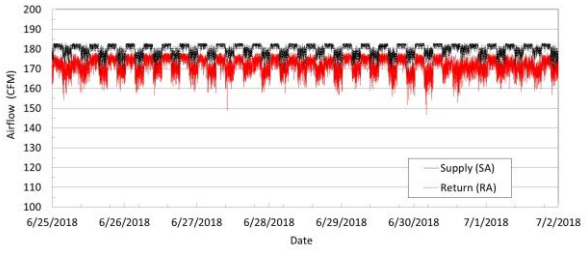
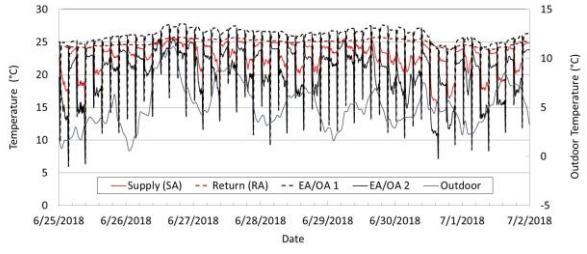
Arctic Monitoring (25/06/2018 to 01/07/2018)

Free cooling mode (cycling every 3 hours)





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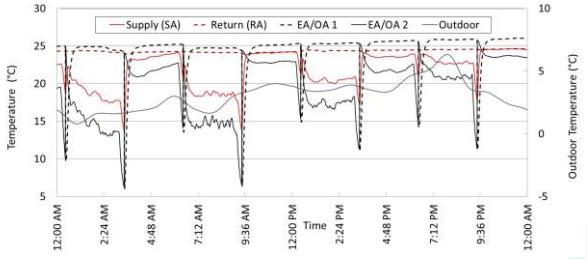
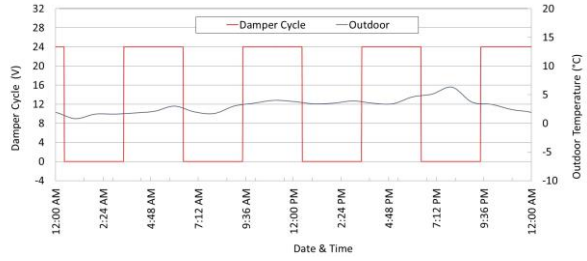
Arctic Monitoring (25/06/2018)

Free cooling mode (cycling every 3 hours)





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Conclusions

- Extended monitoring in the Arctic for three heating seasons, 2017-18, 2018-19 and 2019-20,
- Frost-tolerant and capable of withstanding outdoor temperatures below -40°C,
- Without deteriorating its thermal and ventilation performances,
- Continuous supply of outdoor air without stopping to defrost,
- Performance and resiliency proven under harsh Arctic operating conditions,
- Viable solution to housing ventilation in the Arctic to ensure adequate ventilation that will improve IAQ and health in northern communities



Thank you

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EXPERIMENTAL INVESTIGATION OF FROST FORMATION ON AIR TO AIR COUNTER FLOW HEAT EXCHANGER IN AIR HANDLING UNIT AND CLIMATIC INFLUENCE ON DRY, WET, FROST OPERATION CONDITION

40TH AIVC CONFERENCE, GHENT

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1

Subject under investigation

Frosting problem on high efficient air to air counter-flow heat exchanger.

1. Experimental tests on a counter-flow plate heat exchanger in a climatic chamber.



2. Percentage of operation condition of the exchanger – dry, wet and frost, across:

- Southern Scandinavia
- Central Europe
- Southern Germany and Austria
- Scotland



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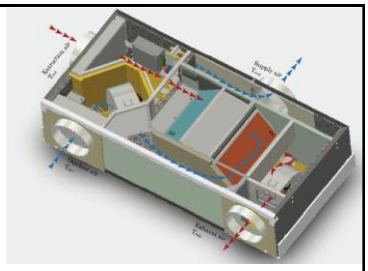
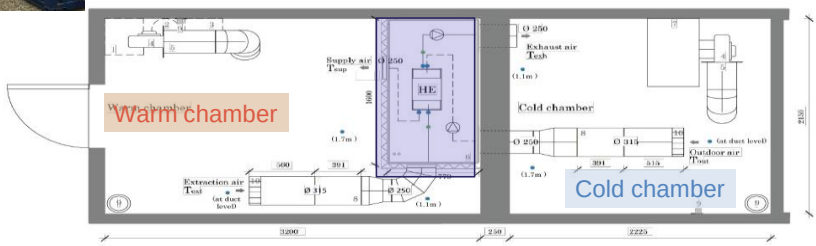
Measurement set up





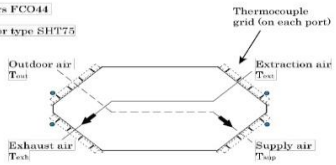


1 Domestic water pump
2 Water heater
3 Electrode boiler humidifier
4 Centrifugal fan
5 Duct electric heater

6 Airmaster air handling unit
Type AM 500 HDIDE
7 Cooling unit
8 Lindab UltraLink Sensor FTSU
9 Air vent (infiltration dampers)
10 Honeycomb flow straightener

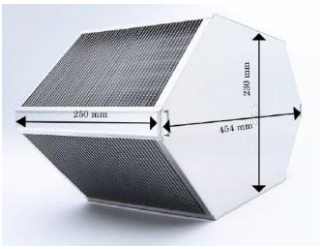
50mm polystyrene
Thermal conductivity 0.033 W/(mK)
Thermal resistance of at least 1m²K/W fulfilled

- Differential pressure measurement
  Differential pressure transducers FCO44
- Relative humidity measurement
  Sensirion digital humidity sensor type SHT75
- Temperature measurement
  Type K thin thermocouples



16 thermocouples on each port

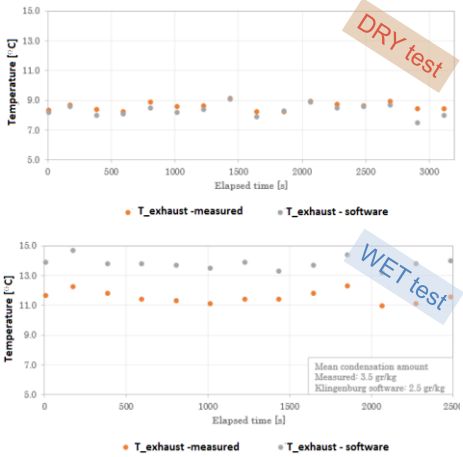
Counter flow heat exchanger investigation



$\eta_{\_}$ measured in dry test = 77% (given 81%)
$\eta_{\_}$ measured in wet test = 81% (given 82%)

Measurements according to:
Danish Standard. DS/EN 13141-8:2014
Dansk Standard. DS/EN 308:1997
European Standard. EN 306:1997

Software validation



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Determining conditions that would result in frost formation

Analysis of indoor humidity vs. outdoor temperatures

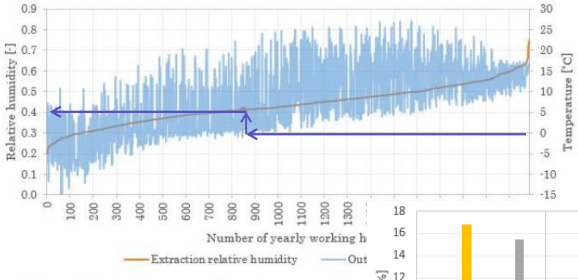
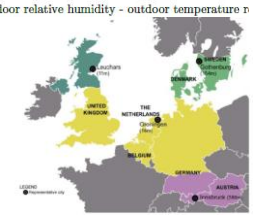
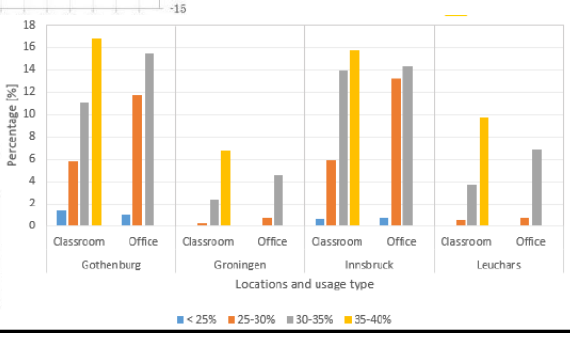


Figure 7.1: Indoor relative humidity - outdoor temperature r



Dynamic models with realistic loads and occupancy schedules have been created.



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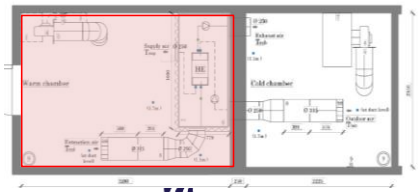
System tuning

Frost formation test condition

EXPERIMENT	INDOOR PARAMETERS	EQUIVALENT TO:
CONDITION 1	22 °C and 22 % RH	22 °C and 22 % RH
CONDITION 2	16 °C and 38 % RH	22 °C and 27 % RH
CONDITION 3	15 °C and 46 % RH	22 °C and 30 % RH
CONDITION 4	16 °C and 58 % RH	22 °C and 40 % RH

the same absolute humidity



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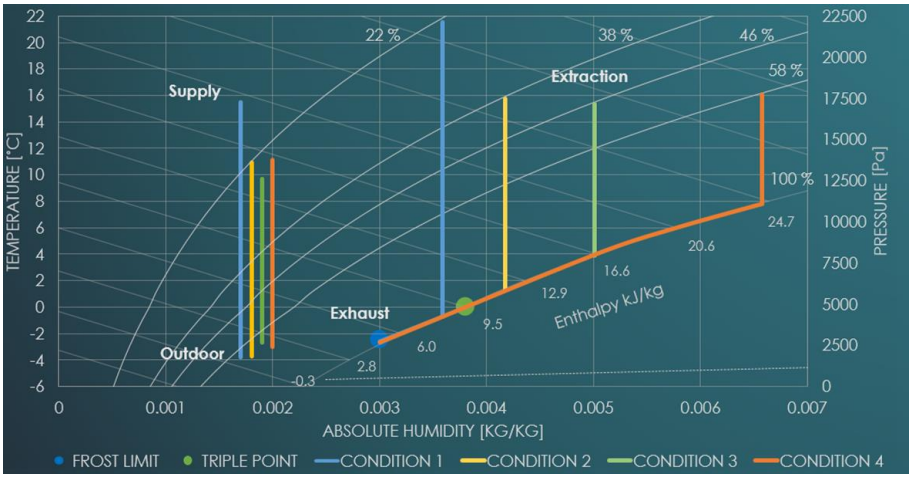
Results



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Results – temperatures on the exhaust port

Condition 1: 22˚C / RH 22 %

Balanced flow

-1.2	-2.3	-2.5	-2.3
0.1	-0.3	-0.5	-0.5
1.8	1.5	1.2	1.2
3.8	3.1	3.1	3.3

Condition 2: 16˚C / RH 38 %

Unbalanced flow

-1.7	-2.2	-2.4	-2.4
-0.3	-0.6	-0.8	-1.0
1.0	0.8	0.3	0.5
2.4	1.6	1.6	1.7

Condition 3: 15˚C / RH 46 %

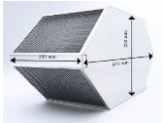
Unbalanced flow

-1.6	-1.8	-2.2	-1.9
-0.4	-0.9	-1.4	-0.7
0.8	0.4	-0.1	0.2
2.0	1.5	1.3	1.6

Condition 4: 16˚C / RH 58 %

Unbalanced flow

-1.2	-2.0	-2.4	-1.9
1.0	-1.5	-1.7	0.2
3.6	0.4	0.0	2.2
5.4	4.1	3.8	4.2





Results – visual







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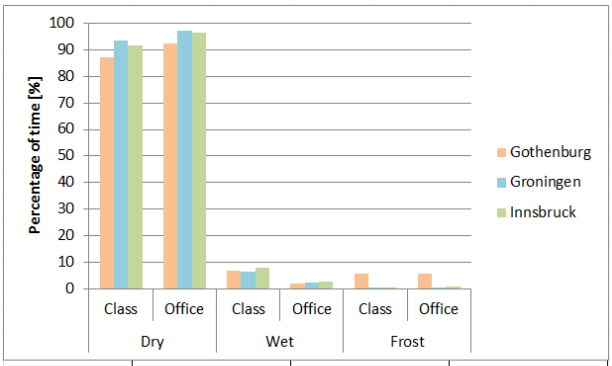
Percentage of operation condition of the exchanger: dry, wet and frost



	Dry		Wet		Frost	
	Class	Office	Class	Office	Class	Office
Gothenburg	87,3	92,4	6,9	1,9	5,8	5,7
Groningen	93,4	97,2	6,3	2,4	0,3	0,3
Innsbruck	91,5	96,4	8	2,9	0,6	0,7

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Conclusions

- Frost appears on the exit region of the exhaust port at ≈ 0 °C mean temperature.
- Frost start forming not always at lowest temperature in exhaust port.
- Relative humidity in the extracted air influences the location where frost starts forming on exhaust port.
- Intake air temperature strongly influences exhaust port temperature – cold bridge. Change of the construction of heat exchanger could increase frost free operation.
- In investigated locations indoor humidity is relatively low 20 – 41 % (at 22 °C indoor air temperature) when outdoor temperature is negative.



Thank you for attention.



Efficiency of heat recovery ventilation in real conditions: feedback from several measurement campaigns

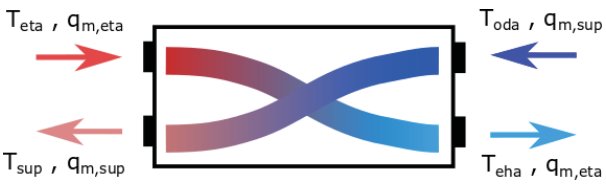
AIVC 2019 - Ghent

sebastien.pecceu@bbri.be

BBRI – Belgian Building Research Institute

HRV efficiency ?

- Efficiency = fraction of the available heat that is recovered



eta : 'extracted air'
eha : 'exhausted air'
sup : 'supply air'
oda : 'outdoor air'

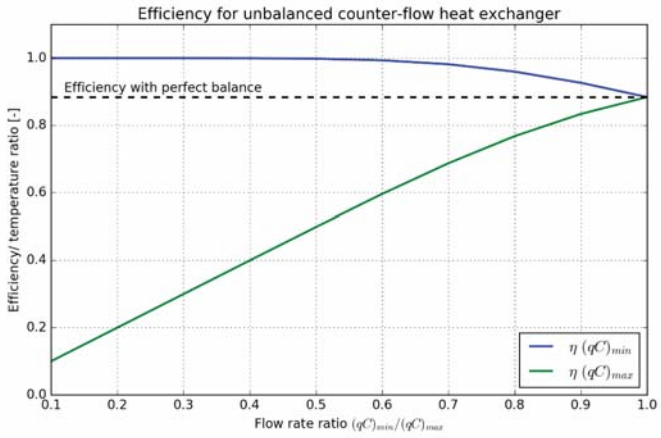
- For perfectly balanced flows: use of "temperature ratios"

$$\eta_{sup} = \frac{T_{eta} - T_{eha}}{T_{eta} - T_{oda}} = \eta_{eha} = \frac{T_{sup} - T_{oda}}{T_{eta} - T_{oda}} = \eta$$

- Around 80% for common HRV units

Impact of imbalance

- The real efficiency depends on the flow rate !
- Temperature ratios (= apparent efficiency) change with flow imbalance



- The real "energy efficiency" (fraction of available energy that is recovered) is the lowest one

Measuring HRV unit efficiency on site?

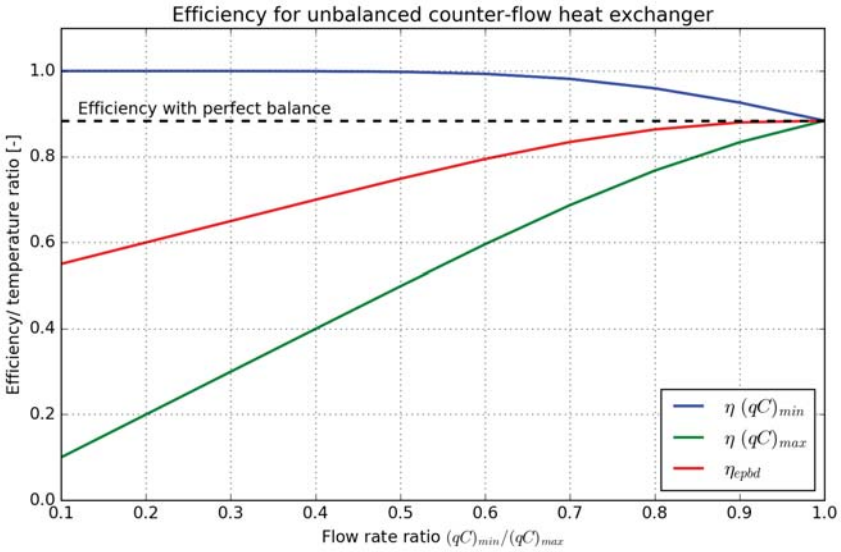
- Continuous flow measurement difficult in practice → measurement only based on temperatures ratios
- How to handle perturbations?
  - Possible flow imbalance
  - Fan heat
  - …

→ Use the average of both temperature ratios

→ Identical the lab test procedure applicable for EPB products in Belgium, see Caillou et al. – AIVC 2012

→ Will be written as η_{epbd} as reference to EBP test procedure

Impact of averaging: illustration with imbalance



- Up to 20% imbalance (x=0.8), the averaged value is close to the "true" value of the unit
- Impact of averaging is similar on fan heat

Measurement campaigns

Campaign 1

- 9 installations
- Measurement inside the unit

Campaign 2

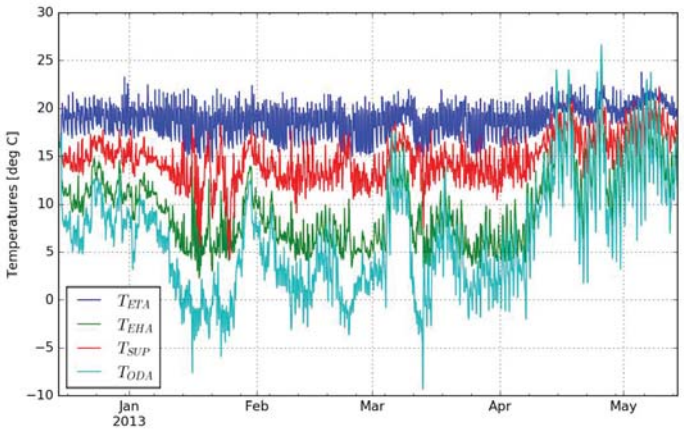
- 4 installations (whose 2 common with Campaign 1)
- Measurement inside the unit

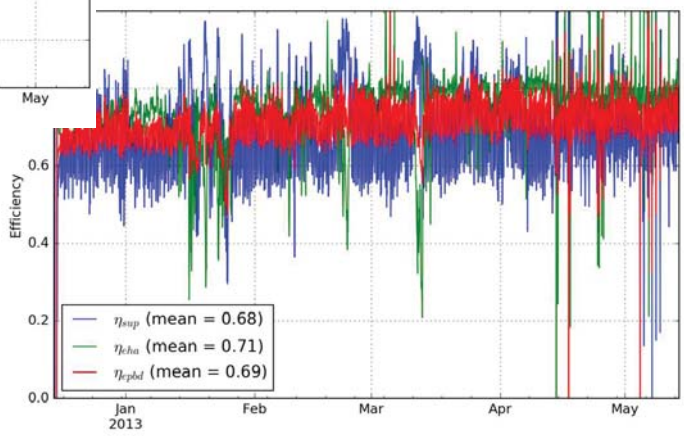
Campaign 3

- 5 installations
- Measurement upwards and downwards the ventilation unit (in ducts)



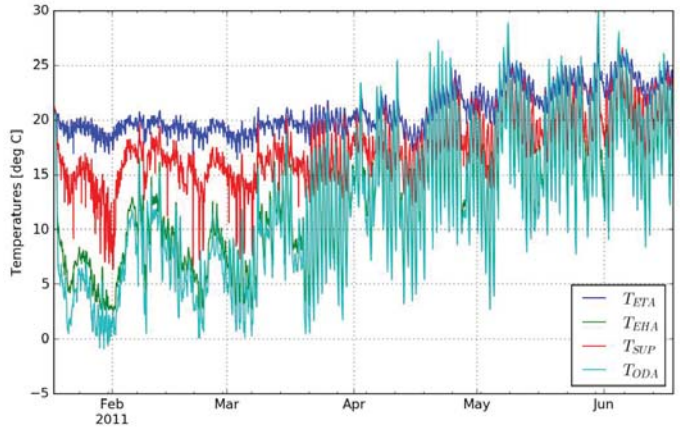
Campaigns 1 & 2 – A "normal" case

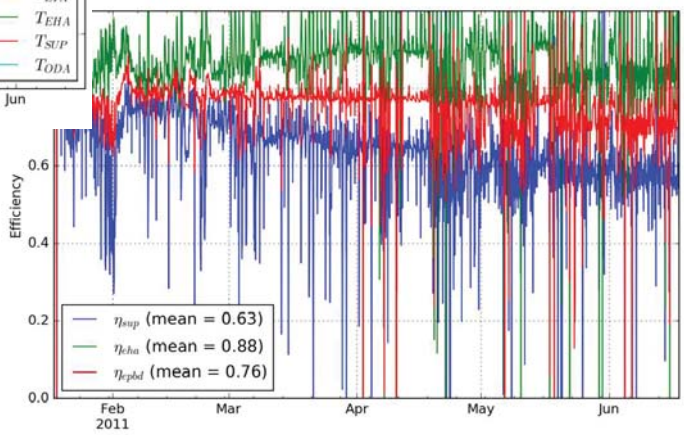




- η_{sup} and η_{eha} very close to each other
- η_{epbd} about 70% in average on the monitoring period

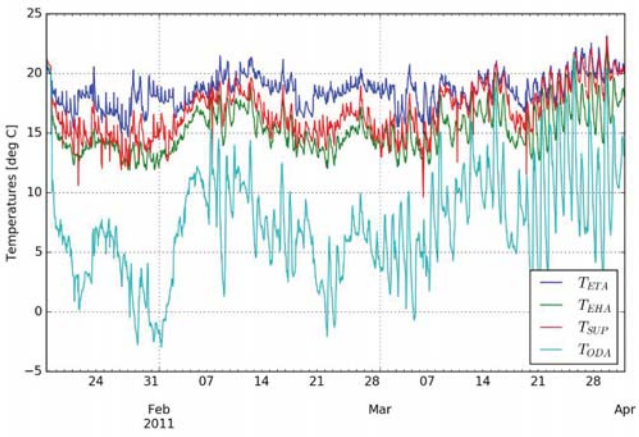
Campaigns 1 & 2 – A "almost normal" case

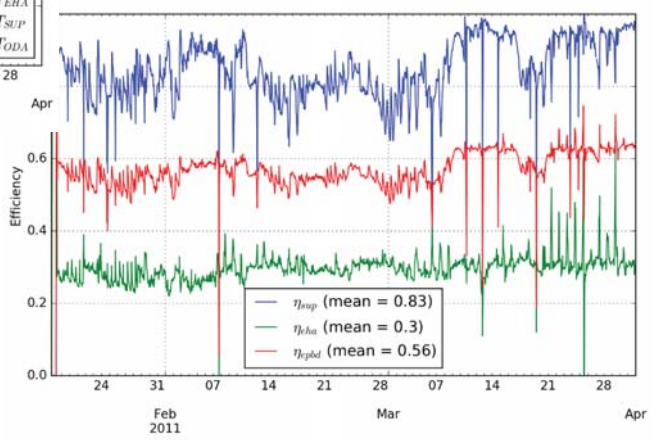




- Average difference of 0.25 between η_{sup} and η_{eha}
- Increasing with time
- η_{epbd} about 75% in average on the monitoring period

Campaigns 1 & 2 – An "abnormal" case

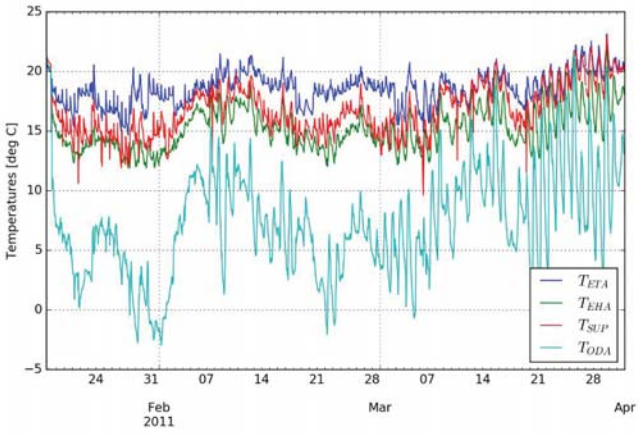




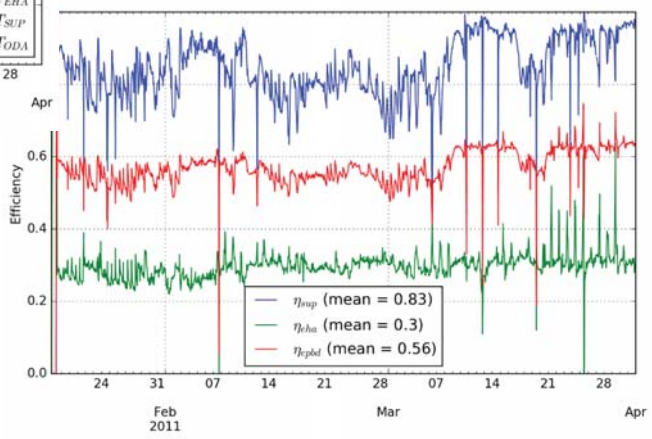
- Obviously malfunctioning
- Known imbalance of 30%
- Not sufficient to explain the malfunctioning

Efficiency of HRV in real conditions – AIVC 2019 – Ghent

Campaigns 1 & 2 – An "abnormal" case



Summary of campaigns 1 & 2:
2 "abnormal" cases out of 11

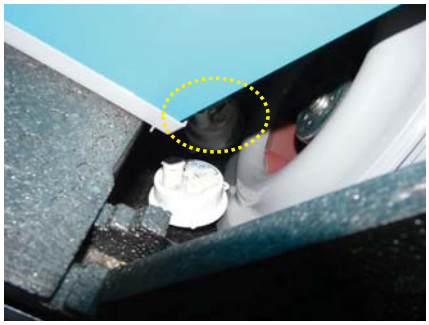


- Obviously malfunctioning
- Known imbalance of 30%
- Not sufficient to explain the malfunctioning

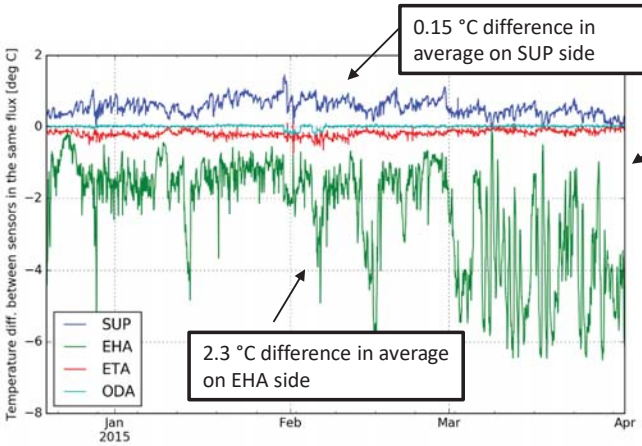
Doubling of the sensors – reliability of inside measurement

- Performed on a single installation
- Target of the measurement: verify the impact of sensor location within the unit



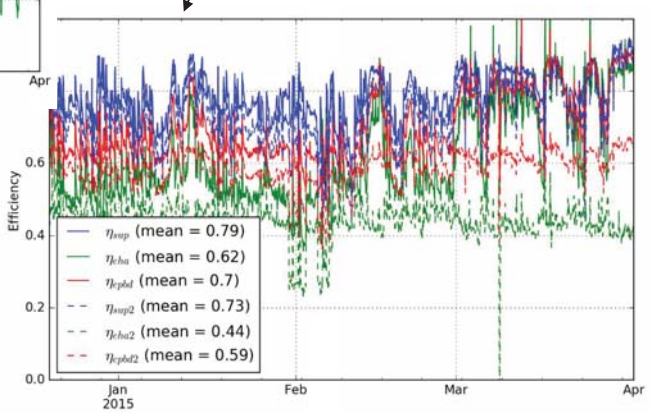


Doubling of the sensors – reliability of inside measurement



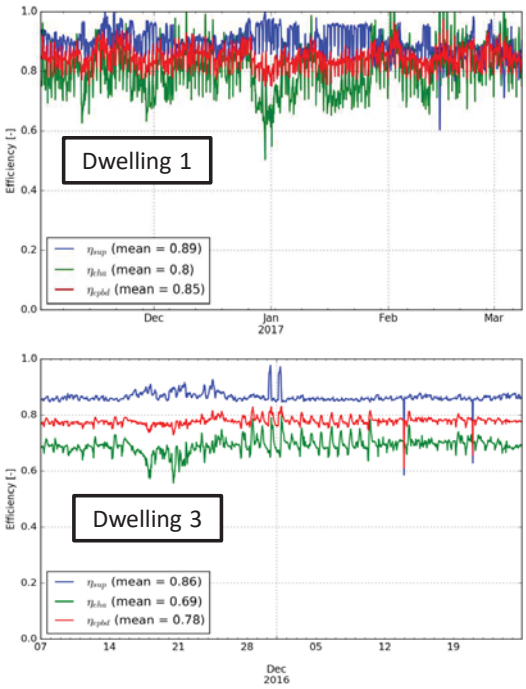
Temperature difference bewteen sensors in the same "flux"

Apparent efficiencies from the two sets of measurements



- Possible causes
  - Heterogeneity of the temperature field at the HX outlet
  - Sensor in contact with thermal bridge/insulation defect in the unit
- Internal measurements to be considered with caution!

Third campaign: measurement outside the unit (in ducts)



Dwelling	1	2	3	4	5
$\eta_{sup,av}$	0.89	0.85	0.86	1.01	0.83
$\eta_{eha,av}$	0.8	0.76	0.69	0.7	0.76
$\eta_{epbd,av}$	0.85	0.8	0.78	0.85	0.8

- 2 different models in the 5 tested units, with both "declared" efficiency of 0.84*
- Qualitatively: more stable measurements

- Average "epbd" values in line with lab measured values
- No "abnormal" cases
- Asymmetry in some cases (imbalance ?)

*following applicable test procedure in Belgian EPB regulation

Conclusions

- Measurement method
  - Measurement inside the ventilation unit can be sensitive to sensor location and is not advised
  - External measurements (in ducts) seem more stable and reliable
- Heat recovery performance
  - Measured performance (of units) on field in line with the lab measured performance
  - Only a few apparently problematic on the selected sample (also possible impact of the measurement method!)

Conclusions

- Measurement method
  - Measurement inside the ventilation unit can be sensible to sensor location and is not advised
  - External measurements (in ducts) seem more robust and reliable
- Heat recovery performance
  - Measured performance (of units) on field in line with the lab measured performance
  - Only a few apparently problematic on the selected sample (also possible impact of the measurement method)
- Other factors at the building scale can the global energy efficiency (ductwork or building airtightness, insulation, etc)!

Thank you for your attention

Sébastien Pecceu – sebastien.Pecceu@bbri.be
BBRI – Belgian Building Research Institute, Belgium

PLEIAQ

IMPACT OF DUCTWORK LEAKAGES ON FAN ENERGY USE IN SINGLE HOUSES

AIVC 2019 – VALERIE LEPRINCE (PLEIAQ)

JELMER DE JONG (BRINK) , MARCUS LIGHTFOOT (UBBINK)

1

PLEIAQ

Introduction

There are a number of studies that demonstrate significant energy use impacts of ductwork airtightness

- up to 50% saving on fan energy use for ductwork class C instead of 1.5*class A (Berthault, 2015)

French ductwork database has shown that

- almost 50% of the single houses tested have a ductwork 2.5 class A or worse. (Moujalled, 2018)

The impact of ductwork leakages is still neglected in most countries (Leprince, 2017)

- above all in residential buildings.
- Not taken properly into account in Energy Performance calculations.







2

PLEIAQ

Objectives of the study

- Explaining the impact of ductwork leakages on required pressure and flowrate at fan
- Calculating the impact of leakages in 4 case studies of single houses with various geometries and ventilation systems.
- Estimating the impact of leakages on the sound pressure in dwellings

3

PLEIAQ

Ductwork leakages and fan energy use

Fan power scale with flowrate multiplied with the pressure at fan

$$P_{el} = \frac{\Delta P * Q}{\eta * 3600}$$

- The more flowrate is needed the more power is needed
- And the more pressure drop the fan has to fight the more power is needed

4

PLEIAQ

Ductwork leakages and fan energy use

Pressure losses in the ductwork are the sum of

- Friction losses (linear losses)
- Dynamic losses (singularity losses)

$$\Delta p = \left(\frac{1000 f}{D_h} + \sum C\right)\left(\frac{\rho V^2}{2}\right)$$

It scales with the square of the flow speed and then with the square of the flowrate

5

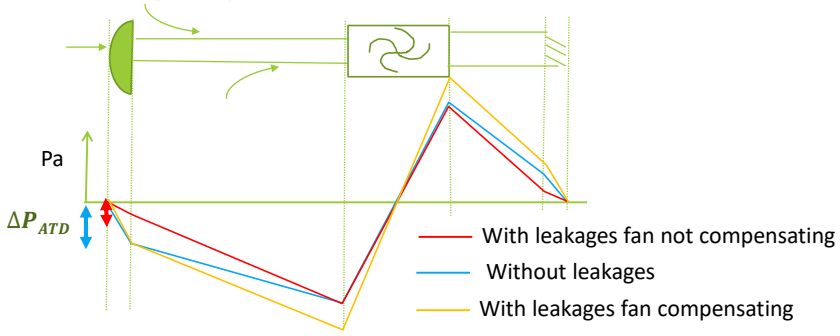
PLEIAQ

Ductwork leakages and fan energy use

Fan and pressure losses

- To maintain hygienic flowrate the fan needs to compensate both additionnal flowrate and additionnal pressure drop
- Around 10 Pa needed at ATD (fix ATD)

$q_{ATD} = C\ \Delta P_{ATD}^{\ n}$

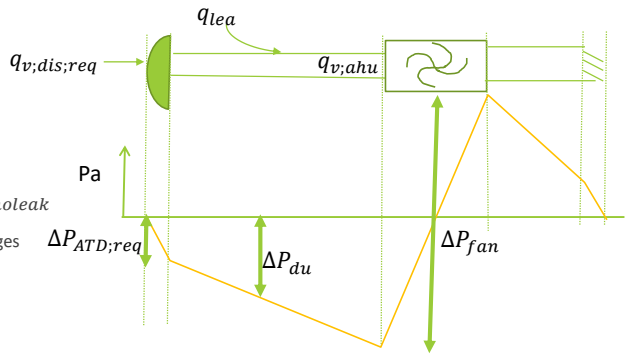


6

Ductwork leakages and fan energy use

Equations

- $q_{v;ahu} = q_{v;dis;req} + q_{lea}$
- $q_{lea} = A_{du} * c_{lea} * \Delta P_{du}^{ep} * 3600$
  - A_{du}: duct area
  - c_{lea}: leakage coefficient
- $\Delta P_{fan} = \Delta P_{ATD;req} + \left(\frac{q_{v;dis;req}+q_{lea}}{q_{v;dis;req}}\right)^2 * \Delta P_{du;noleak}$
  - $\Delta P_{du;noleak}$: Pressure drop in the ductwork without leakages



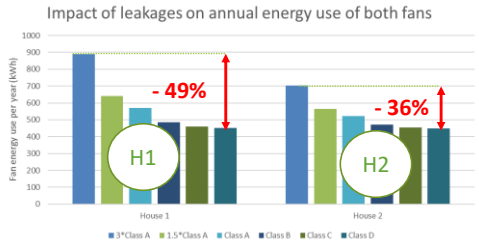
7

Case studies

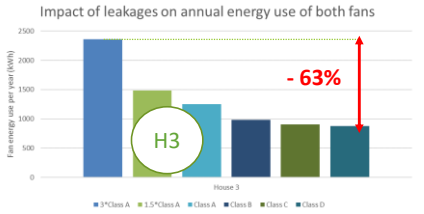
	House 1: Medium sized	House 2: Medium sized	House 3: Large	House 4: Large (Humidity control)
Hygienic flowrate (m³/h)	225	225	300	100
Ventilation kind	HR	HR	HR	Extract only
Required pressure at ATD (Pa)	10	10	10	70
Ductwork properties	Radial air Ø75mm Total length 125 m. Supply =Extract	Trunk & branch air Ø160mm -> 6m Ø125mm -> 40 m Supply =Extract	Radial air Ø75mm Total length 200 m. Supply =Extract	Radial air Ø125mm -> 6m Ø80mm -> 20m Supply =Extract
Ductwork area (each) m²	14.72	9.36	23.6	7.4
Pressure drop in ductwork (without leakages) (Pa)	100	100	150	80

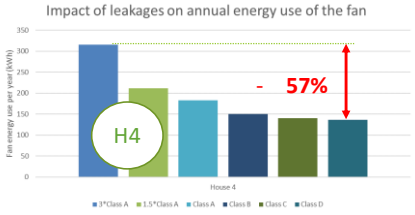
8

Case studies



Fan energy use for ductworks class D are 36% to 63% lower than for ductwork 3*Class A





9

Impact on sound pressure in dwellings

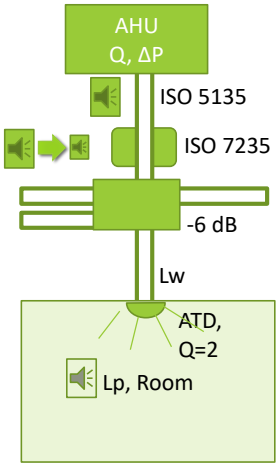
The more flowrate and pressure the fan is producing the more casing radiation (sound power) is produced by the fan.

- Sound pressure according to flowrate and pressure obtains through laboratory measurements

Within the room:

$$L_p = L_w + 10 * \log\left(\frac{Q}{4\pi r^2} + \frac{4}{A}\right)$$

- L_p(dB(A)) Sound pressure in the room
- L_w (dB (A)) Sound power after the distribution box
- Q =2, Coefficient depending of the angle of radiation
- r=1.5 : Distance to the source
- A=20m²Sabine(living-room), 8.5m²Sabine (bedroom) Reference sound absorption area



10

Impact on sound pressure

	HOUSE 1		HOUSE 2		HOUSE 3	
	3*Class A	Class D	3*Class A	Class D	3*Class A	Class D
Required flowrate (m^3/h)	286	226	264	225	424	302
Required pressure (Pa)	172	111	148	110	309	162
Sound power to dwelling (dB)	78.7	73.1	75.5	73.1	80.4	78.7
Sound power to dwelling with A correction and silencer dB(A)	43.9	38.5	41	38.5	46.8	43.9
Sound power to each room (- 6dB)	37.9	32.5	35	32.5	40.8	37.9
Sound pressure in bedrooms dB(A)	35.2	29.8	32.3	29.8	38.1	35.2
Sound pressure in living rooms dB(A))	32.2	26.8	29.3	26.8	35.1	32.2

Measured according to ISO 5135 for the Residential Air Handling Unit Excellent 400 of Brink has been used (provided by manufacturer).

Sound attenuation of the silencer Brink (ISO AKS 1m, diam 160 mm) provided by the manufacturer.

<30 dB(A)	Quiet
30-35 dB(A)	Audible sound
>35 dB(A)	Loud

Conclusions

The study has provided equations to calculate the impact of leakages on fan energy use according to

- the required hygienic flowrate
- the required pressure at ATD
- ductwork properties (area, leakage coefficients, and pressure drop without leakages)

On 4 typical single houses:

- Fan connected to leaky ductwork (3*Class A) can **use 57% and up to 169% more energy** than fan connected to very tight ductwork (Class D), to provide hygienic flowrate.

In houses with a Heat Recovery system

- The sound pressure of the ventilation system in bedrooms can become **loud with a leaky ductwork** instead of quiet with a tight ductwork

The contribution of a solar air heater collector to the cooling load in a Building

Pavlos Toumpoulidis*[1], Argiro Dimoudi[1], Panos Kosmopoulos[2], Stamatis Zoras[1]

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[2]K-eco Projects co, f. Director of the Laboratory of Environmental and Energy Design of Buildings and Settlements, DUTH, Thessaloniki, Greece

*Corresponding Author: ptoumpou@env.duth.gr

40th AIVC - 8th TightVent & 6th venticool Conference
15-16 October 2019, Ghent, Belgium

1

Presentation Outline

Presentation and description of the solar air collector system of test cell ZED-KIM.

Presentation and analysis of the results of the system in order to evaluate the energy efficiency and thermal energy that rejected out of the test cell.

Estimation of the reduction of the cooling load in conjunction with the weather conditions prevailing in the study area.

2

ZED–KIM (Zero Energy Demand-Kimeria)



Location: Campus of the Engineering School, 4 km east of the city of Xanthi, in Greece

3

Description of the solar air collector system

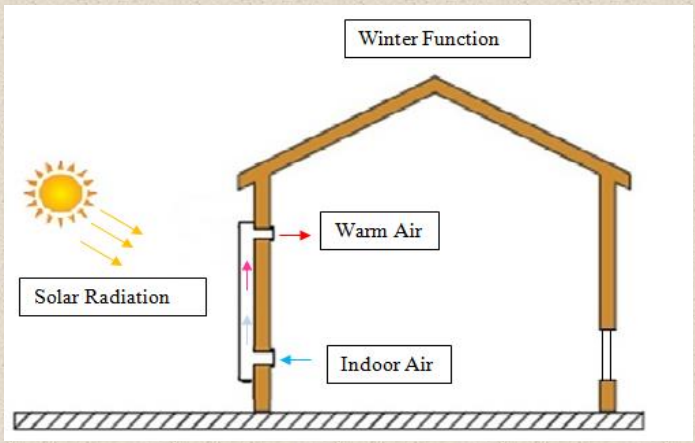


Dimensions:1,54mX0,70mX0,18m
Collector surface: 1,08m^2
Absorber surface: 0,97m^2
Nominal Power: 700W
Stagnation temperature: 155°C
Nominal Air flow: 100m^3/h
PV Panel: 10W

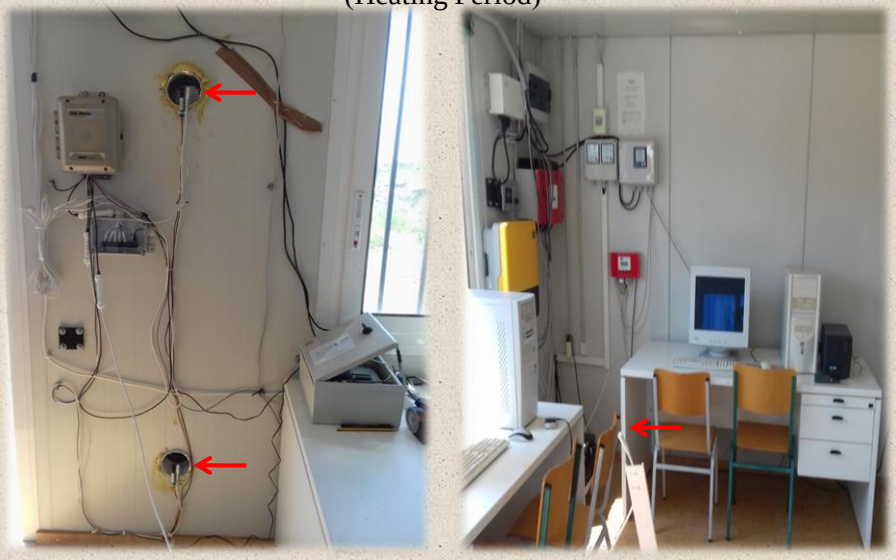


4

Solar air collector system function
(Heating Period)



Interior of Test Cell – Monitoring equipment
(Heating Period)



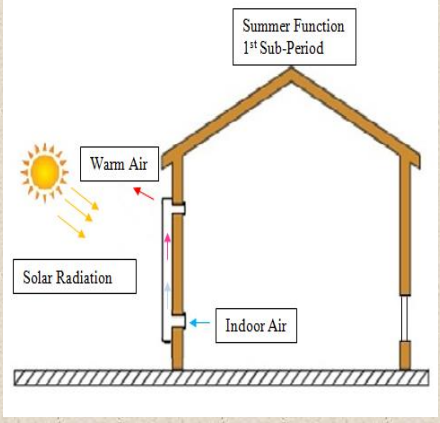
Solar air collector system function
(Cooling Period)

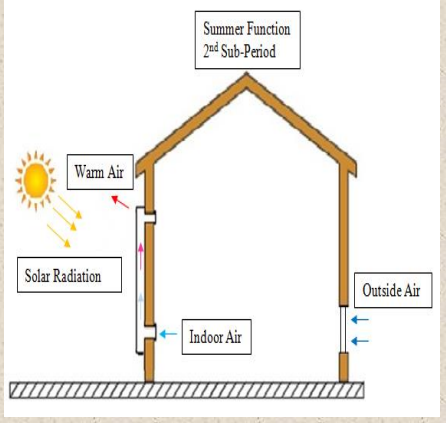





7

Solar air collector system function
(Cooling Period)





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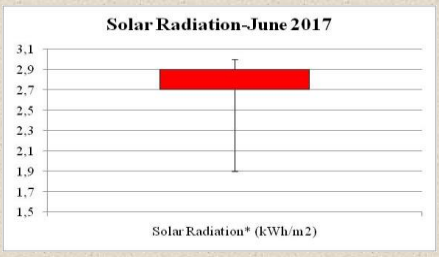
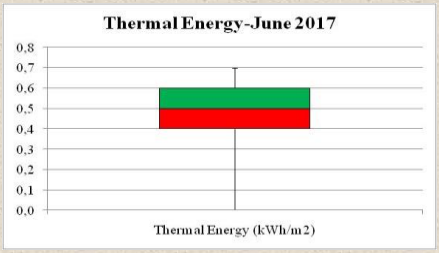
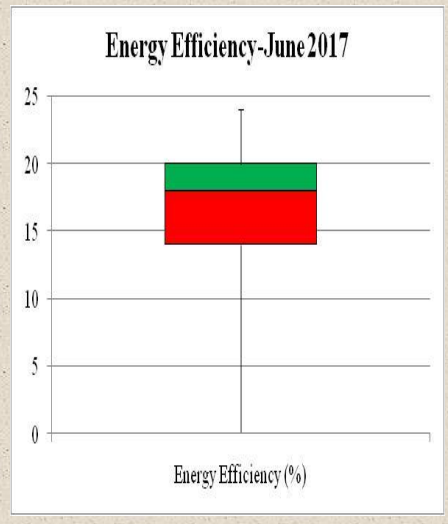
Results







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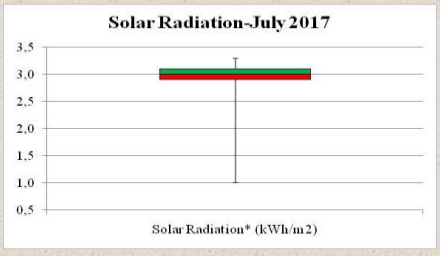
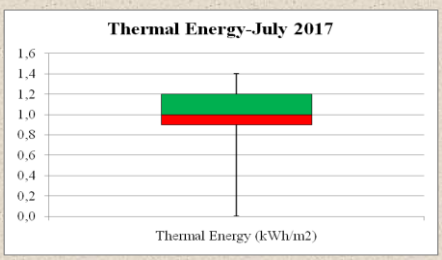
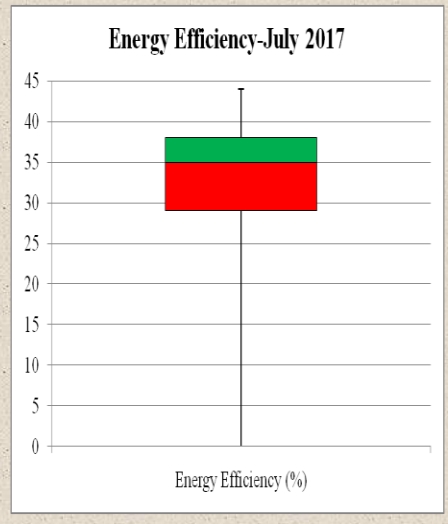
Results







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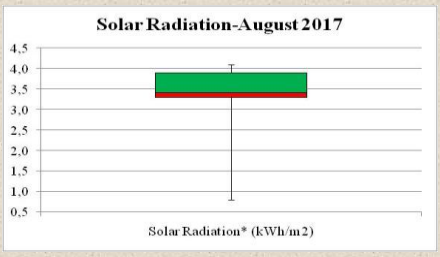
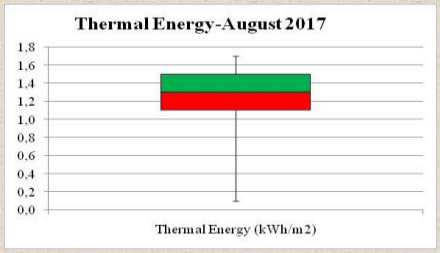
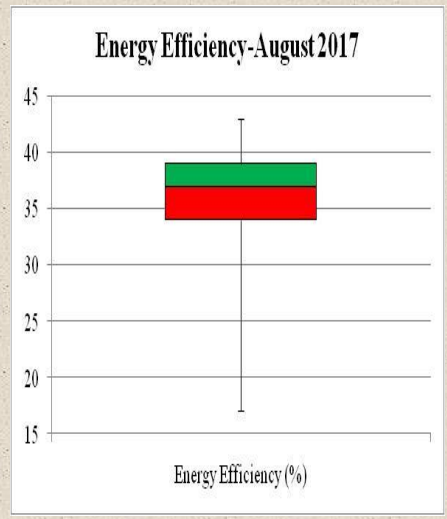
Results







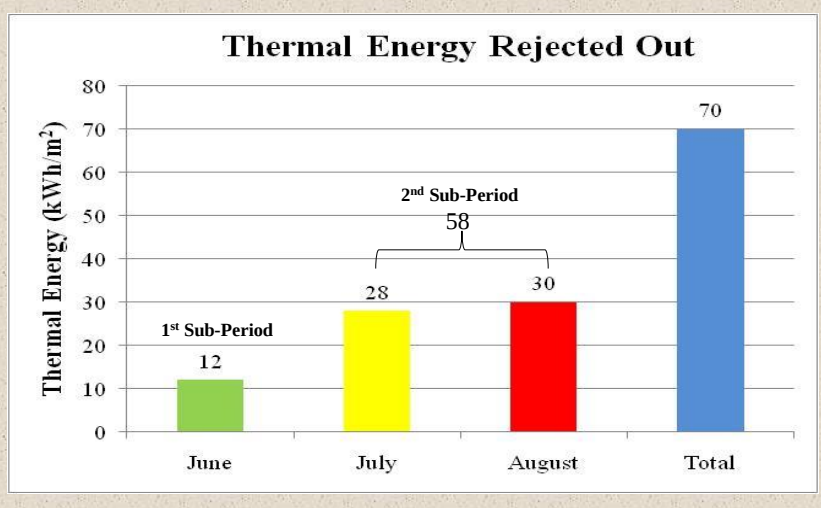
Results

Mean value of solar radiation, thermal energy and energy efficiency of the solar air collector

Month	Solar Radiation* (kWh/m^2)	Thermal Energy (kWh/m^2)	Energy Efficiency (%)
June	2.7	0.5	16
July	2.8	0.9	32
August	3.3	1.2	36
Median Value (Measurements Period)	2.8	0.9	32

*Solar radiation incident to collector surface

Results



13

Results

The average consumption, regarding the cooling load, of a typical household is equal to 2.440kWh/year.

The cooling load for the total area of 20m^2 is equal to 488 kWh/year.

Based on the above and taking into account that the total thermal energy which rejected out using solar collector systems was equal to 70 kWh, a reduction of 15% of cooling load was achieved.

14

Conclusions

The solar air collector system has an important role about the thermal loads that rejected out of the test cell in cooling period.

The use of solar air system in conjunction with other interventions both on building shell and using other passive and active systems, even in climatic conditions such as those that prevailed during the measurement period, it can be lead at a nearly zero energy building.

Thank you for your attention

ptoumpou@env.duth.gr

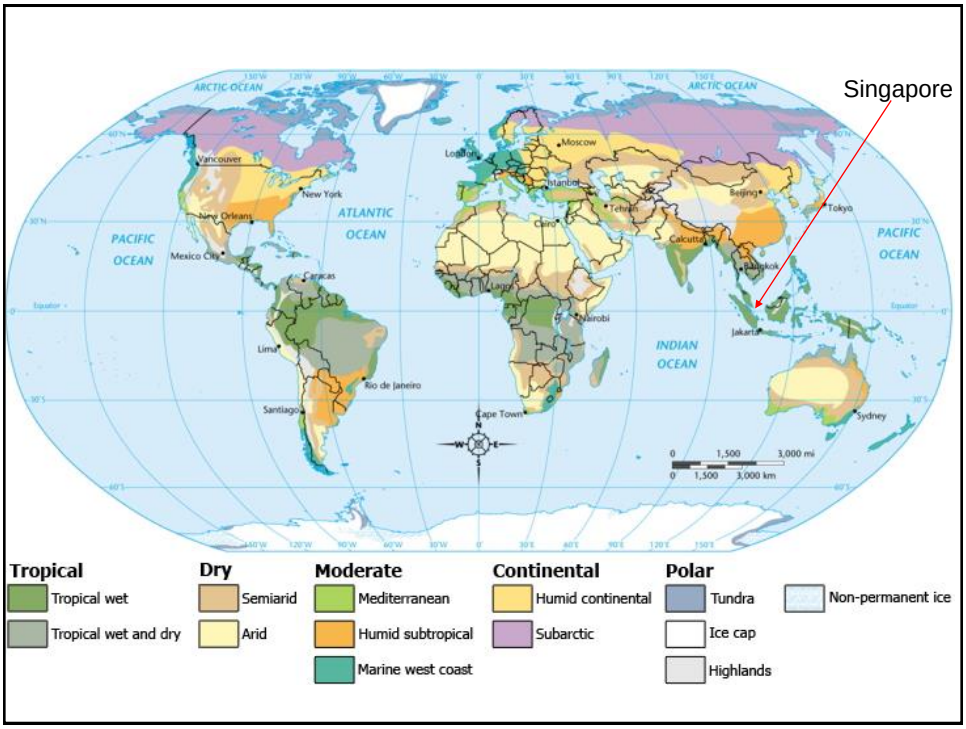
40th AIVC – 8th TightVent & 6th Venticool Conference
From energy crisis to sustainable indoor climate 40 years of AIVC
15-16 October 2019, Ghent, Belgium

Evolution of ventilation strategies in air-conditioned buildings in Singapore – IAQ and Energy perspectives

Chandra Sekhar, PhD
Fellow ASHRAE, Fellow ISIAQ
Professor
Department of Building, School of Design and Environment

NUS National University of Singapore

1



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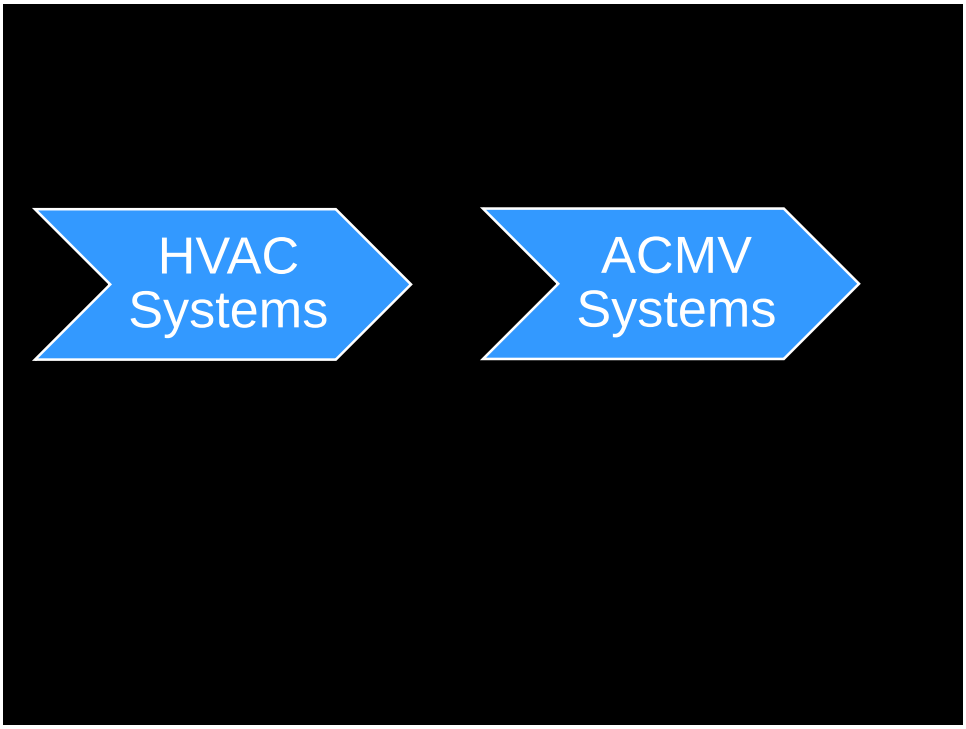
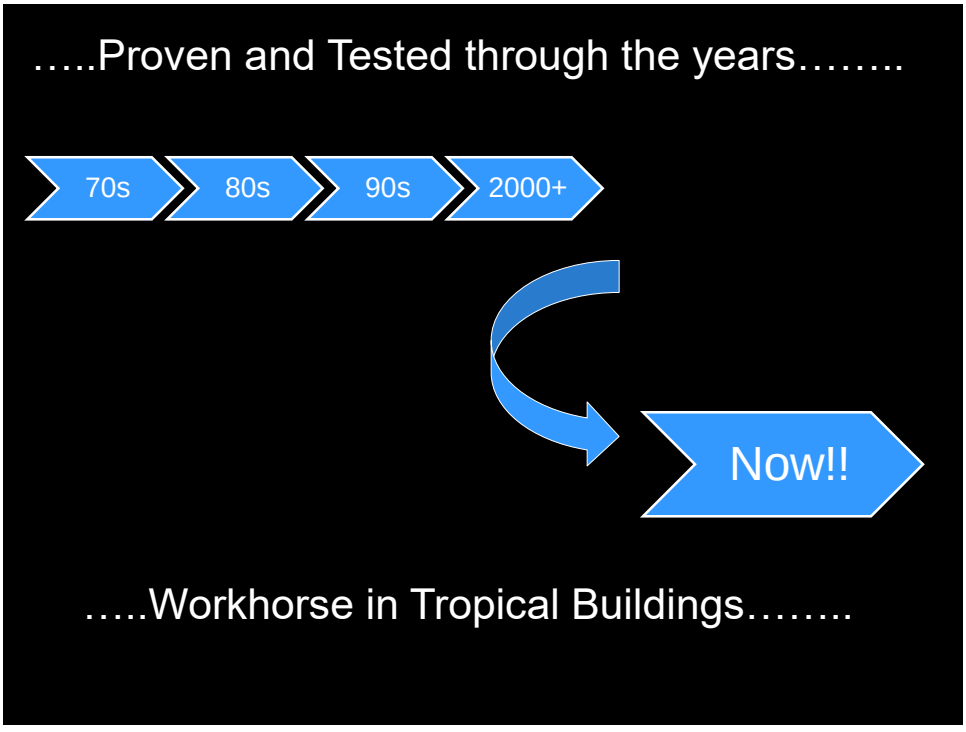
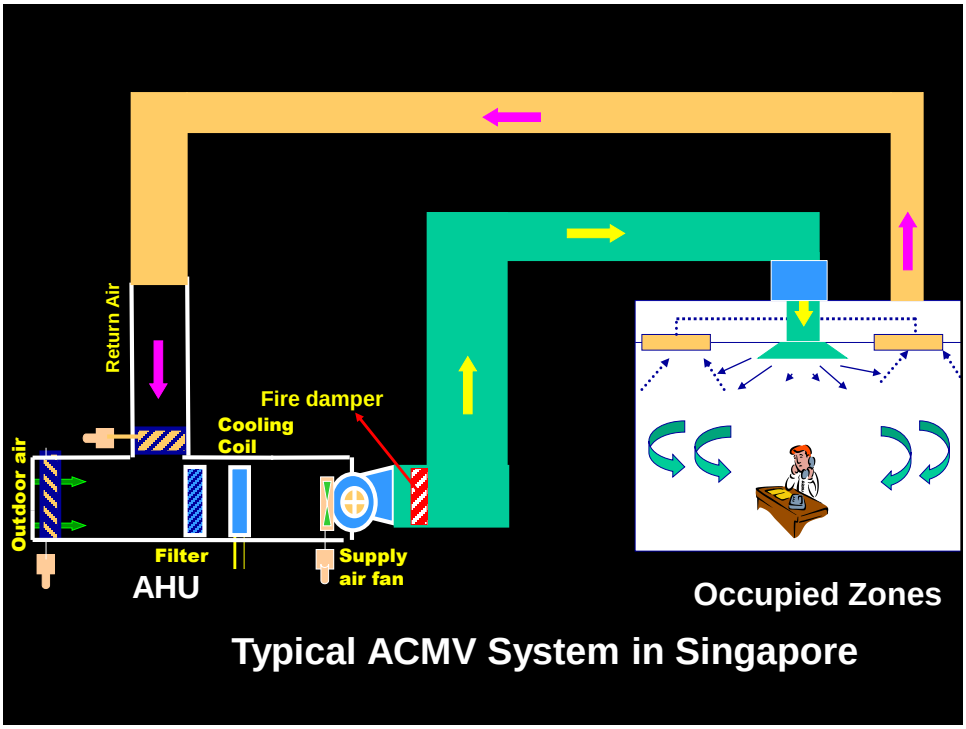

HVAC Systems
ACMV Systems

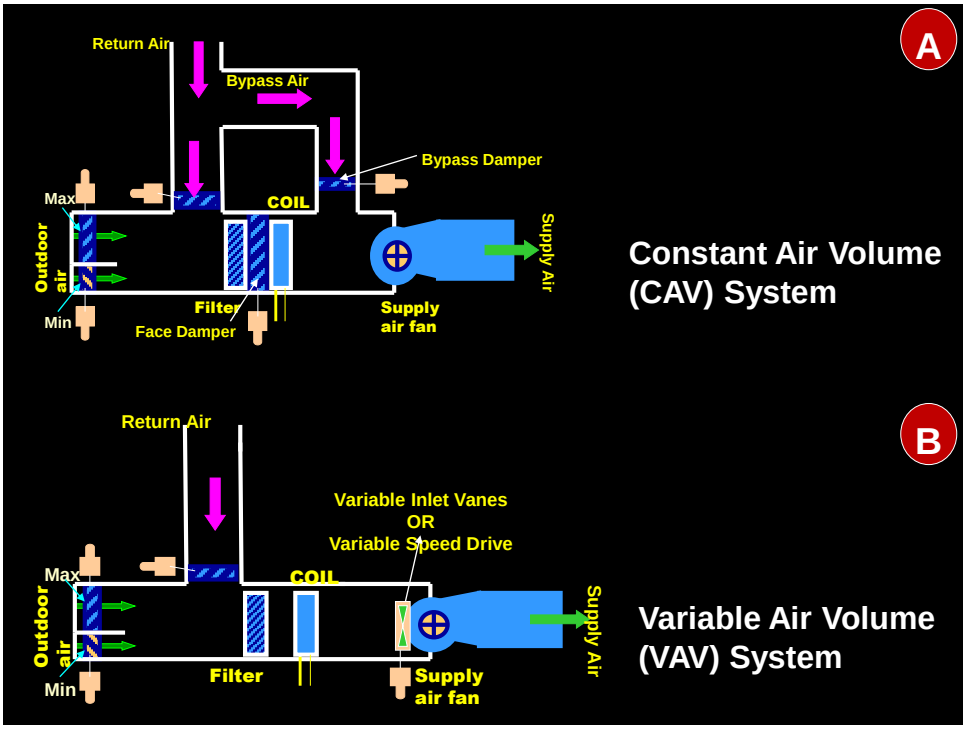
3


.....Proven and Tested through the years.....
70s
80s
90s
2000+
Now!!
.....Workhorse in Tropical Buildings.....

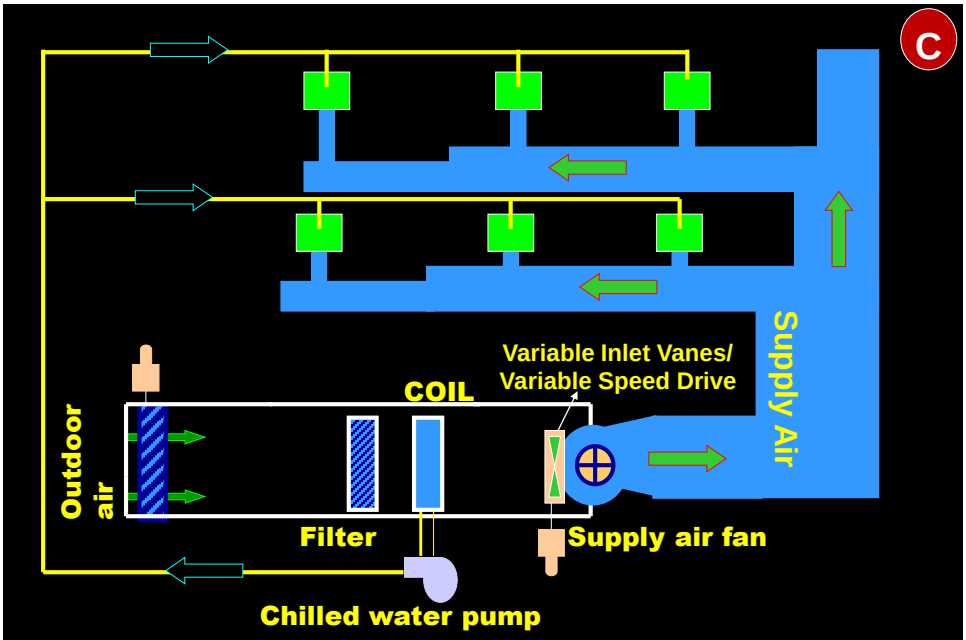
4


Return Air
Fire damper
Cooling Coil
Outdoor air
Filter
Supply air fan
AHU
Occupied Zones
Typical ACMV System in Singapore

5


A
Return Air
Bypass Air
Bypass Damper
Max
COIL
Outdoor air
Supply Air
Min
Filter
Face Damper
Supply air fan
Constant Air Volume (CAV) System
B
Return Air
Variable Inlet Vanes
OR
Variable Speed Drive
Max
COIL
Outdoor air
Supply Air
Min
Filter
Supply air fan
Variable Air Volume (VAV) System

6



Primary Air Fan Coil System

7

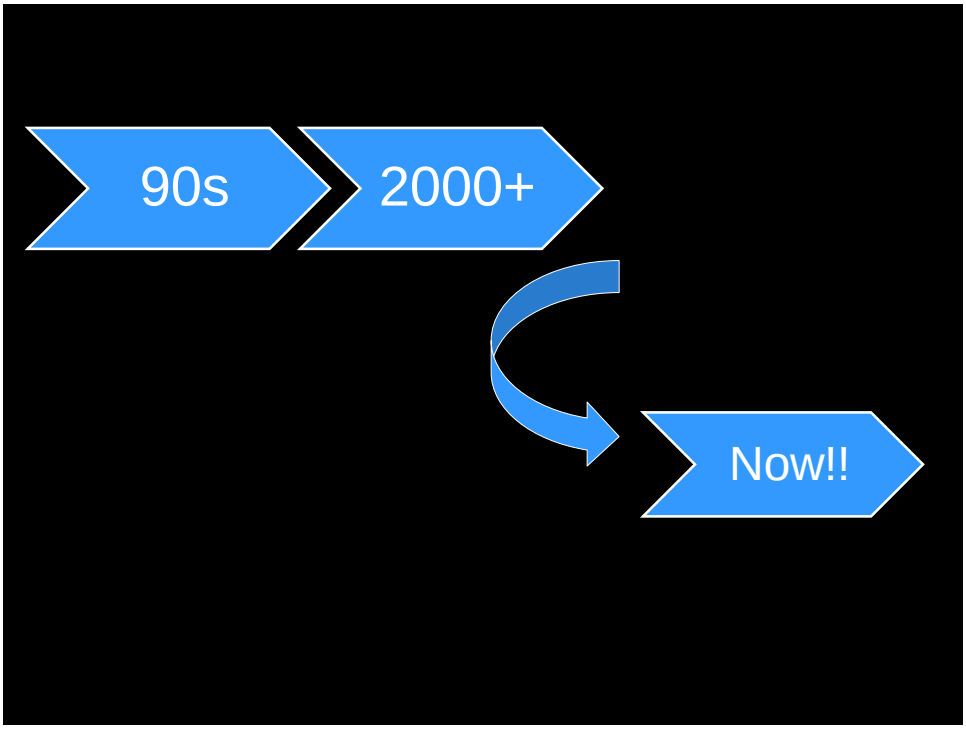
Studies from Singapore Air-conditioned Buildings in mid-late 90s

Table 7 Summary of measured and computed parameters

	Singapore audit (range of mean values of five buildings)
Carbon dioxide	506–797 p.p.m.
Carbon monoxide	0.8–1.6 p.p.m.
Total volatile organic compounds (TVOC) (toluene equivalent)	0.35–2.25 p.p.m.
Particulate matter	20–35 $\mu g/m^3$
Operative temperature	22.3–24.2°C
Air velocity	0.13–0.18 m/s
Outdoor air change rate	0.34–2.6/h
Outdoor air flow rate	0.37–1.14 lps/m^2
Global air exchange effectiveness (AEE_G)	0.96–1.8
Occupant level air exchange effectiveness (AEE_{OL})	0.74–1.11
Localized air exchange effectiveness (AEE_G)	0.58–1.23
Indoor pollutant standard index (IPSI)	1.47–3.12
Energy index	12.1–55.1 kW h/m^2/month

Sekhar, S. C., Tham, K. W., & Cheong, K. W. (2003). Indoor air quality and energy performance of air-conditioned office buildings in Singapore. INDOOR AIR, 13(4), 315-331.

8



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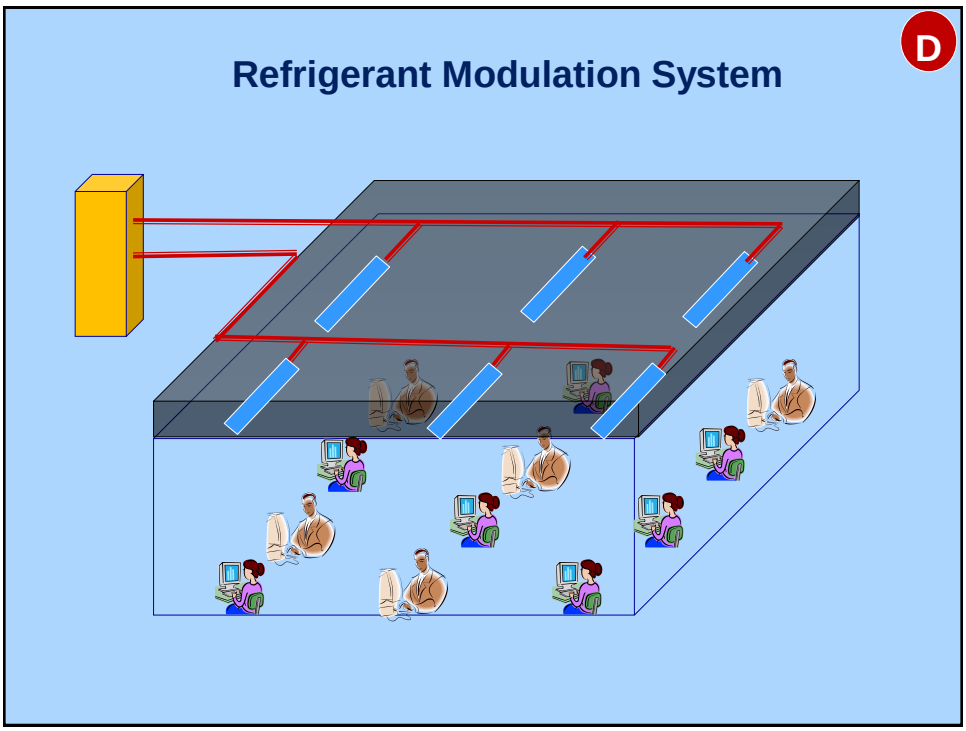
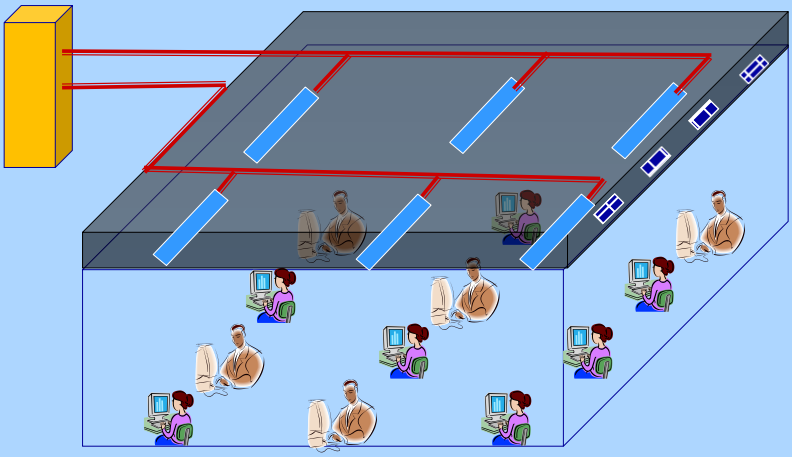


10

Refrigerant Modulation System

D



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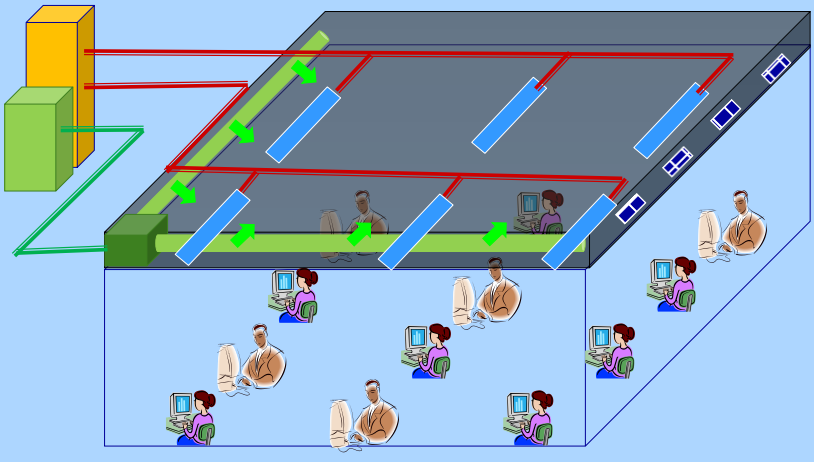
Refrigerant Modulation System

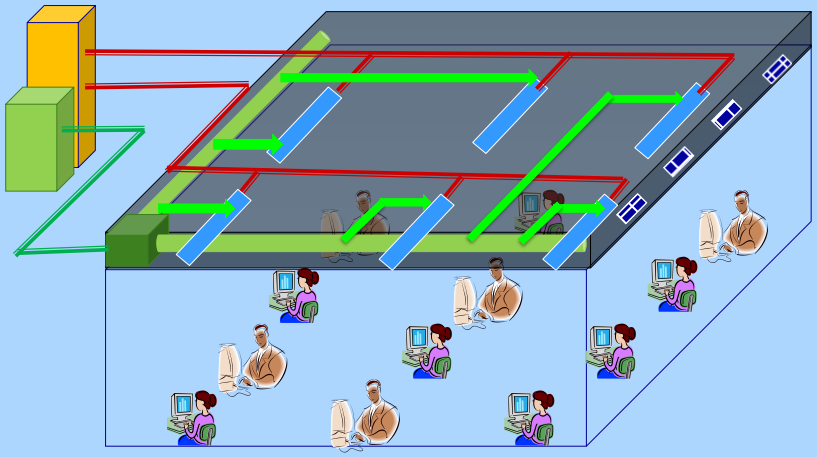
D



12

Refrigerant Modulation System

D



13

Conditioned O/A directly introduced into the space

Table 3
Ventilation parameters in the two buildings—ACH & outside air quantities

	Location	Volume (m^3)	Area (m^2)	ACH	Fresh air (l/s) (from ACH)[a]	Design occupancy		Actual occupancy	
						Occupant	l/s per occupant	Occupant	l/s per occupant
Building E	E2-P1	1146	358	0.30	85.95	36	2.39	24	3.60
	E2-P2	1146	358	0.30	85.95	36	2.39	24	3.60
	E2-P3	1146	358	0.30	85.95	36	2.39	24	3.60
	E2-P4	1146	358	0.30	85.95	36	2.39	24	3.60
	E2-P5	1146	358	0.30	85.95	36	2.39	24	3.60
Building NE	NE2-P1	1085	310	0.8	217	31	7	48	4.5
	NE2-P2	1085	310	0.8	217	31	7	48	4.5
	NE2-P3	1085	310	0.8	217	31	7	48	4.5
	NE2-P4	1085	310	0.8	217	31	7	48	4.5
	NE2-P5	1085	310	0.8	217	31	7	48	4.5

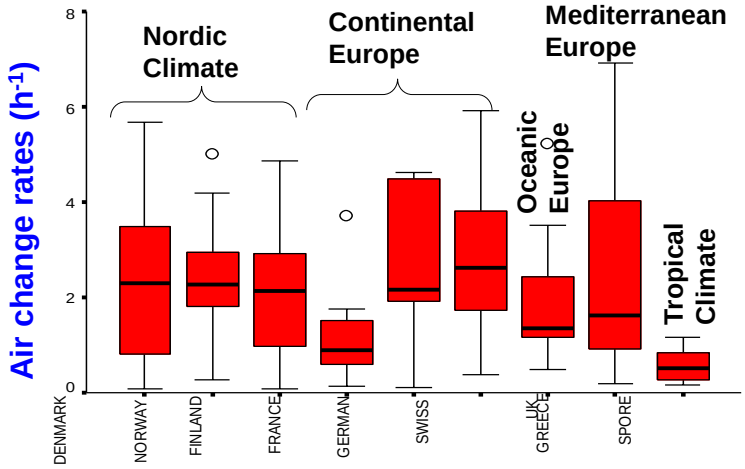
[a]Based on an effective space volume of 90%.

Conditioned O/A ducted and connected to the indoor FCUs and then introduced as part of the S/A introduced into the space

Sekhar, S. C., & Lim, A. H. (2003). Indoor air quality and energy issues of refrigerant modulating air-conditioning systems in the tropics. BUILDING AND ENVIRONMENT, 38(6), 815-825. doi:10.1016/S0360-1323(03)00025-8

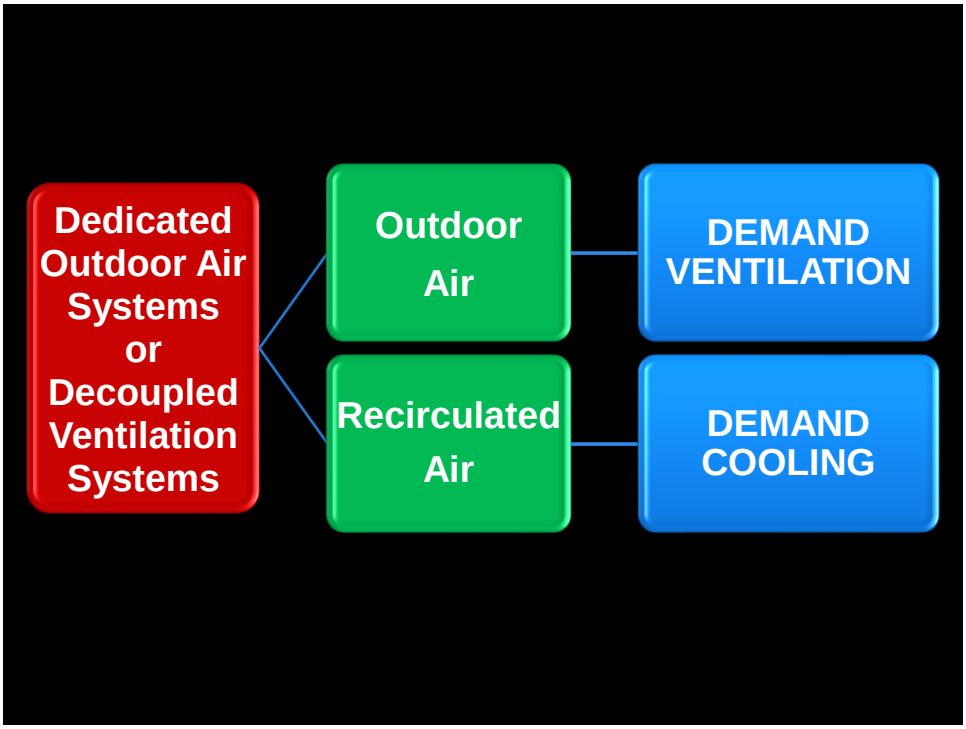
14

Zuraimi MS, Roulet C-A, Tham KW, Sekhar SC, David Cheong KW, Wong NH & Lee HK, 2004. "A comparative study of VOCs in Singapore and European Office Buildings", Building and Environment, *Volume 41, Issue 3, March 2006, Pages 316-329*

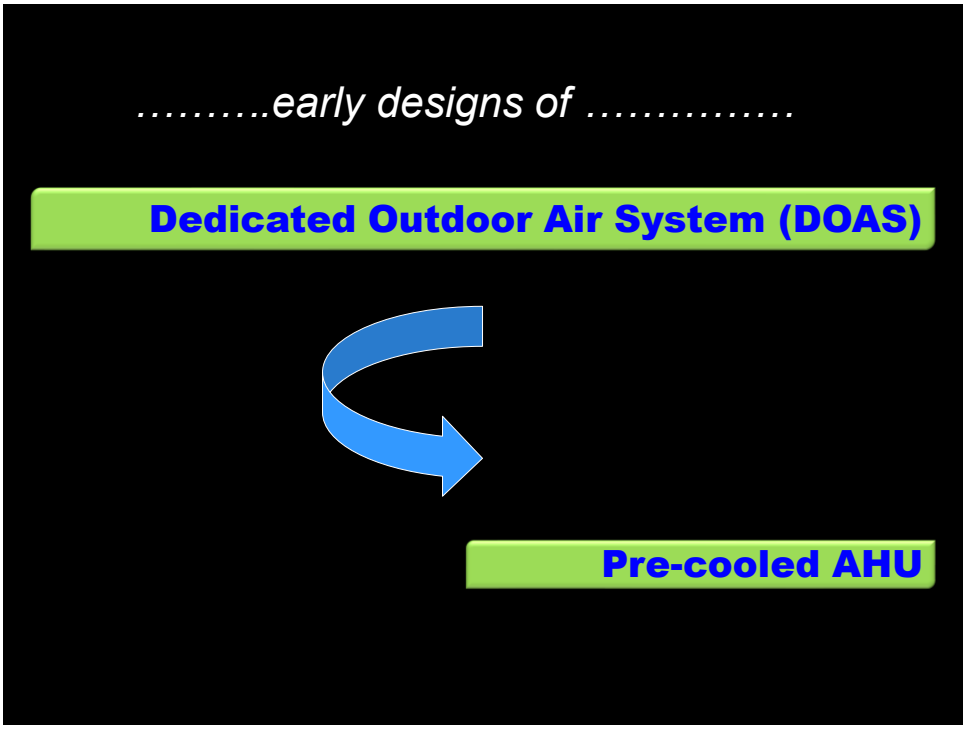


Air change rates (ACH) measured in the European and Singapore buildings studied

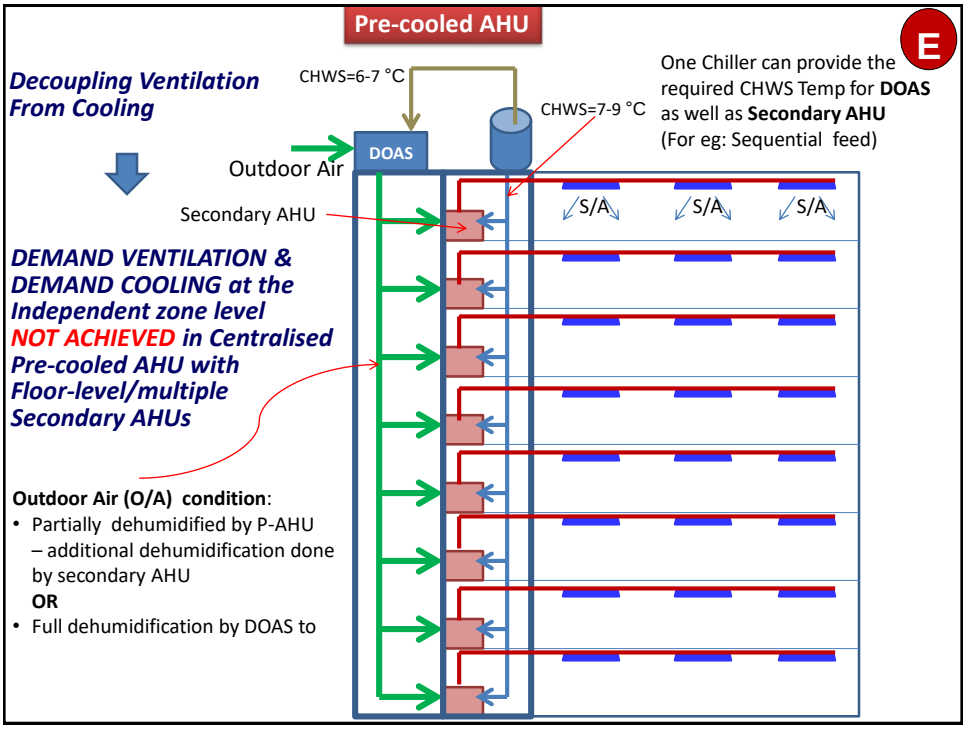
15



16


.....early designs of .....
Dedicated Outdoor Air System (DOAS)
Pre-cooled AHU

17


Pre-cooled AHU
E
Decoupling Ventilation From Cooling
CHWS=6-7 °C
CHWS=7-9 °C
One Chiller can provide the required CHWS Temp for DOAS as well as Secondary AHU (For eg: Sequential feed)
DOAS
Outdoor Air
Secondary AHU
S/A
S/A
S/A
DEMAND VENTILATION & DEMAND COOLING at the Independent zone level NOT ACHIEVED in Centralised Pre-cooled AHU with Floor-level/multiple Secondary AHUs
Outdoor Air (O/A) condition:
• Partially dehumidified by P-AHU – additional dehumidification done by secondary AHU
OR
• Full dehumidification by DOAS to

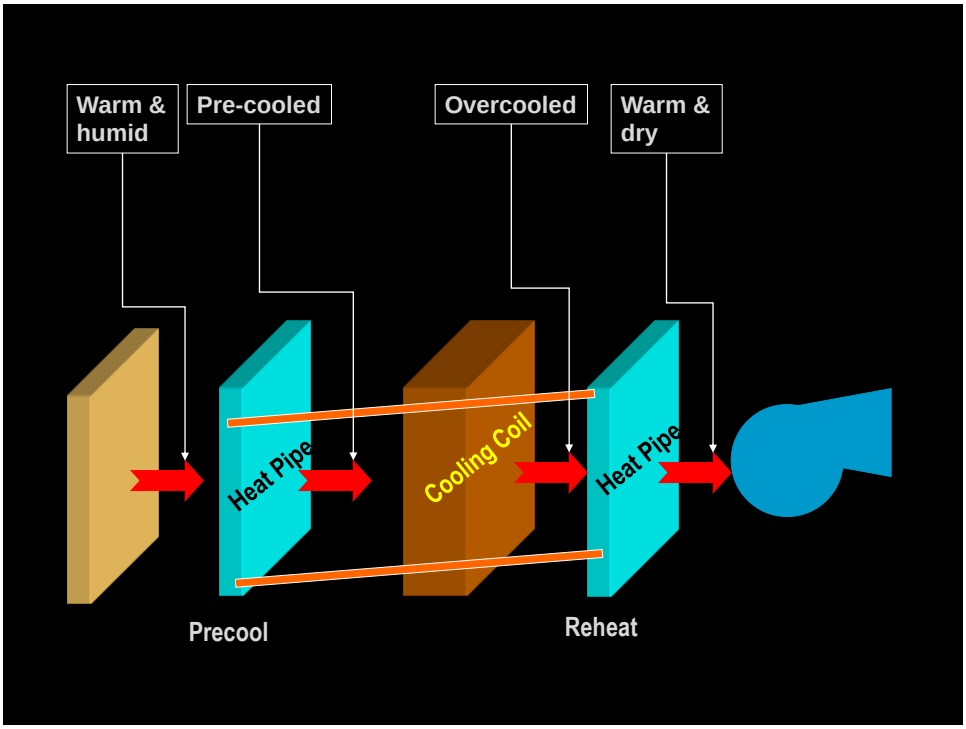
18



19

Heat Pipes

20



21

The Case Study

Animal Care Facility (ACF)

- specific pathogen-free rodent breeding facility
- approximately 1,000 m^2
- designed to meet international standards of animal care
- Mice and rats held in flexible film isolators or in individually ventilated cages

ACF requires stringent indoor conditions

- 100 percent outdoor air throughout the day (24 hours)
- relative humidity (RH) of approximately 55 % with a maximum of 60 %
- temperature of 22 °C (±1 °C)

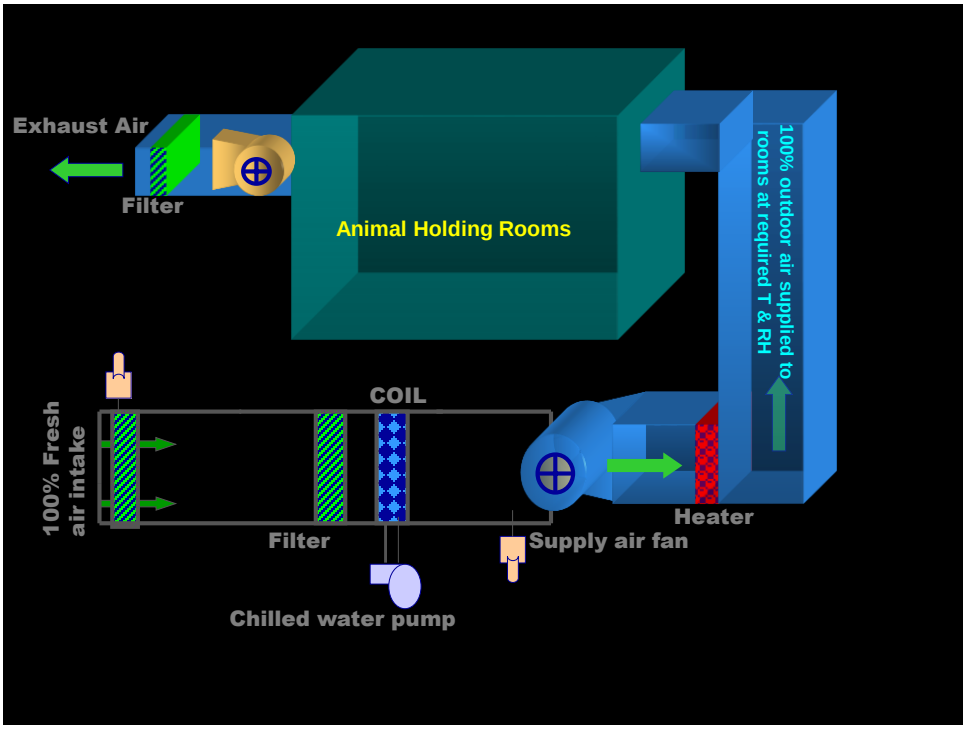
original design - heaters due to the stringent thermal requirements

➔ **high energy consumption**

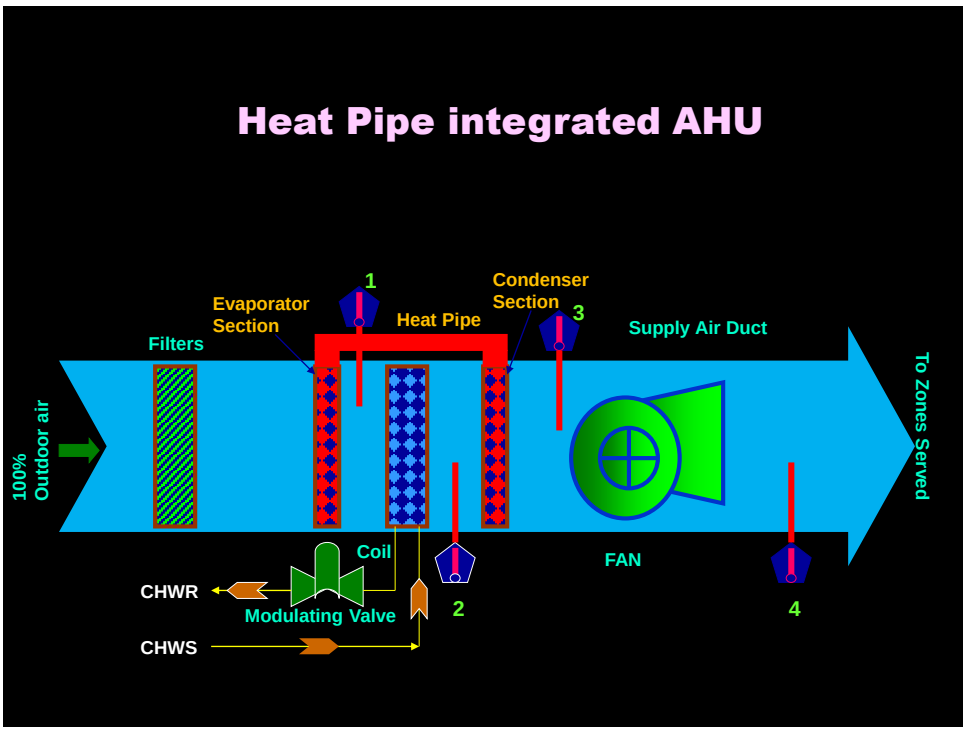
heat pipes

➔ energy conserving retrofit scheme

22


Exhaust Air
Filter
Animal Holding Rooms
100% outdoor air supplied to rooms at required T & RH
COIL
100% Fresh air intake
Filter
Heater
Supply air fan
Chilled water pump

23


Heat Pipe integrated AHU
1
Evaporator Section
Heat Pipe
Condenser Section
3
Supply Air Duct
Filters
100% Outdoor air
To Zones Served
Coil
FAN
CHWR
Modulating Valve
2
4
CHWS

24

Energy Savings at the Animal Care Facility (ACF)

	Ave Capacity Without Heat Pipes (kW)	Ave Capacity with Heat Pipes (kW)	Energy Consumption without Heat Pipes (kWh)	Energy Consumption with Heat Pipes (kWh)	Energy Savings (kWh)
7.00 am	315.1	256.5	2520.9	2052	**468.9**
3.00pm	395.5	314.1	3163.9	2512.7	**651.1**
11.00pm	352.5	297.7	2820.3	2381.8	**438.6**
Daily			8505	6946.5	**1558.6**
Monthly			255150.9	208394.1	**46756.8**

Energy Savings due to Heat Pipe → **18.3 %**

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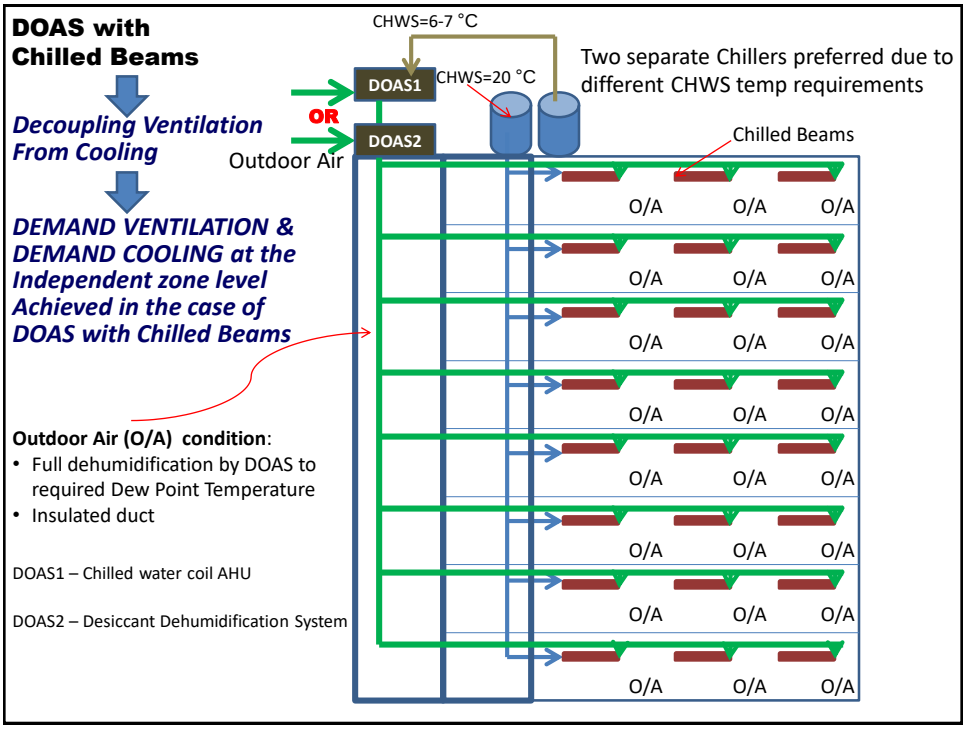
Now!!

…… Evolution within the past decade or so
…… Current Thinking

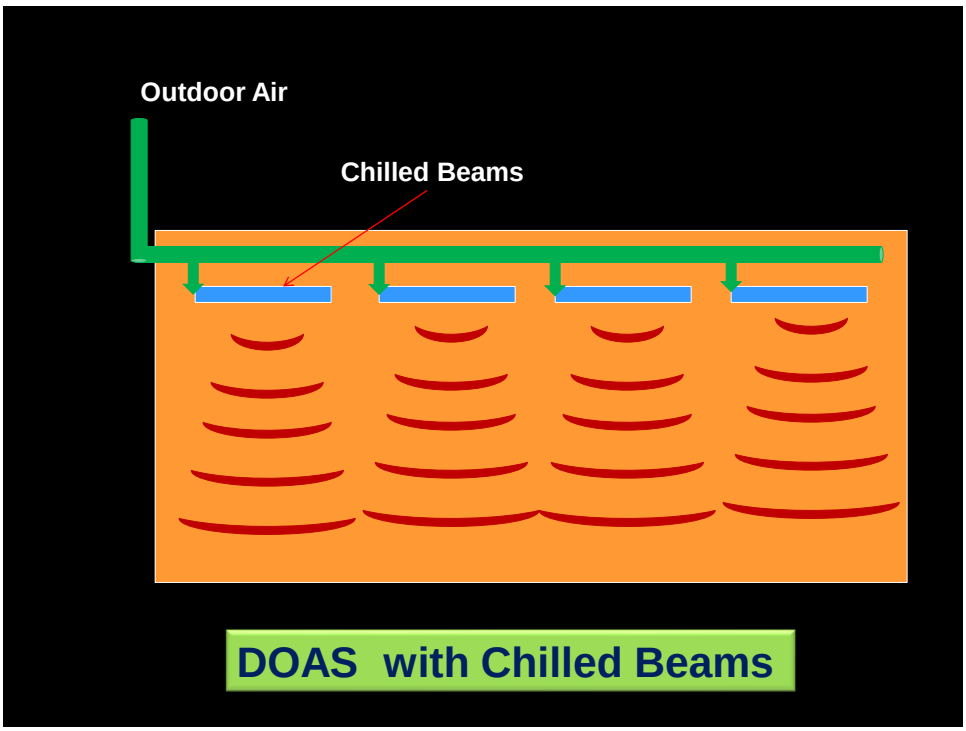
ACMV Concepts

- High Temperature Cooling and Dehumidification
- Move only as much air as is needed for ventilation
- It is much more energy efficient to move water/fluid to occupied zones for heat transfer/cooling
- Elevated space temperature and elevated air speed for Thermal Comfort

26


DOAS with Chilled Beams
Decoupling Ventilation From Cooling
DEMAND VENTILATION & DEMAND COOLING at the Independent zone level Achieved in the case of DOAS with Chilled Beams
Outdoor Air (O/A) condition:
• Full dehumidification by DOAS to required Dew Point Temperature
• Insulated duct
DOAS1 – Chilled water coil AHU
DOAS2 – Desiccant Dehumidification System
CHWS=6-7 °C
CHWS=20 °C
Two separate Chillers preferred due to different CHWS temp requirements
DOAS1
OR
DOAS2
Outdoor Air
Chilled Beams
O/A

27


Outdoor Air
Chilled Beams
DOAS with Chilled Beams

28



ACMV Concept - Primary Air & Chilled Beams

29



NUS launches Singapore's first new-build net-zero energy building

30 January 2019 | General News

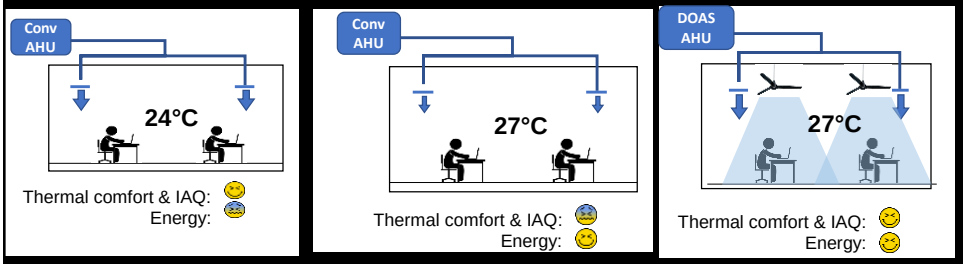
New building is also the first component of a 'well and green' precinct that integrates human-centric designs within a sustainable environment

The National University of Singapore (NUS) today unveiled the first new-build net-zero energy building in Singapore. Located within its School of Design and Environment (SDE), the new SDE4 building is energy efficient and environmentally friendly, with a suite of innovative building strategies to improve the comfort and well-being of building users.

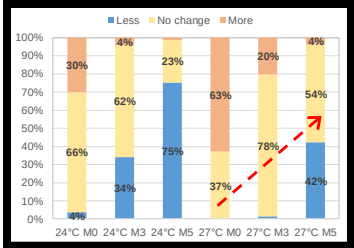
30

Concept of Hybrid Air-conditioning

Reduce the cooling demand by increasing the room temperature and to improve thermal comfort and IAQ by elevated air movement

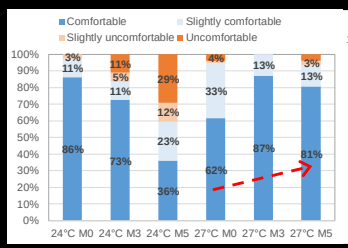


Mock-up Chamber - Subjective experiments (Nov 2017 – Feb 2018)

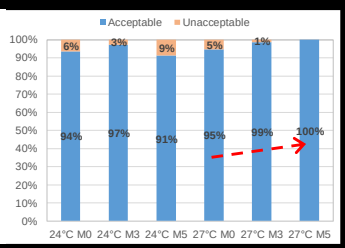


Air movement preference

- Preferred air movement environment observed at 24 °C with M0 (0.07 m/s) and 27 °C with M3 (0.94 m/s)
- Thermal comfort improved at 27 °C with elevated air movement although thermal comfort votes decreased at 24 °C due to high air speeds
- Percentage of IAQ acceptability increased at 27 °C with elevated air movement



Thermal comfort



IAQ acceptability

NZEB-SDE4@NUS launched on 30 January 2019



First purpose-built ZEB in Singapore

33

Singapore

CP13 – Code of Practice for Mechanical Ventilation and Air-conditioning in Buildings

80s
- CP13 – first launched 1980

90s
- CP13 Revised (1999)
- IAQ Guidelines First launched (1996)

2000+
- CP13 Revised and Re-designated as SS553 (2009)
- SS554 First launched (2009)

2010+
- SS553 Revised (2016)
- SS554 Revised (2016)

34


Singapore Standards Council
SS 553:2016+A1:2017
(ICS 91.140.30)
SINGAPORE STANDARD
Code of practice for air-conditioning and mechanical ventilation in buildings
Incorporating Amendment No. 1
Published by
Enterprise Singapore
Singapore Standards Council
SS 554 : 2016
(ICS 13.040.20; 91.040.01)
SINGAPORE STANDARD
Code of practice for indoor air quality for air-conditioned buildings
Published by
Enterprise Singapore

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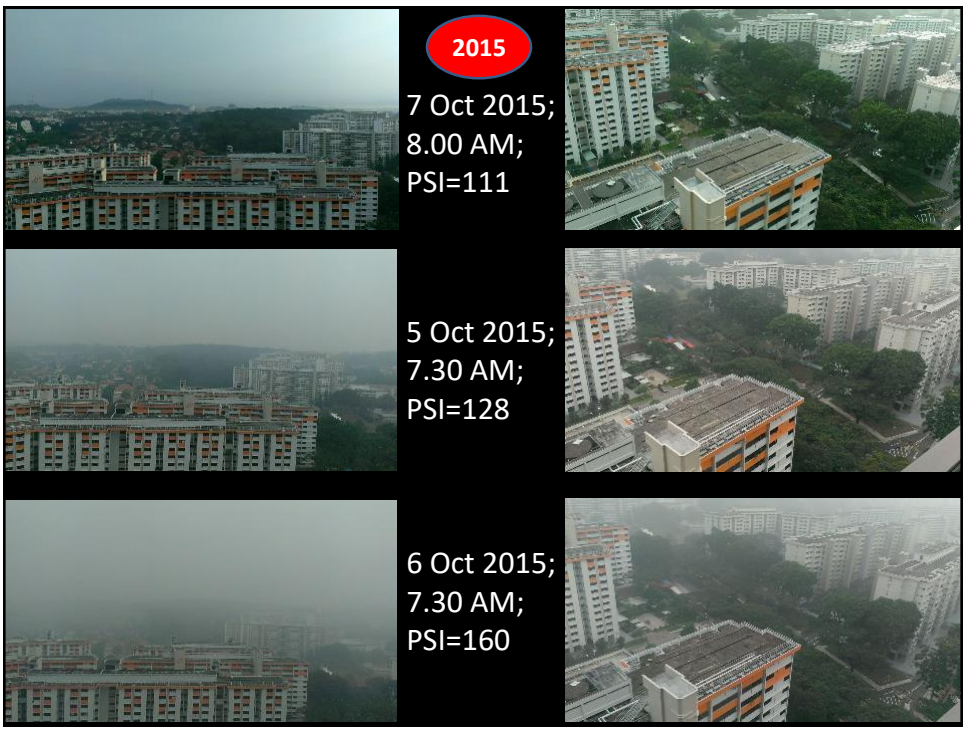

2015
7 Oct 2015;
8.00 AM;
PSI=111
5 Oct 2015;
7.30 AM;
PSI=128
6 Oct 2015;
7.30 AM;
PSI=160

36

2015

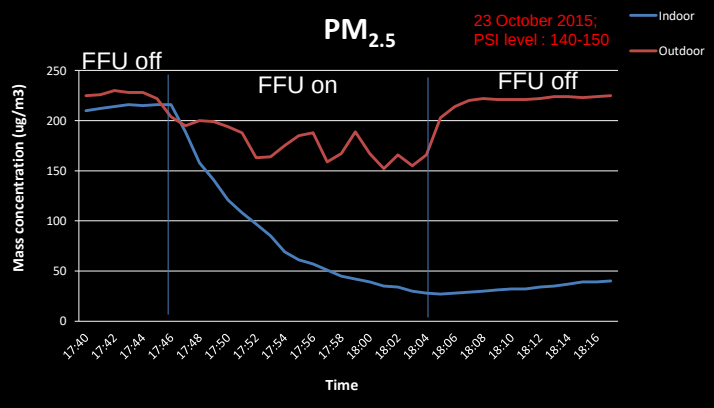




37

Study in a NV School (MERV 13 filter; 350 Fan)

2015



I/O ratio: 0.16% Filter efficiency: 84 %
Time constant: 20 mins

38

2016

Enhancing the recommended filter ratings (from MERV13 to MERV 14) and providing information on filter use

Details	SS554:2009	Proposed revision
Filter rating	Primary filter: MERV 6 Secondary filter: MERV 13	**MERV 14** (better protection than MERV 13)

ASHRAE 52.2 Minimum Efficiency Reporting Value (MERV)	Composite average particle size efficiency, % in size range, µm		
	0.3 to 1.0	1.0 to 3.0	3.0 to 10.0
6	NA	NA	$35 \le E_3 < 50$
13	$E_1 < 75$	$90 \le E_2$	$90 \le E_3$
14	$75 \le E_1 < 85$	$90 \le E_2$	$90 \le E_3$

Gas-phase filtration	Not mentioned	"Gas-phase filters could be used in conjunction with the particulate filter to control gaseous pollutant. For such purposes the fan motor needs to be sized accordingly such that the required air flow rate can be maintained."
Information in Annex	Only filter efficiency	1. Needs for air filtration for better IAQ 2. Types of filters – selection and energy considerations, efficiency, best practices 3. Types of gas-phase filters

39

2016

Alignment for air filtration clauses with SS553

	Nature of the Standard	Filter ratings
SS554	Specifies performance	"SS553 specifies the minimum filter requirement. In preparation for unforeseeable haze events, the use of fine dust filters, especially those having at least a rating of Minimum Efficiency Reporting Value (MERV) 14 (ASHRAE 52.2:2012) or F8 (EN779:2012), is recommended. Such filters can remove particulates more effectively than coarse dust filters and can keep the building and the ACMV system clean at all times."
SS553	Specifies design specifications	"The Minimum Efficiency Reporting Value (MERV) for cleaning the air in all air-handling units shall be equivalent to MERV 6 or better, and MERV 14 when the outdoor pollution level is in the unhealthy range in accordance with MOH's guidelines. The MERV for cleaning outdoor air supplied to fan coil units shall be equivalent to MERV 6 or better, and MERV 14 when the outdoor pollution level is in the unhealthy range in accordance with MOH's guidelines. Fan motors shall be sized such that the required air flow rate can be maintained."

40

Key Messages

- Year-round Hot and Humid Climate
- ACMV Systems (No “H” in HVAC Systems) – Gradual evolution over the past 40 years
- High Recirculation Rates – as high as 90%
- Decoupling ventilation from cooling – Move less air – High Temperature cooling – Elevated space temperatures with elevated air speeds
- Ventilation and IAQ Standards

  1980 ➤ 1996 ➤1999 ➤2009 ➤2016

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Thank You for your Attention

45

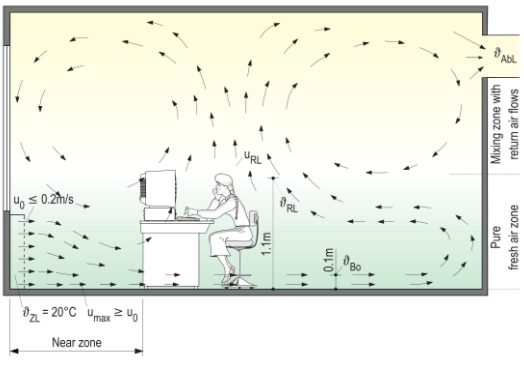
Dynamic performance of displacement ventilation in a lecture hall

Natalia Lastovets, Kai Sirén, Risto Kosonen, Juha Jokisalo, Simo Kilpeläinen

Department of Mechanical Engineering
Aalto University

Motivation

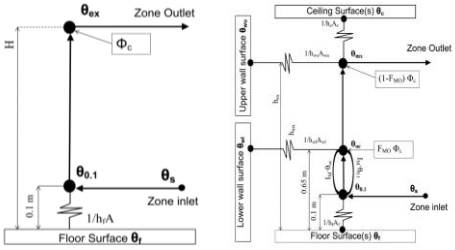
- A heat-balance-based method is usually applied in displacement ventilation (DV) system design.
- Inaccurate temperature prediction can cause poor thermal comfort and wrong sizing of DV systems.
- This study introduces the dynamic temperature gradient model of DV and analyses the **effect of the thermal mass** and **changing heat gain profiles** on the **temperature stratification.**



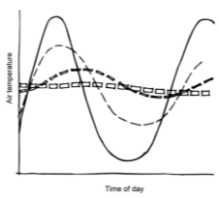
Backgroung

- Nodal modals are generally used to calculate temperature gradient.
- Room air temperatures are affected by variation of heat loads in operation time and thermal mass effect, which is not taken into account in the steady-state models.

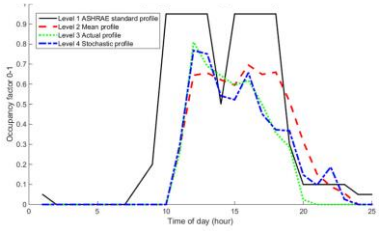
Nodal models



Building thermal mass

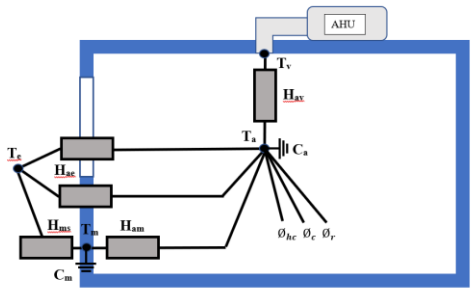


Daily occupancy profile



Objectives

- To create dynamic two-capacity model to calculate temperature gradient in rooms with DV.
- To study the effect of thermal mass and changing heat gains to the temperature gradient.
- To validate the model with the measurements in a lecture room.



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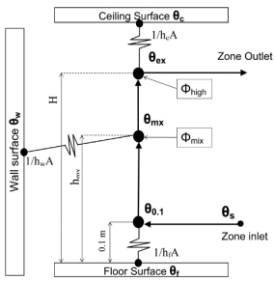
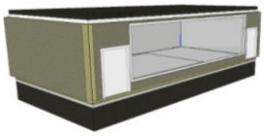
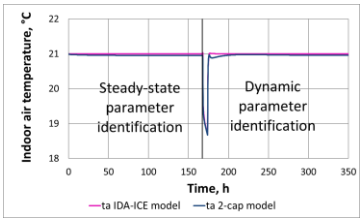
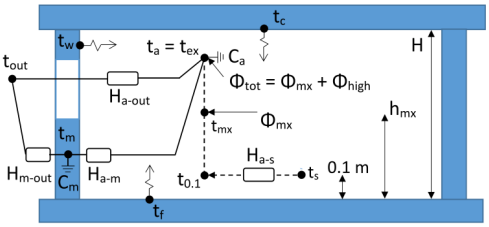


Methodology

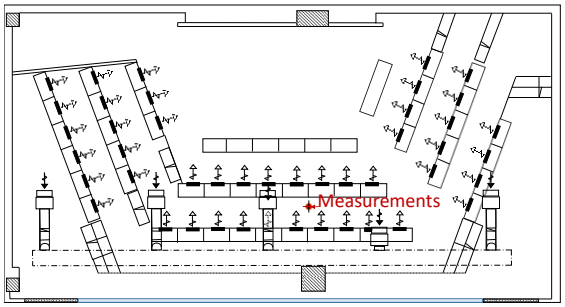
IDA-ICE model	Calibration of model parameters	DV 2-capacity model
Geometry		
	Steady-state parameter identification (total conductance H_{ams})	
	Dynamic parameter identification (H_{ms} H_{am} C_m C_a)	
		The vertical air temperature gradient calculation







Experimental setting

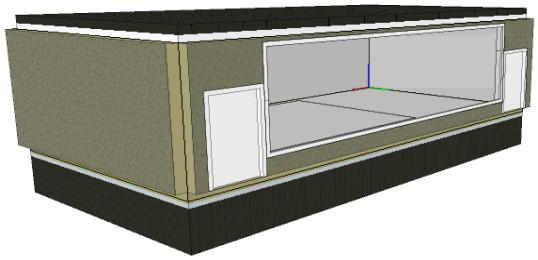




- The air temperature measurements: supply air, surrounding air and room air temperatures at 20 heights.
- The supply air flow rate.
- The internal heat loads from lighting units and students

Floor area (m^2)	No seats	Supply air devices	Exhaust air devices
108	65	50 supply units under the seats	5 exhaust grilles near the ceiling

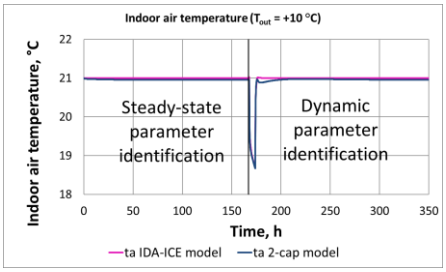
IDA-ICE model



- The calibration was conducted without any internal heat gains
- The default airflow rate of mixing ventilation was chosen for the calibration.

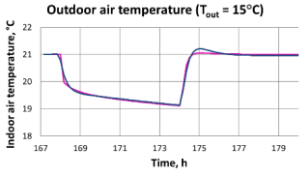
- The IDA-ICE model was created to calibrate the conductances and capacitances in the 2-capacity model.
- The wall structures were modelled according to the design values.
- The size of the room area was adjusted from the volume of the room. The internal staircase was also shrimped to equal floor thickness and added to the floor area

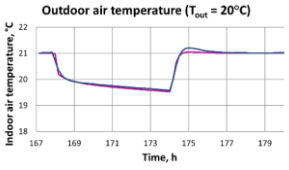
Calibration of model parameters



Steady-state parameter identification: steady state energy balance was matched with the indoor air node point to fix the total conductance.

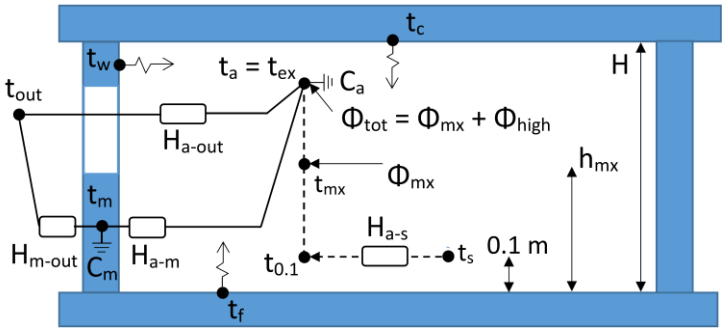
Dynamic parameter identification: model parameters were searched in a dynamic state by applying a sudden change in the external temperature.





The calibration parameters				
Steady-state	Dynamic			
H_{ams}, W/K	H_{am}, W/K	H_{ms}, W/K	C_a, kJ/K	C_m, kJ/K
102	1431	110	1636	48701

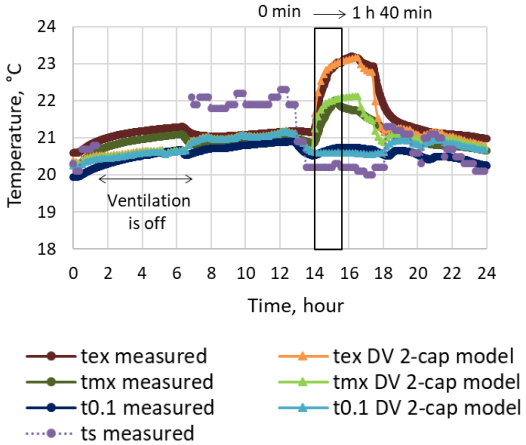
DV 2-capacity model

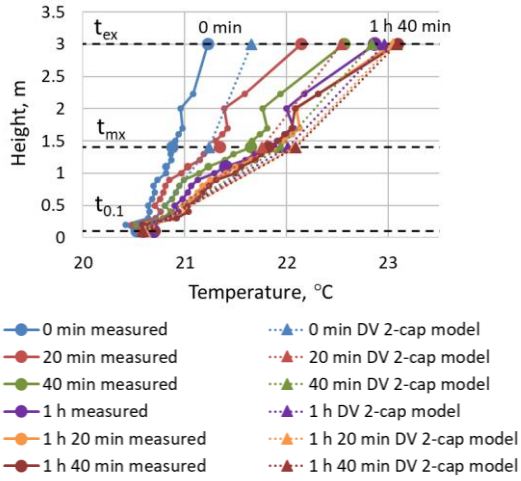


- The mixing height temperature is calculated using the plume theory.
- The IDA ICE simulation results were used to calibrate the conductances and capacitances of the model.

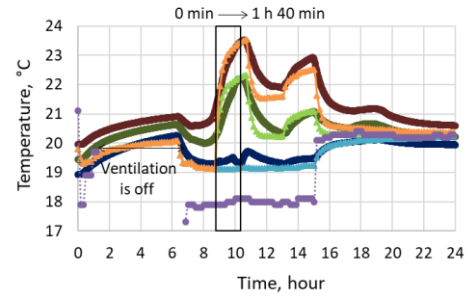
Model inputs		
Φ_{tot}	W	Total heat loads
Φ_{mx}	W	Heat loads in the occupied zone
T_{out}	°C	Outside air temperature
T_s	°C	Supply air temperature
H_{ae}	W/K	Window conductance
q_v	m^3/s	Air flow rate
Calibrated parameters		
H_{ms}	W/K	Conductances on both sides of the mass node
H_{am}	W/K	
C_m	J/K	Thermal mass capacity
C_a	J/K	Room air capacity
Calculated air temperatures		
$T_{0.1}$	°C	at the level 0.1 m from the floor
T_{mx}	°C	at the mixing height
T_{ex}	°C	exhaust air temperature

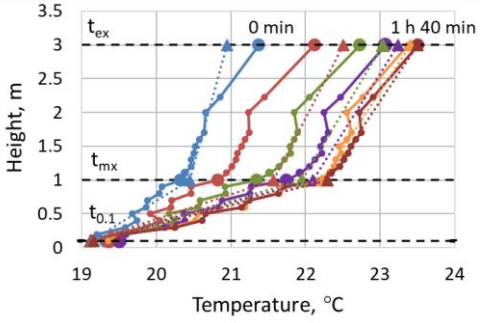
Results





Results





tex measured
tmx measured
t0.1 measured
ts measured
tex DV 2-cap model
tmx DV 2-cap model
t0.1 DV 2-cap model

0 min measured
20 min measured
40 min measured
1 h measured
1 h 20 min measured
1 h 40 min measured
0 min DV 2-cap model
20 min DV 2-cap model
40 min DV 2-cap model
1 h DV 2-cap model
1 h 20 min DV 2-cap model
1 h 40 min DV 2-cap model

Conclusions

- Since the premises with DV are usually not constantly occupied and characterized with indoor air temperature stratification, the accurate dynamic model of indoor vertical temperature gradient is important in DV design.
- The procedure to estimate the lumped thermal parameters of the building internal mass presented in the study can be effectively used to identify the parameters using short-term operation data.
- The presented model is able to take into account time schedules of heat gains and thermal mass of building.
- The results show that the trained two-capacity model can predict the indoor air temperature gradient in dynamic conditions.
- The model can be applied in design DV in various dynamic conditions.

Numerical Modelling of Large Air-Conditioned Space: Comparison of Two Ventilation Systems

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1

- Large single cell spaces have become a considerable characteristic of modern buildings, e.g. shopping malls, lecture theatres, airports terminals and large open plan offices.

- Ventilation of large spaces (> 5m ceiling height) differs from spaces with small volume because of the possibility of wide variation in indoor environment variables (e.g. air temperature, velocity, contaminant concentration, etc.)

- The Air Distribution Index (ADI) is an index combining the level of thermal comfort, indoor air quality and consequently energy performance provided by an air distribution system used in typical spaces. It is used in this study to compare the performance of two different ventilation systems impinging jet (IJV) and mixing (MV) in large spaces

No research has been carried to test the ADI in large occupied spaces

2

Air distribution index

The Air Distribution Index (ADI) combines IAQ and thermal comfort by integrating several parameters such as overall ventilation effectiveness for removing pollutants and for temperature distribution ($\bar{\varepsilon_c}, \bar{\varepsilon_t}$), percentage of dissatisfied (PD) for air quality and predicted percentage of dissatisfied for thermal comfort (PPD).

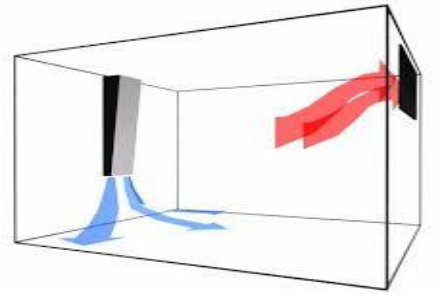
$$ADI = \sqrt{(N_c \times N_t)}$$

$N_c = \frac{\bar{\varepsilon_c}}{PD}$	air distribution number for air quality
$N_t = \frac{\bar{\varepsilon_t}}{PPD}$	air distribution number for thermal comfort
$\bar{\varepsilon_c} = \frac{C_e - C_\infty}{\bar{C} - C_\infty}$	overall ventilation effectiveness for the removal of pollutants
$\bar{\varepsilon_t} = \frac{t_e - t_\infty}{\bar{t} - t_\infty}$	overall ventilation effectiveness for heat removal

$$PD = 395 \times EXP(-1.83\bar{v}^{0.25})$$

$$PPD = 100 - 95 \times EXP - \{0.03353(PMV)^4 + 0.2179(PMV)^2\}$$

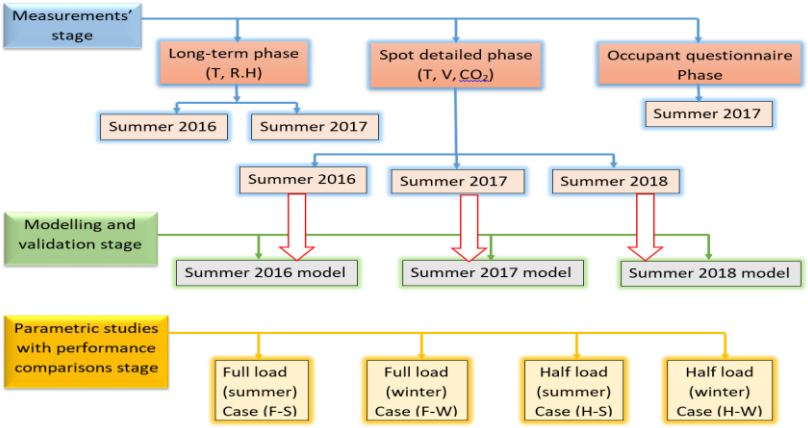
Impinging Jet ventilation system



A high momentum air jet discharged downwards onto the floor and as the jet impinges onto the floor, it spreads over a considerable area causing the jet momentum to recede but still has enough force reaching long distances in the room.

Very few studies reported on evaluating the performance of Impinging Jet Ventilation (IJV) system in large spaces.

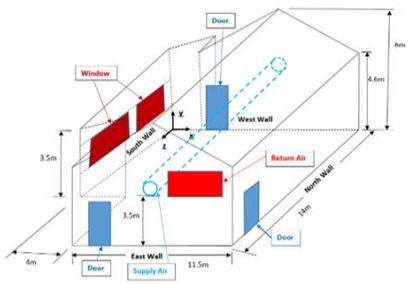
The overall study

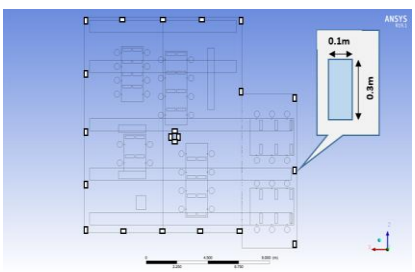


5

Numerical Method: models

- Large open plan office used with floor-to-ceiling height of 6m
- For the MV simulation, external air is delivered through a 13m cylindrical supply duct with a 0.7m diameter with eight air diffusers (0.8m x 0.15m) at a height of 3.7 m
- For the IJV simulation, the supply air is delivered into the building interior through 21 IJV ducts each with a supply opening area of 0.03 m^2 and a distance of 0.7 m above the floor were uniformly distributed inside the office.

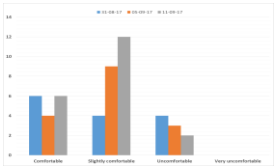


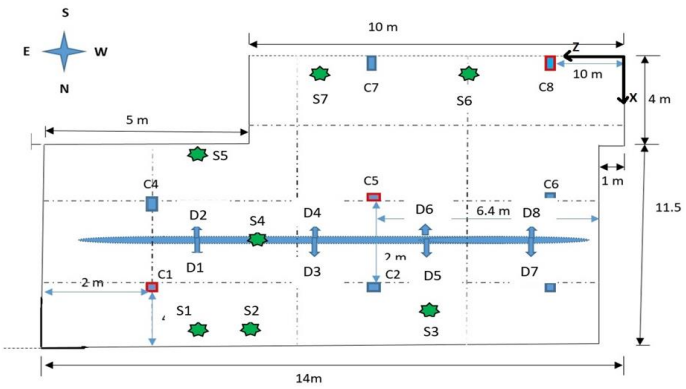


6

Measurements in MV existing space

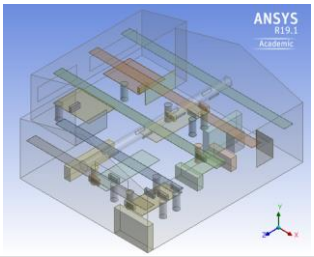
- Long-term phase (Temp, RH) 2016, 2017
- Spots detailed phase (Temp. Vel. CO_2) 2016,2017,2018
- Occupants Questionnaires (thermal comfort, IAQ) 2017

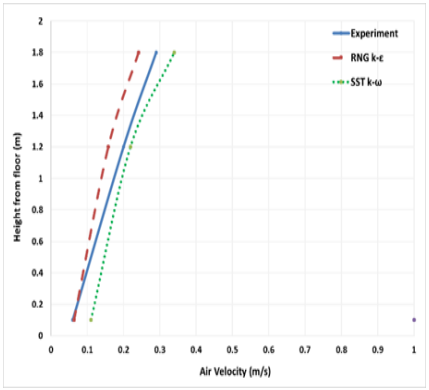


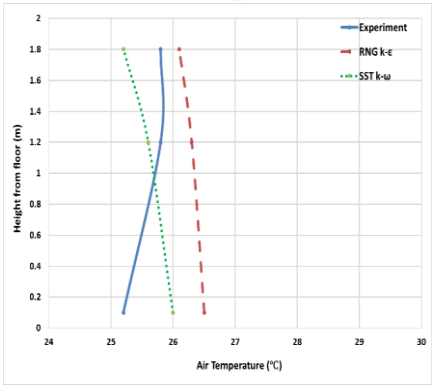


7

- Numerical Model
- Boundary conditions
- Grid independent study
  (7,233,904) (16,045,809) (24,168,713)
- Turbulence modeling
  RNG k-ε , SST k-ω
- Validation with measurements





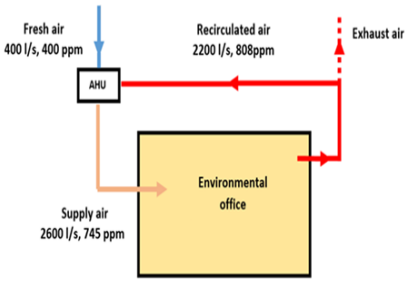


8

Two test conditions to compare performance of MV and IJV ventilation systems

- Full occupancy – 40 occupants (Case F)
- Half occupancy – 20 occupants (Case H)

Case name		Case F		Case H	
Occupancy		Full		Half	
Distribution system		MV	IJV	MV	IJV
Flow rate (m^3/s)		2.6	2.6	1.7	1.7
Diffusers	Number	8	21	8	21
	Area (m^2)	0.12	0.03	0.12	0.03
	Velocity (m/s)	2.7	4.1	1.8	2.7
	Temperature (°C)	18	19	19	20
	CO_2 (ppm)	745	745	652	652

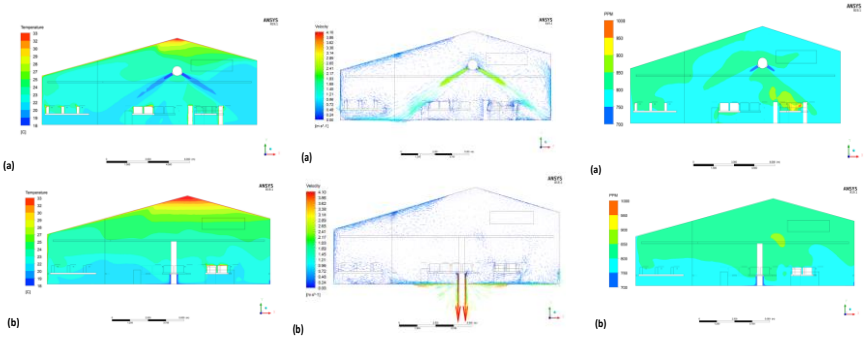


9

RESULTS

CFD Results for (Case F-full occupancy)

- Temperature contour
- Velocity vector
- CO_2 concentration contour

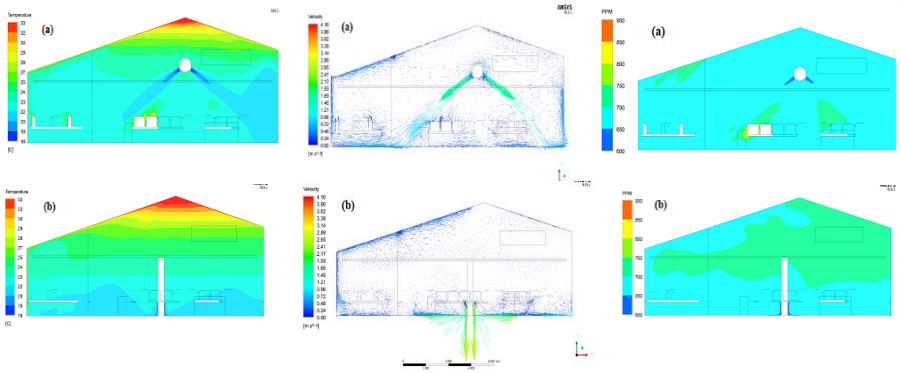


(a) is results for MV and (b) for IJS

10

CFD Results for Case H – half occupancy

- Temperature contour
- Velocity vector
- CO_2 concentration contour



(a) is results for MV and (b) for IJS

11

The predicted ADI for the MV and IJV systems for the two cases

Cases		Case F		Case H	
Distribution system		MV	IJV	MV	IJV
Flow rate (m^3/s)		2.6	2.6	1.7	1.7
Diffusers	Number	8	21	8	21
	Area (m^2)	0.12	0.03	0.12	0.03
	Velocity (m/s)	2.7	4.1	1.8	2.7
	Temperature (°C)	18	19	19	20
	CO_2 (ppm)	745	745	652	652
$\bar{\varepsilon_c}$		1.17	1.78	1.16	2.35
PD (%)		15.2	15.2	15.2	15.2
N_c		7.7	11.7	7.63	15.4
$\bar{\varepsilon_t}$		1.5	2.23	1.75	3.5
PPD (%)		40	31	26	24
N_t		3.75	7.2	6.73	14.6
ADI		5.4	9.2	7.2	15.0

12

Conclusion

- The IJV system showed better air quality and thermal comfort when compared with those for the MV system and thus produced higher ADI values.
- The IJV system performed better than the MV system in terms of the energy consumption since the air supply temperature for the IJV system was higher by 1°C than that for the MV system for both cases.
- In general, the ADI concept presented in this work could be a beneficial tool for evaluating a ventilation system performance in large spaces as it provides assessments for both air quality and thermal comfort.

Thank you

Air Infiltration and Ventilation Centre 16 October 2019
Session 3C – Optimized HVAC design and operation.

Proposal of Optimal Control Method in order to reduce Mutual Interference of Air Conditioning Indoor Units

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The University of Kitakyushu

Yasuyuki SHIRAISHI
Professor,
The University of Kitakyushu

The University of Kitakyushu
Shiraishi Laboratory

Architecture with Environment
Shiraishi Lab.

1

1. Background・Purpose

Background of research.／Purpose of research.

2. Overview of Model Predictive Control(MPC)

Overview of MPC.／About prediction model.

3. Outline of CFD Analysis

Analysis model.／Obtain step response used for SISO control.／
Obtain step response used for MIMO control. ／Analysis cases

4. Analysis Results

The room temperature and the outlet air temperature of representative zone／
A temperature control error of the room temperature in all zones／
The room temperature (each point) of the inW01 zone／A temperature control error in the Average temperaure of the room in the inW01／The temperature fields and flow fields at 5,400s in case2

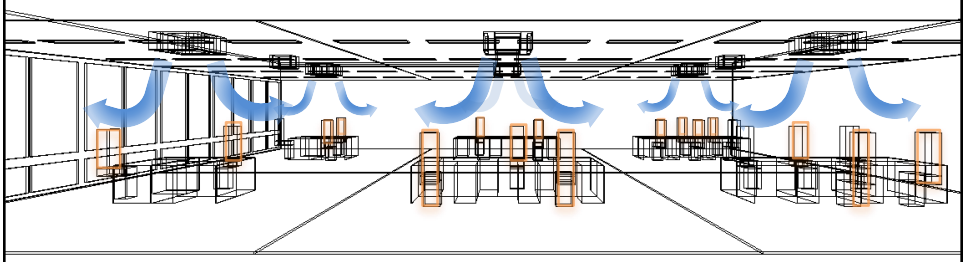
5. Conclusion

Summary／Future prospects

2

1-1. Background of research

▶In recent years, multi-split packaged air-conditioning systems have become commonplace in office buildings in Japan.



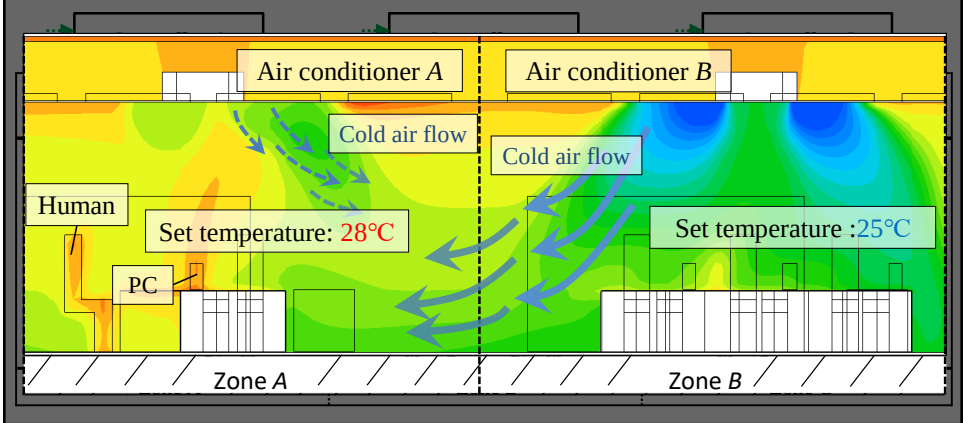
The advantage of this system is …

- That each indoor unit can be operated and controlled individually.
- Users can change the temperature settings of the indoor units as desired.

1-1. Background of research

However, when a single air-conditioned space is shared by a plurality of indoor units…

Single-Input Single-Output (SISO) control

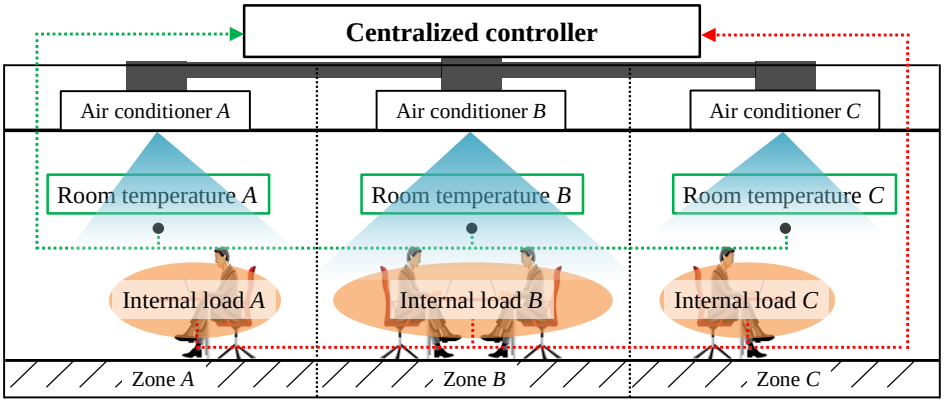


SISO control cannot consider the thermal environment of the adjacent zones, problems such as mutual interference between indoor units occur.

1-1. Background of research

However, when a single air-conditioned space is shared by a plurality of indoor units…

Multiple-Input Multiple-Output (MIMO) control



It is possible to optimally control the entire space in consideration of the thermal environment of the adjacent zone, which can reduce mutual interference.

1-1. Background of research

However, when a single air-conditioned space is shared by a plurality of indoor units…

Multiple-Input Multiple-Output (MIMO) control

We carry out coupled analysis of computational fluid dynamics (CFD) and MATLAB/Simulink incorporating MIMO MPC…

- Improvement of control performance.
- Reduction effect of mutual interference between adjacent indoor units.

was verified.

It is possible to optimally control the entire space in consideration of the thermal environment of the adjacent zone, which can reduce mutual interference.

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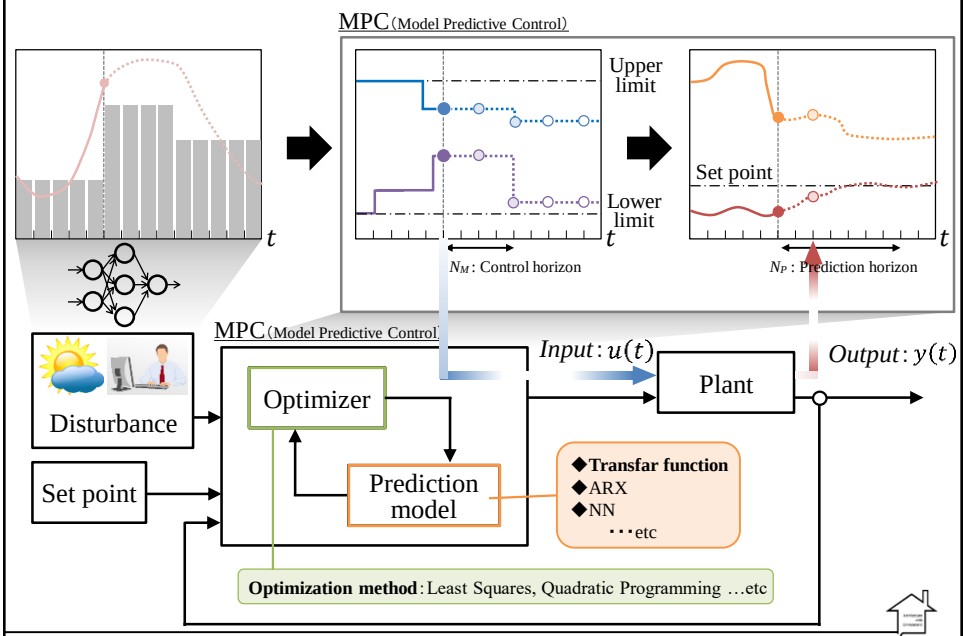
5,400s in case2

5. Conclusion

Summary／Future prospects

2-1. Overview of MPC



1. Background・Purpose

Background of research.／Purpose of research.

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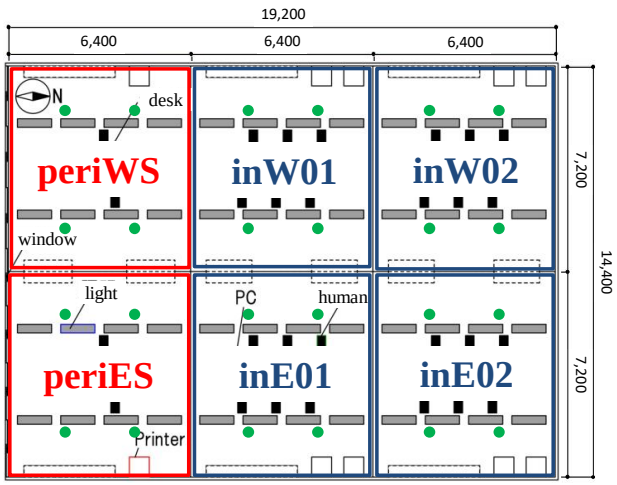
Average temperaure of the room in the inW01／The temperature fields and flow fields at
5,400s in case2

5. Conclusion

Summary／Future prospects

3-1. Analysis model

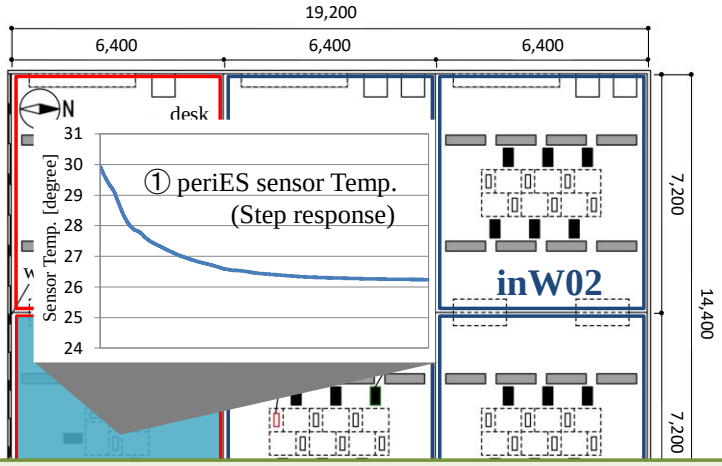


● : Room temperature sensor (Z = 1.1m)

Assuming a space where a part of a general office space is cut, and zoned in a total of 6 zones.

3-2.1. Obtain step response used for SISO control

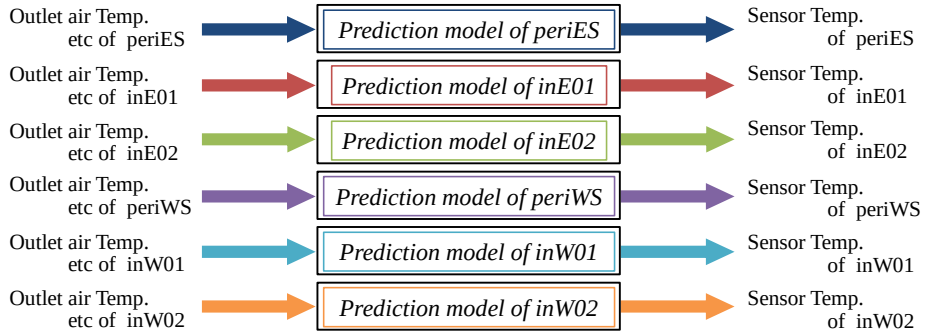
1. When periES blowing temperature is changed



The prediction model inE01, inE02, periWS, inW01, and inW02 of the other five zones are also obtained in the same flow.

3-2.1. Obtain step response used for SISO control

In the SISO MPC…



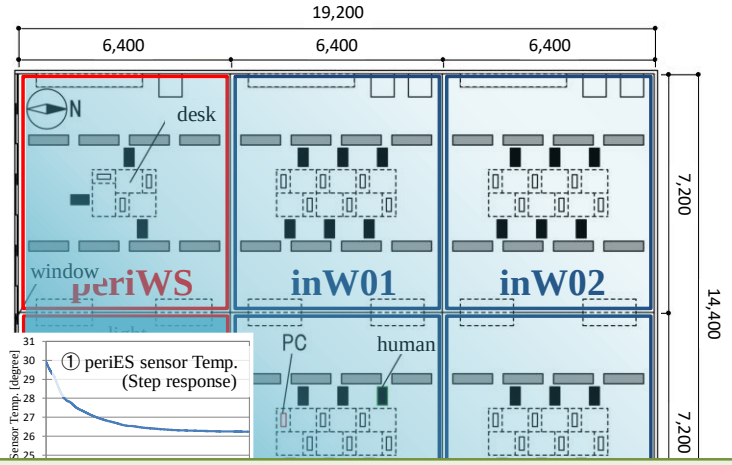
$$y_{n\_SISO}(t+j) = \sum_{k=1}^{\infty} a_n(k)\,\Delta u_n(t+j-k) + \sum_{k=1}^{\infty} b_n(k)\,\Delta d_n(t+j-k) \quad (2.1)$$

Terms for air conditioners — Terms for internal load

Predict sensor temperature using step response of only target zone

3-2.2. Obtain step response used for MIMO control

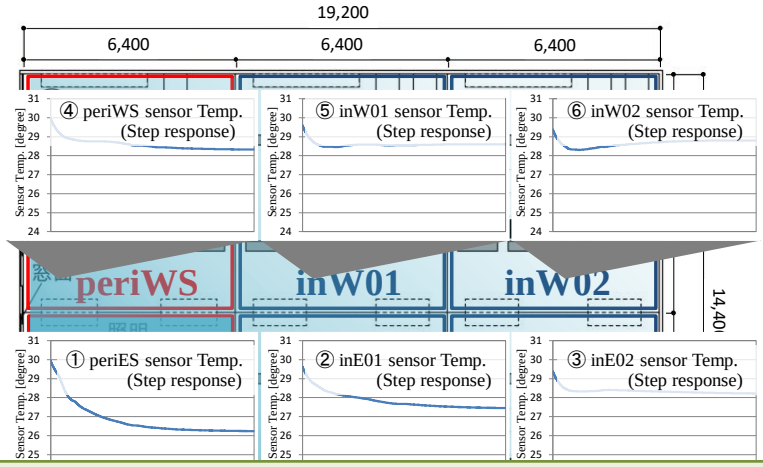
1. When periES blowing temperature is changed



It is difficult to control <u>in consideration of the heat transfer phenomenon from the adjacent zone</u> in the SISO control using the step response of only the controlled zone.

3-2.2. Obtain step response used for MIMO control

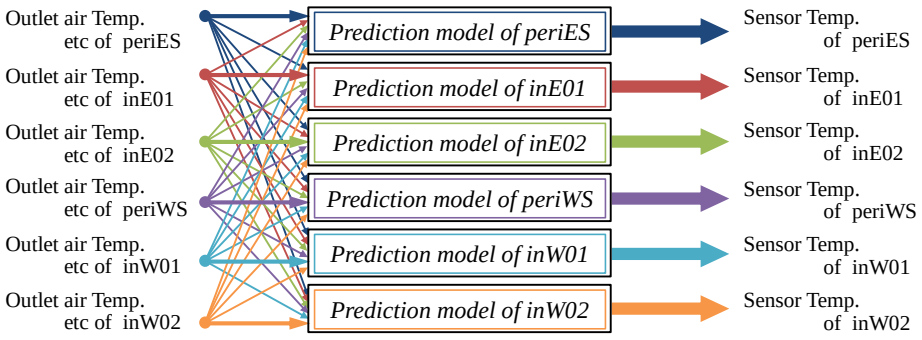
1. When periES blowing temperature is changed



In the same flow, a total of <u>36 step responses are obtained per zone</u> for both the outlet air temperature and internal load.

3-2.2. Obtain step response used for MIMO control

In the MIMO MPC…



$$y_{n\_MIMO}(t+j) = \sum_{i=1}^{m}\left\{\sum_{k=1}^{\infty} a_{ni}(k)\Delta u_i(t+j-k) + \sum_{k=1}^{\infty} b_{ni}(k)\Delta d_i(t+j-k)\right\} \quad (2.2)$$

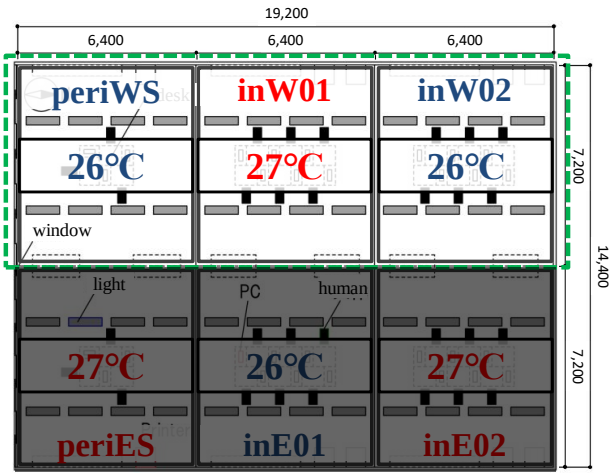
Terms for air conditioners　　Terms for internal load

Control is performed by incorporating the step responses of all zones in the control law.

15

3-3. Analysis cases

CASE1 :SISO MPC　　**CASE2 :MIMO MPC**



We compared the control performance and behavior of outlet air temperature and room temperature.

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1. Background・Purpose

Background of research.／Purpose of research.

2. Overview of Model Predictive Control(MPC)

Overview of MPC.／About prediction model.

3. Outline of CFD Analysis

Analysis model.／Obtain step response used for SISO control.／
Obtain step response used for MIMO control. ／Analysis cases

4. Analysis Results

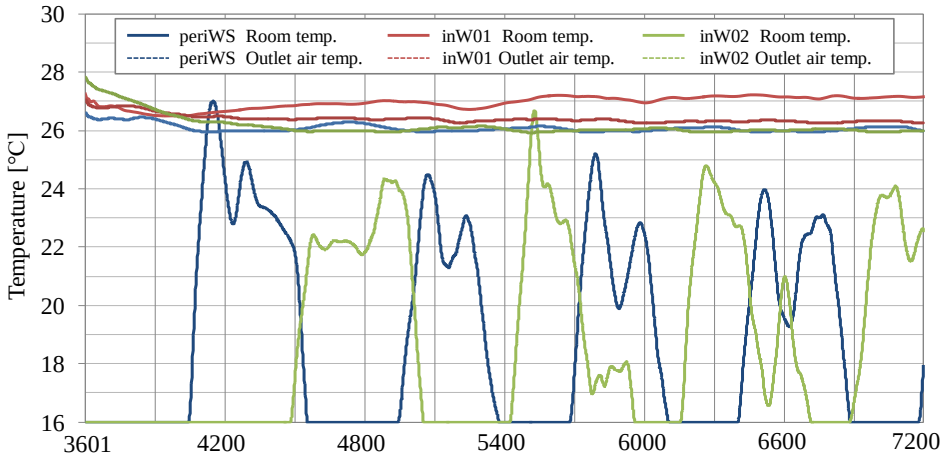
The room temperature and the outlet air temperature of representative zone／
A temperature control error of the room temperature in all zones／
The room temperature (each point) of the inW01 zone／A temperature control error in the Average temperaure of the room in the inW01／The temperature fields and flow fields at 5,400s in case2

5. Conclusion

Summary／Future prospects

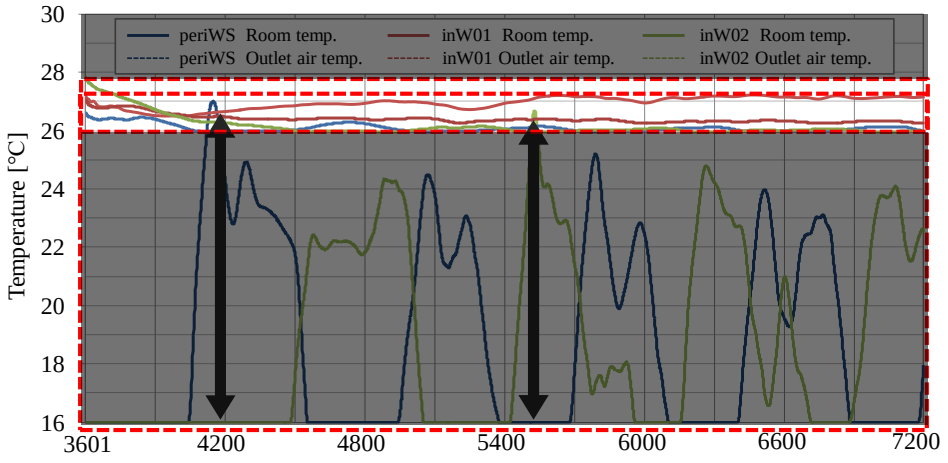
4-1. The room temperature and the outlet air temperature

CASE1 :SISO MPC | **CASE2 :MIMO MPC**



4-1. The room temperature and the outlet air temperature

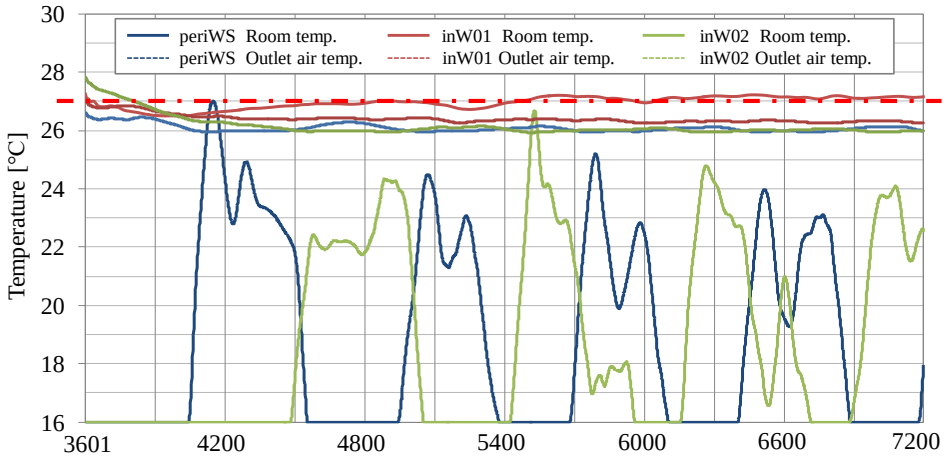
CASE1 :SISO MPC | CASE2 :MIMO MPC



Where the set temperature was 27 degrees, the outlet air temperature became the return air temperature at all times.

4-1. The room temperature and the outlet air temperature

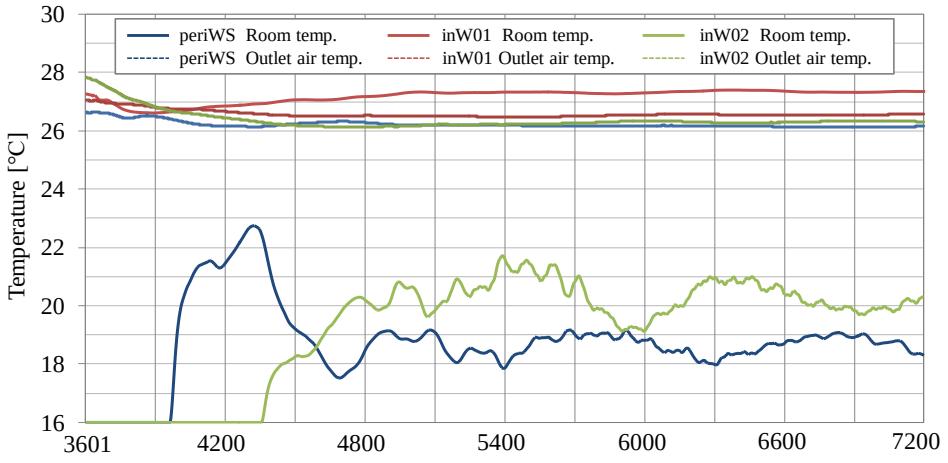
CASE1 :SISO MPC | CASE2 :MIMO MPC



An error of about 0.4 degrees was confirmed in the inW01 zone with a set temperature of 27 degrees.

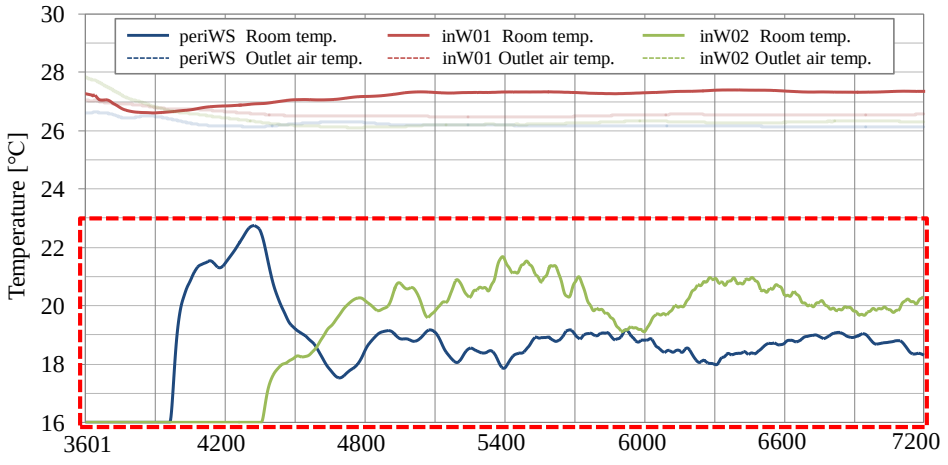
4-1. The room temperature and the outlet air temperature

CASE1 :SISO MPC | **CASE2 :MIMO MPC**



4-1. The room temperature and the outlet air temperature

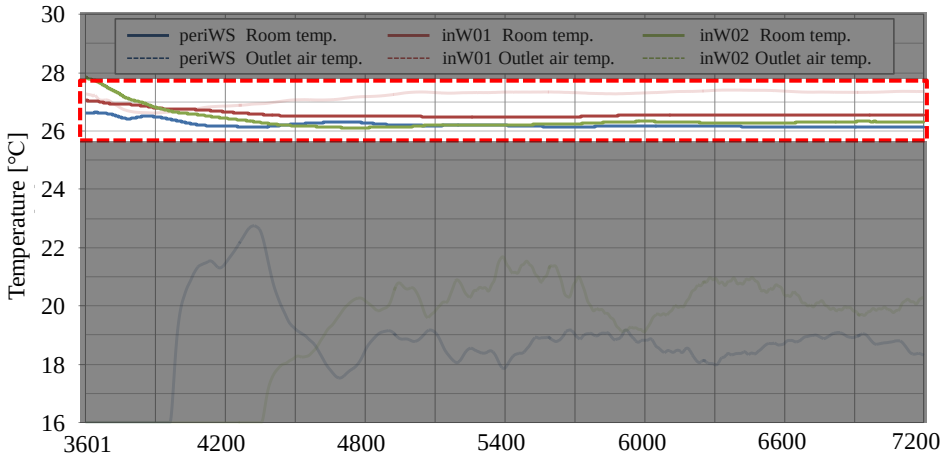
CASE1 :SISO MPC | **CASE2 :MIMO MPC**



In the centralized MPC, the temperature fluctuation range of the two zones with the set temperature of 26 degrees was suppressed compared to CASE1.

4-1. The room temperature and the outlet air temperature

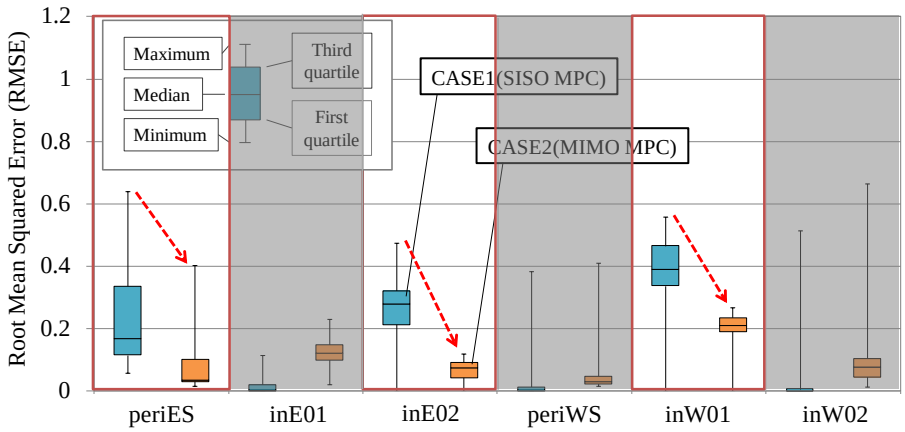
CASE1 :SISO MPC | CASE2 :MIMO MPC



The control error of inW01 with a set temperature of 27 degrees at room temperature was slightly improved.

4-2. A temperature control error of the room temperature

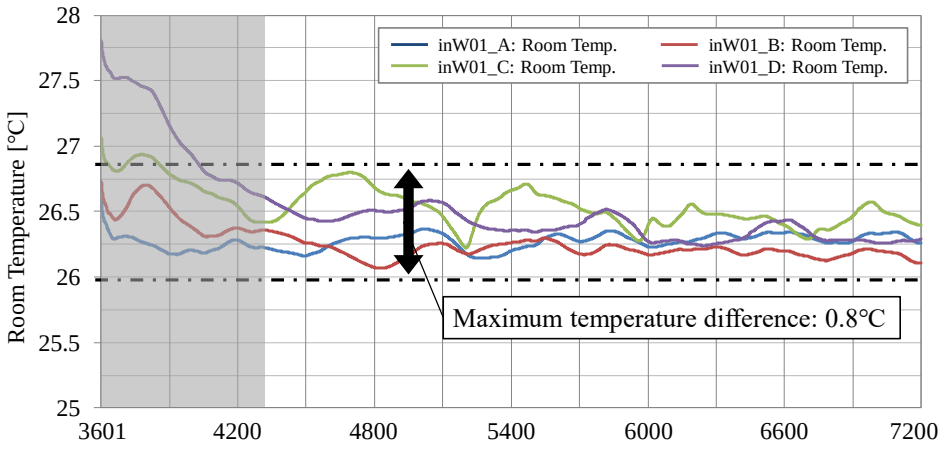
CASE1 :SISO MPC | CASE2 :MIMO MPC



It was confirmed that CASE2 improved control performance in all zones where the set temperature was 26 degrees.

4-3. The room temperature (each point) of the inW01 zone

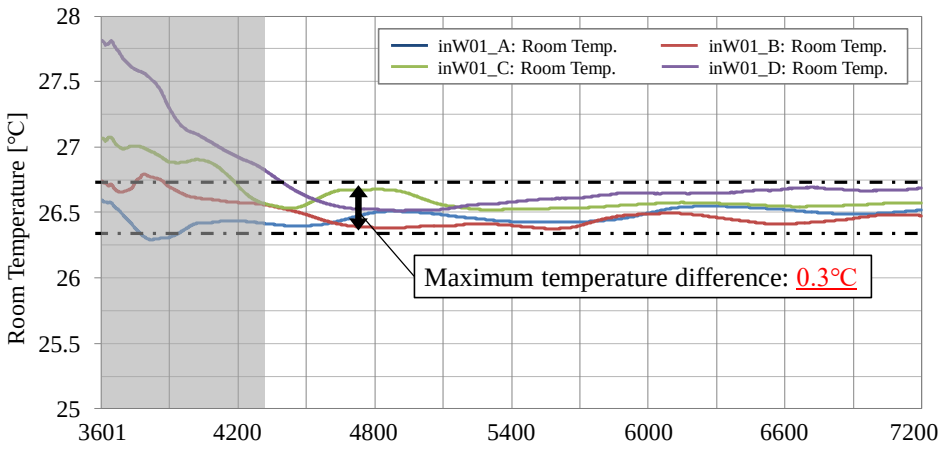
CASE1 :SISO MPC | CASE2 :MIMO MPC



Comparing the behavior of the occupancy-area sensor temperature in the inW01 zone, the temperature fluctuation range in CASE1 is large.

4-3. The room temperature (each point) of the inW01 zone

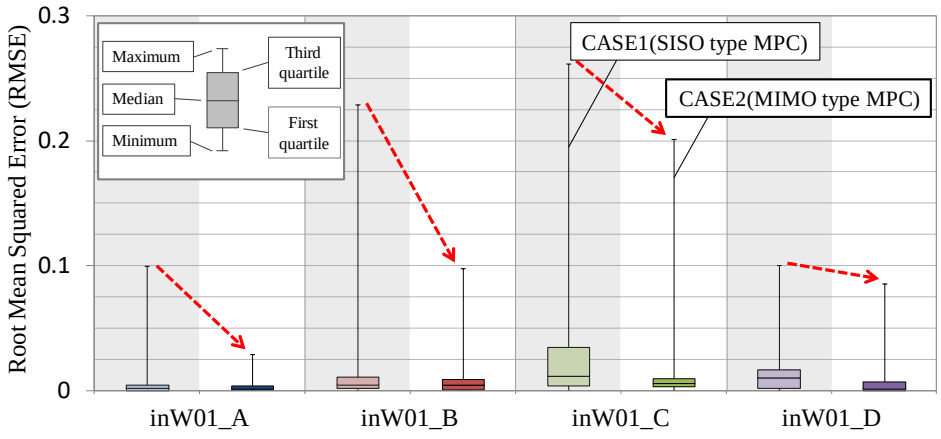
CASE1 :SISO MPC | **CASE2 :MIMO MPC**



In the occupancy-area sensor temperature of the inW01 zone in the centralized MPC, the temperature fluctuation in occupancy-area was suppressed.

4-4. A temperature control error in the Average temperaure

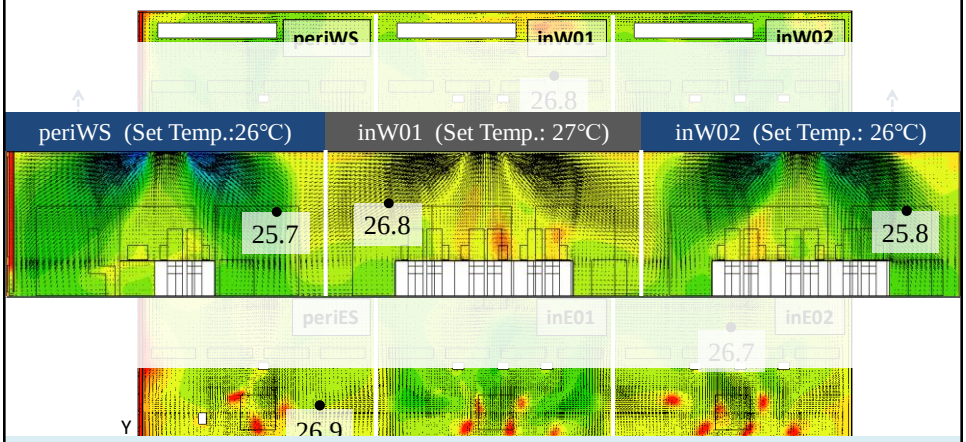
CASE1 :SISO MPC | **CASE2 :MIMO MPC**



The fluctuation of the occupancy-area temperature is suppressed at all four points in the inW01 zone in CASE2.

4-5. The temperature fields and flow fields at 5,400s

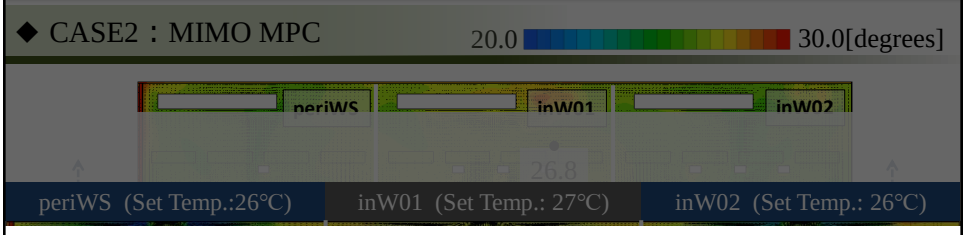
◆ CASE2：MIMO MPC 20.0 30.0[degrees]



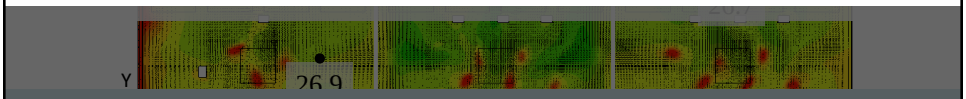
It was also confirmed that the temperature of not only each sensor but also the entire office space is generally controlled to the set temperature of each zone.

4-5. The temperature fields and flow fields at 5,400s

◆ CASE2：MIMO MPC



From the above results, the effectiveness of the MIMO MPC proposed in this research is confirmed.



It was also confirmed that the temperature of not only each sensor but also the entire office space is generally controlled to the set temperature of each zone.

5. Conclusion

Summary

- The improvement of control performance and the reduction effect of mutual interference were confirmed by the introduction of the MIMO MPC for the office space with different set temperatures among each zone.
- The fluctuation range of the outlet air temperatures where the set temperature is 26 degrees is large in SISO MPC but small in MIMO MPC.

Future prospects

∗ In the future, control incorporating multi-objective optimization that simultaneously controls the outlet air temperature and ventilation air volume will be studied.

Thank you for your time and attention.

Minimizing the influence of the **stack effect** and **wind** on the operation of **mechanical exhaust ventilation systems**

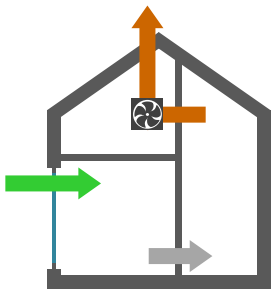
AIVC Conference 2019, Ghent
Samuel Caillou, Romy Van Gaever

1

The Belgian standard NBN D 50-001 permits the use of mechanical exhaust systems (MEV) in dwellings

Natural supply to living spaces → transfer → Mechanical extraction from service spaces

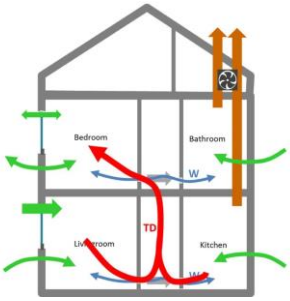
Natural supply: inlets designed at 2 Pa



Rem: MEV systems are called System C in Belgium

2

Wind, stack effect and airtightness influence the operation of MEV systems



- Wind

  flow rate higher windward + lower leeward
- Stack effect

  flow rate higher downstairs + lower upstairs
- Airtightness → airflow through leakages

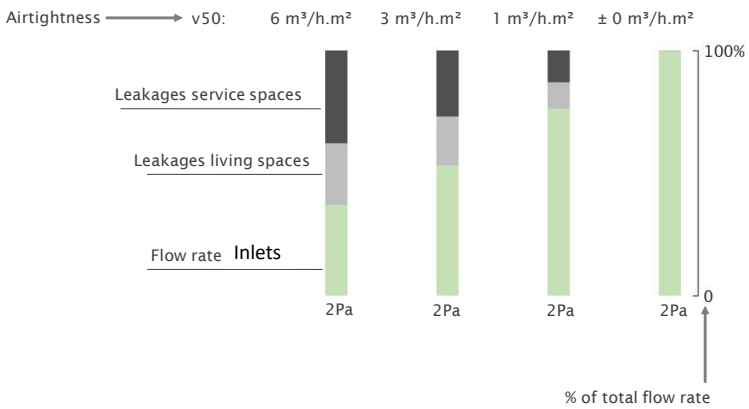
  lower flow rate through inlets

  + infiltrations in service spaces

AIVC conference paper 2017 " The effectiveness of mechanical exhaust ventilation systems in dwellings"

3

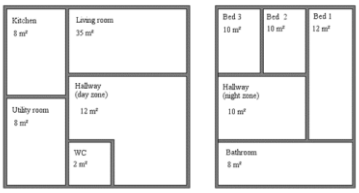
Example of influence of airtightness on MEV systems



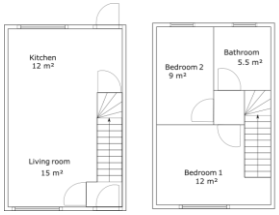
4

A simulation study using Contam investigates solutions to improve the operation of MEV systems in two reference dwelling

Large, detached 3-bedroom house



Small, terraced 2-bedroom house



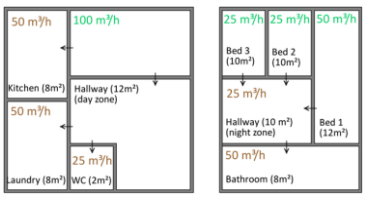
CONTAM
Multizone Airflow and Contaminant Transport Analysis Software

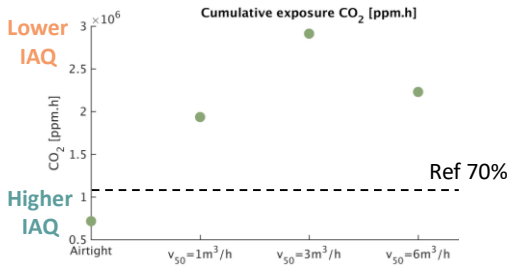
→ CO_2

occupants exposure CO_2–levels during the heating season

5

All solutions are compared to a classical MEV system with air inlets designed at 2 Pa



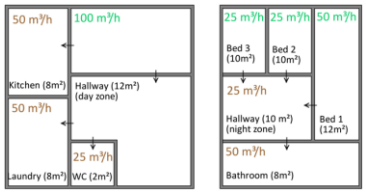


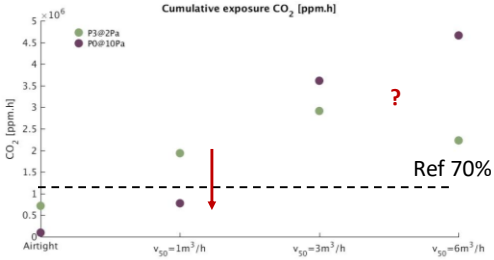
With decreasing airtightness, more airflow through leakages in service spaces due to mechanical driving force.
At very low airtightness, high airflow through all leakages in all spaces
Remark: uniform distribution of leakages!

*Simular results for both reference dwellings

6

Solution 1: MEV system with **smaller air inlets** designed at 10 Pa



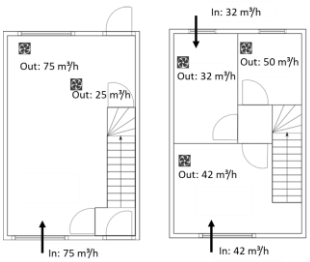


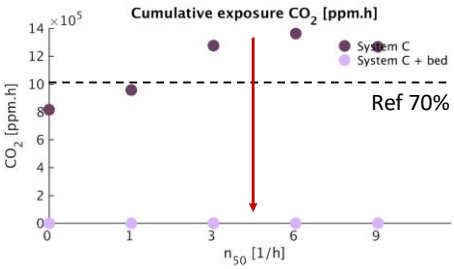
Good airtightness: low levels of occupant exposure to CO_2 due to less variable and more controlled flow
Low(er) airtightness: negative effect of smaller inlets due to less controlled flow as a result of flow through the leakages (in service spaces)

*Simular results for both reference dwellings

7

Solution 2: MEV system with **additional mechanical extraction** in the bedrooms



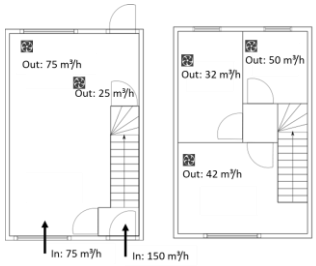


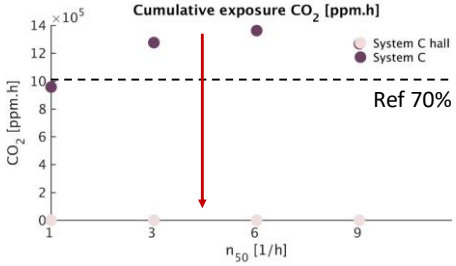
All airtightness: very low levels of occupant exposure to CO_2 due to additional mechanical components
But higher total airflow rates → demand control ventilation recommanded

*Reference dwelling 1: need for additional extraction in living room

8

Solution 3: **air inlet in the entrance hall** and mechanical extraction in all spaces





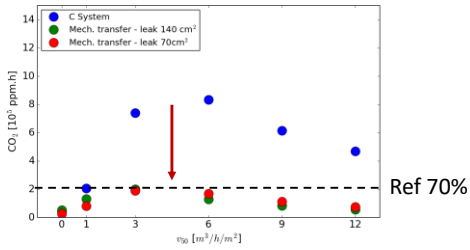
All airtightness: very low levels of occupant exposure to CO_2 due to lower influence of wind and stack effect, and due to additional mechanical components
But higher total airflow rates → demand control ventilation recommanded

*Simular results for both reference dwellings

9

Solution 4: MEV system with **mechanical transfer** openings in the living room and bedrooms





Low(er) levels of occupant exposure to CO_2
Not as efficient due to recycling of air but still valid solution

10

Ineffective solutions to minimise the effect of wind, stack effect and airtightness

- **Increasing the airflow rates** of mechanical extraction
- **Balancing the airflow rates** per floor level
- Using **larger transfer openings** between the spaces in the dwelling

Ineffective, very small improvement of the occupant exposure to CO_2
(Good airtightness: larger transfer openings lead to slightly higher exposure levels)

11

Conclusions

Adding an **local mechanical component** to the classical MEV system leads to a more effective operation of MEV system

↓

Minimizing influence of wind, stack effect and airtightness

↓

But for some solutions:
higher design flow rates → demand control ventilation recommanded

12

Thank to my colleague Romy Van Gaever

- She is currently busy with another kind of project:





13

The results are based upon work supported by
the Federal Public Service Economy (FPS Economy) and
by Innoviris (Brussels Capital Region) in Belgium

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14

40th AIVC-8th TightVent & 6th venticool Conference
15.October.2019

Multi-Objective Optimization of Energy Saving and Thermal Comfort in Thermo Active Building System based on Model Predictive Control

○Yohei Ogawa
The university of Kitakyushu

Yasuyuki Shiraishi
The university of Kitakyushu

The University of Kitakyushu
Shiraishi Laboratory

Architecture with Environment
Shiraishi Lab.

Composition

1. Introduction
Research background and objective

2. Multi-Objective Optimization
An Optimization Method

3. Outline of Optimal Control Method
Model Predictive Control

4. Outline of Analysis
Analysis case/Analysis model/Analysis condition

5. Analysis Result

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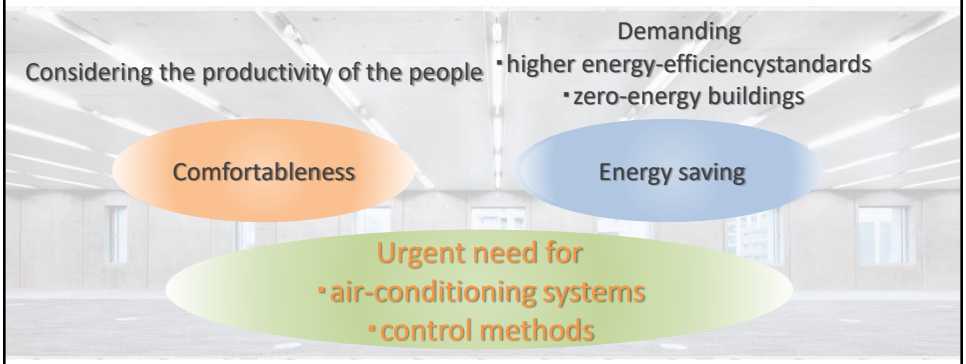
4. Outline of Analysis

   Analysis case/Analysis model/Analysis condition

5. Analysis Result

1. Introduction

There is an urgent need for air-conditioning systems and control methods that are both energy efficient and provide thermal comfort.



As an air-conditioning

Thermo Active Building System (TABS) has been introduced in Japan in recent years.

1. Introduction

About Thermo Active Building System (TABS)

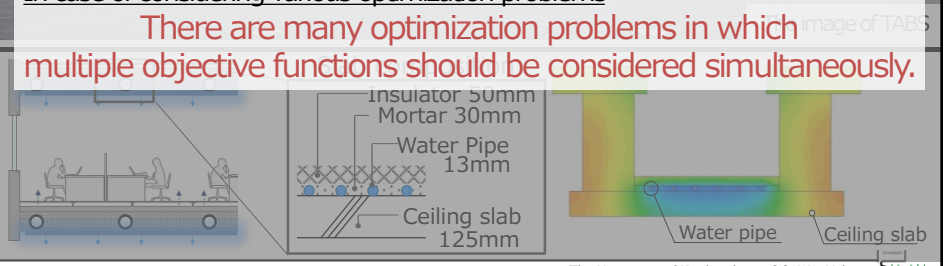
・Higher energy efficiency
・A more comfortable environment for workers
・Cost advantages
・Peak shifting due to the large thermal mass

It is necessary to optimize air-conditioning control*

*reference: Yongjun Sun etc, Peak load shifting control using different cold thermal energy storage facilities in commercial buildings

In case of considering various optimization problems

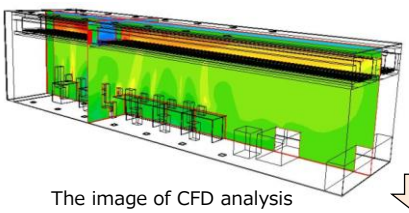
There are many optimization problems in which multiple objective functions should be considered simultaneously.



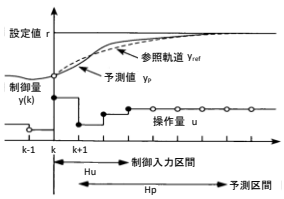
1. Introduction

Previous studies

We have attempted to dynamically control TABS using MPC by targeting half spans of a standard floor, and the effectiveness of this control method has been demonstrated by CFD analysis and numerical simulation using MATLAB/Simulink.



The image of CFD analysis



The image of control method

However, only single-objective optimization for thermal comfort was conducted in these analyses

The present study

We conducted a fundamental examination of multi-objective optimization of thermal comfort and energy efficiency.

Composition

1. Introduction
   Research background and objective
2. Multi-Objective Optimization
   An Optimization Method
3. Outline of Optimal Control Method
   Model Predictive Control
4. Outline of Analysis
   Analysis case/Analysis model/Analysis condition/Analysis result
5. Analysis Result

2. Multi-Objective Optimization

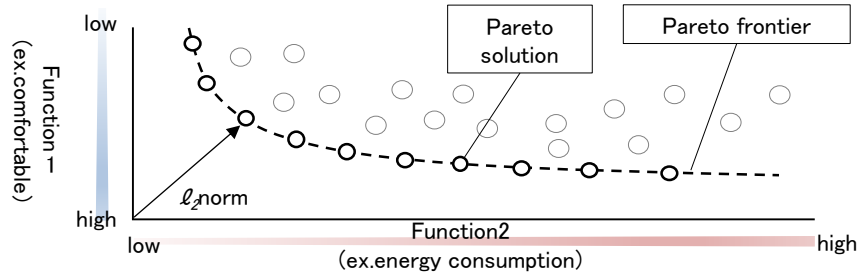
Previous studies

We have determined the optimal operating conditions in an indoor environment using an air handling unit (AHU) and TABS together. The ceiling surface temperature was controlled using MPC with the optimal operating conditions being the target values.

2. Multi-Objective Optimization

Multi-objective optimization is achieved by minimizing or maximizing multiple objective functions within given constraints.

$$minf = \sum_{i=1}^{k} f_i \quad \text{——} \quad (2.1)$$



〈Image of Multi-Objective Optimization〉

➡Weighting is used in the optimization method in this research.

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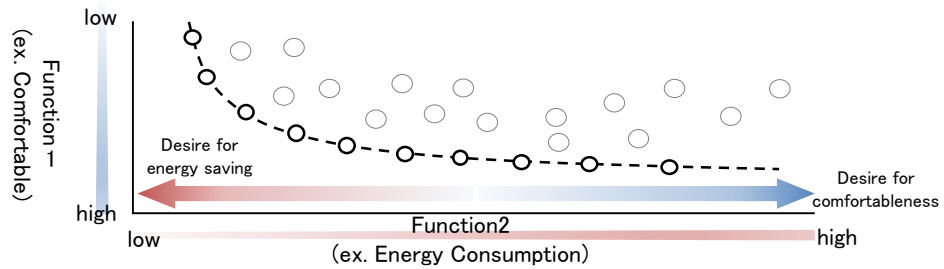
2. Multi-Objective Optimization

In the method we used, each of the Pareto solutions is obtained by solving the weighted sum shown in equation (2.2) as a single objective function.

$$\min_{x \in X} wf = \sum_{i=1}^{k} w_i f_i \quad \text{——} \quad (2.2)$$



〈Image of Multi-Objective Optimization〉

➡A decision maker determines the Pareto solution by setting a weighting for each objective function by using the weighting factor w.

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Composition

1. Introduction
   Research background and objective
2. Multi-Objective Optimization
   An Optimization Method
3. Outline of Optimal Control Method
   Model Predictive Control
4. Outline of Analysis
   Analysis case/Analysis model/Analysis condition/Analysis result
5. Analysis Result

3.Outline of Optimal Control Method

Model Predictive Control(MPC)

MPC is the control method that determines the current value of the optimal manipulated variable (i.e., the water flow rate) while predicting the behavior of a future controlled variable (i.e., the ceiling surface temperature).

- It minimize the error between predicted value and setting value
- It is necessary to predict the movement of future controlled variable at each time interval.

➡We need a model that represents the dynamic causal nexus between manipulated variable and controlled variable.

3.Outline of Optimal Control Method

Model Predictive Control(MPC)

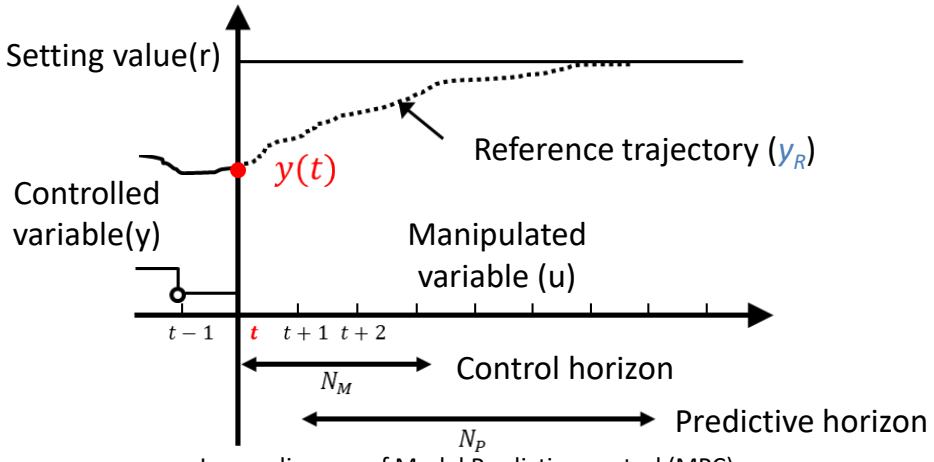


Image diagram of Model Predictive control (MPC)

Caluculate "y_R" approaching to the setting value ideally

3.Outline of Optimal Control Method

Model Predictive Control(MPC)

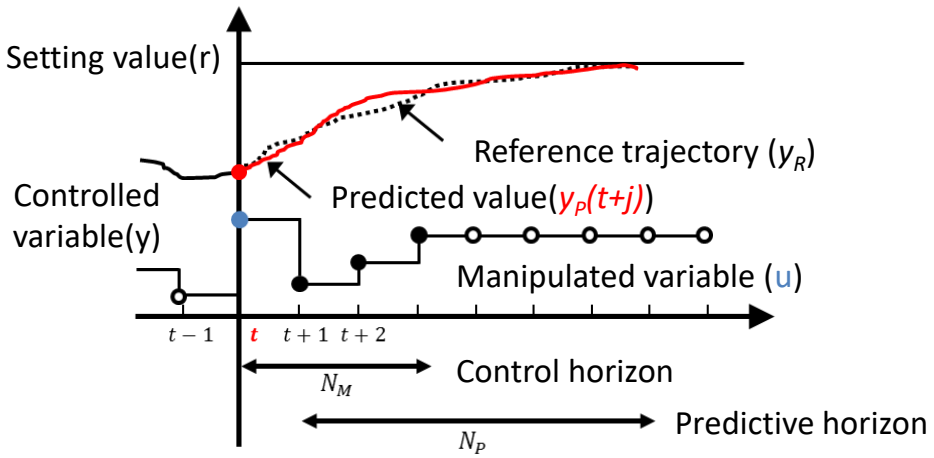


Image diagram of Model Predictive control (MPC)

②Manipulated variable pattern "u" is determined using the least squares method in the predictive horizon

3.Outline of Optimal Control Method

Model Predictive Control(MPC)

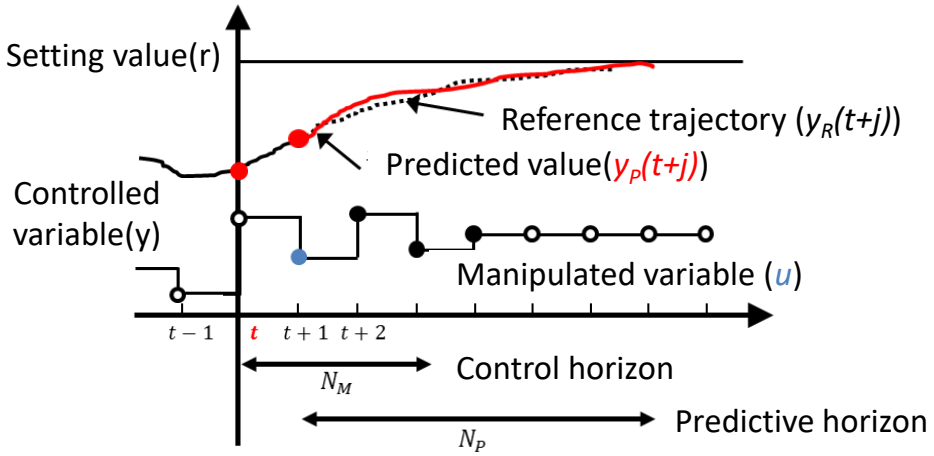


Image diagram of Model Predictive control (MPC)

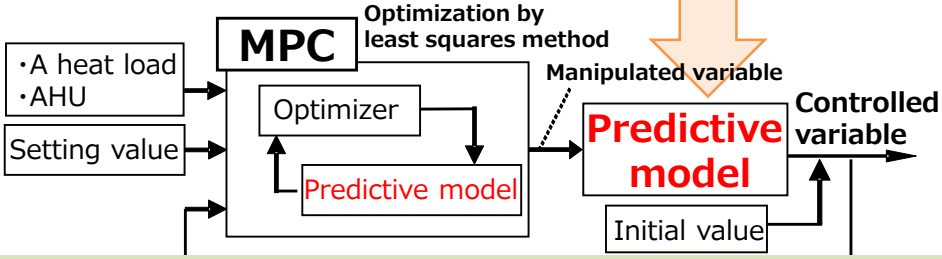
Then calculate the predicted value "$y_P(t+j)$" and the manipulated variable "u" again

2.Outline of analysis method

Model Predictive Control(MPC)

Predict the movement of the future controlled variable at each time step

Express the dynamic relationship between the manipulated variable and the controlled variable



One-dimensional prediction model (transfer function model) was created based on CFD analysis and used this as the prediction model.

3.最適制御手法

Equation (3.1) shows the evaluation function of MPC.

Evaluation function $J(z_k) = J_y(z_k) + J_u(z_k) + J_{\Delta u}(z_k)$ —— (3.1)

$$J_y(z_k) = \sum_{j=1}^{n_y} \sum_{i=1}^{H_p} \left\{ \frac{w_{i,j}^{y}}{S_j^{y}} [y_{ref}(k+i|k) - y_j(k+i|k)] \right\}^2$$

Weight of controlled valuable

$$J_u(z_k) = \sum_{j=1}^{n_u} \sum_{i=0}^{H_p-1} \left\{ \frac{w_{i,j}^{u}}{S_j^{u}} [u_j(k+i|k) - u_0] \right\}^2$$

Weight of input

$$J_{\Delta u}(z_k) = \sum_{j=1}^{n_u} \sum_{i=1}^{H_p-1} \left\{ \frac{w_{i,j}^{\Delta u}}{S_j^{u}} [u_j(k+i|k) - u_j(k+i-1|k)] \right\}^2$$

Weight of input move

An optimal solution is obtained by minimizing the evaluation function $J(z_k)$ using the least squares method or the like.

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Model Predictive Control

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Analysis case/Analysis model/Analysis condition/Analysis result

5. Analysis Result

4.Outline of Analysis

Outline of Analysis

We used a Simulink analysis model whose effectiveness was demonstrated in previous research to conduct case studies in which multi-objective optimization using MPC was performed with manipulated and controlled variables that had been given various weightings.

Objective function①(Comfortableness = Error from target value in ceiling surface temperature)

Objective function ②(Energy saving = Compare the integrated water flow rate with other cases based on Case0)

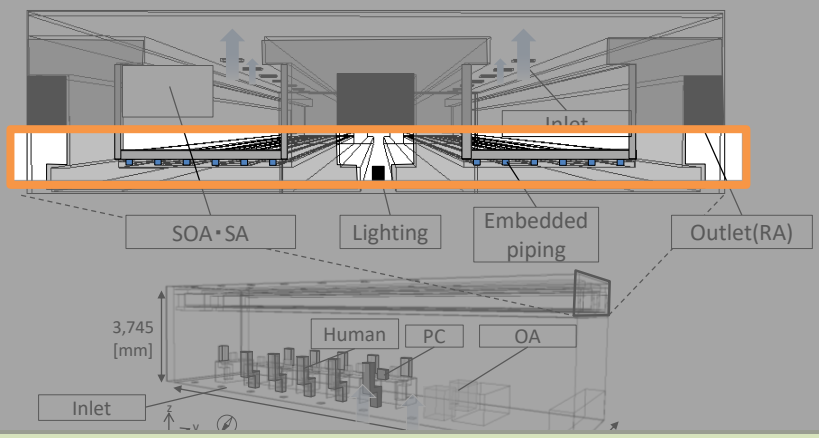
Analysis case

	Weighting factor			Remarks
	Control variable	Manipulated variable	Manipulated variable movement	
	w^y	w^u	$w^{\Delta u}$	
Case0	0.9	0.0	0.1	Comfort priority
Case1	0.45	0.45	0.1	—
Case2	0.3	0.6	0.1	Energy efficiency priority

4.Outline of Analysis

Analysis model

We conducted case studies using unsteady CFD analysis.



To improve the analysis accuracy, a multi-block, which is a mesh generation technique, was inserted only around the embedded piping.

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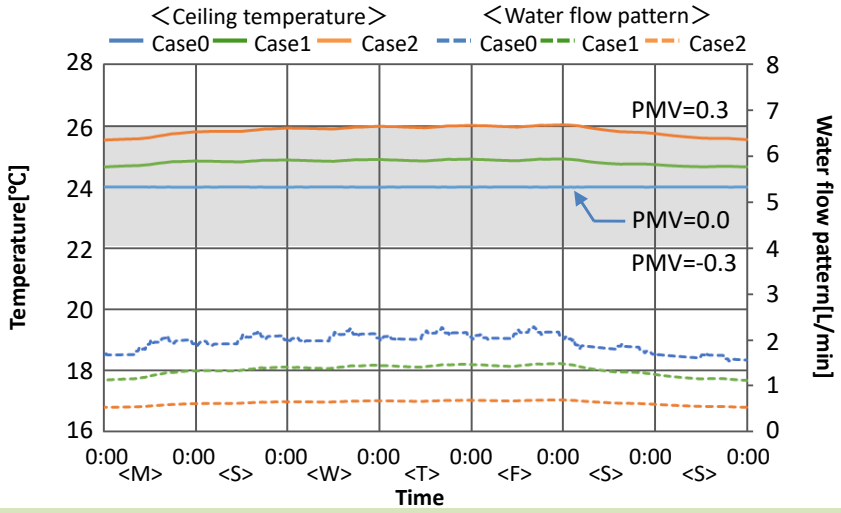
5. Analysis Result

5.Analysis Result

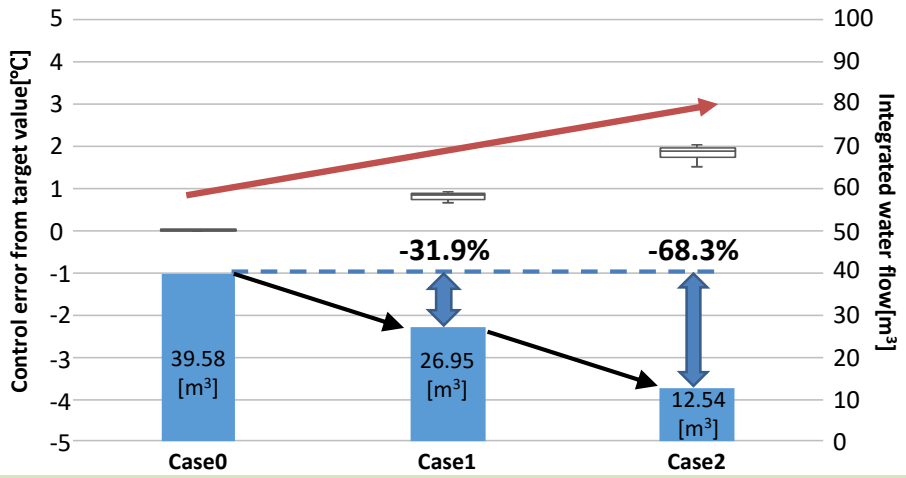
The results for the ceiling surface temperature and water flow pattern



It is inferred that the minimization of the water flow rate is regarded as important because the weight of the controlled valuable is reduced.

5.Analysis Result

Control error from target value in ceiling surface temperature and reduction effect of water flow rate



A reduction effect of 30% in Case 1 and of 68% in Case 2 were obtained in comparison with Case 0.

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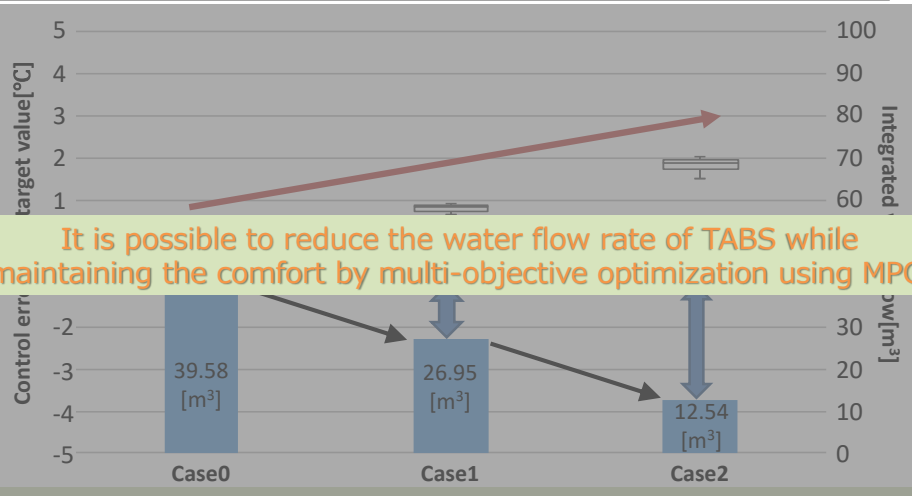
5.Analysis Result

Control error from target value in ceiling surface temperature and reduction effect of water flow rate



It is possible to reduce the water flow rate of TABS while maintaining the comfort by multi-objective optimization using MPC.

A reduction effect of 30% in Case 1 and of 68% in Case 2 were obtained in comparison with Case 0.

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Conclusion

We conducted a fundamental study on multi-objective optimization of thermal comfort and energy saving by numerical simulation using MATLAB/Simulink and CFD.

Summary

- It was confirmed that multi-objective optimization could reduce energy consumption while maintaining thermal comfort.
- In the case prioritized energy saving, it was shown that up to 68.3% of energy saving effects can be realized in comparison with reference case.

Thank you for listening

補足資料

4.Outline of Analysis

Analysis conditions

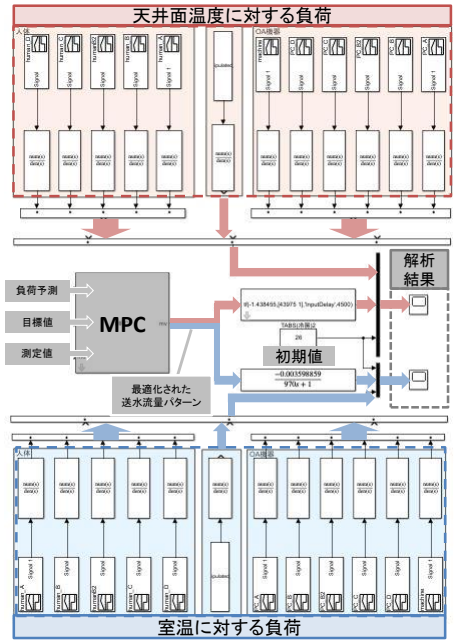
Prediction Model		Transfer function model
Sample time		TABS:1,800s, AHU:5s
H_p(Prediction horizon)		48step
H_u(Control horizon)		24step
Internal load	Human	6.8W/m^2
	OA equipment	5.6W/m^2
	Lighting	8.8W/m^2
Under floor air conditioning system	Flow rate	430~1,040m^3/h
	Air flow temperature	26℃
TABS	Water flow temperature	16℃
Constraints		
u(TABS)		$0 \leq u(k) \leq 4$
Δu(TABS)		$0 \leq \Delta u(k) \leq 4$
Weighting factor		$w^y + w^u + w^{\Delta u} = 1$ $w^y, w^u, w^{\Delta u} \geq 0$

4.Outline of Analysis

Analysis conditions

Domain	3.600m(x)×15.300m(y)×3.745m(z)	
Mesh	Root block	53(x)×140(y)×56(z) =415,520
	Parent block	115(x)×264(y)×12(z)=364,320
	Piping block	131(x)×296(y)×3(z)=116,328
	total	=896,168
Turbulence model	High Re-type standard k − ε model	
Inlet of air flow	Flow rate:430m^3/h (min), 1,040m^3/h(max), $k_{in}① = \frac{3}{2}(U_{in}① \times 0.05)^2$, $\varepsilon_{in}① = C_\mu \cdot k_{in}①^{\frac{3}{2}}/l_{in}$	
Outlet of air flow	Underfloor air conditioning system:Free slip, RA:Constant flow rate and free slip	
Inlet of enveloped pipe	Temperature:16℃, Flow rate:4L/min, $k_{in}② = \frac{3}{2}(U_{in}② \times 0.05)^2$, $\varepsilon_{in}② = C_\mu \cdot k_{in}②^{\frac{3}{2}}/D$	
Outlet of enveloped pipe	Free slip	
Boundary conditions	Velocity:Logarithm law, Temperature:Logarithm law	
Internal heat load	Lighting	3.3W/m^2
	OA	10.0 W/m^2
	Human	4.3 W/m^2

$U_{in}①$: Wing speed[m/s], $k_{in}①$:Turbulence energy[m ^{2}/s^2], $\varepsilon_{in}①$:Dissipation rate of $k_{in}①$ [m^2/s^3], C_μ: Model constant (= 0.09)[−], l_{in}: Length scale[m], $U_{in}②$: Water speed[m/s], $k_{in}②$:Turbulence energy of water [m^2/s^2], $\varepsilon_{in}②$:Dissipation rate of $k_{in}②$ [m^2/s^3],D: Inner diameter of piping [m]



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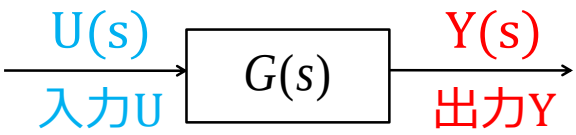
補足. 伝達関数

伝達関数とは



1入力1出力プロセスのブロック線図表現

$$G(s) = \frac{Y(s)}{U(s)}$$

$G(s)$は、入力uから出力yへの伝達関数
と呼ばれ、プロセスの入出力関係を表している

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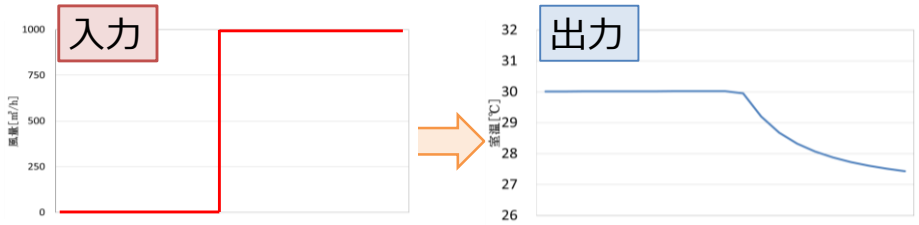
補足. 伝達関数

一次遅れ+むだ時間系

空調空間を対象とした流れ場,温度場の入出力変化



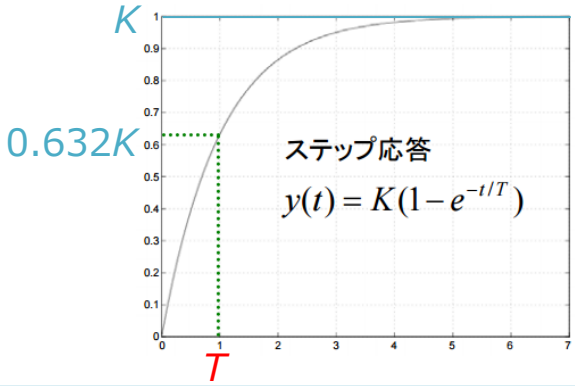
時間の一階微分方程式で表現される

一次遅れ+むだ時間系の入出力モデルで近似が可能

$$y(t) = K(1 - e^{-\frac{t}{T}}) \quad [3.1]$$

補足. 伝達関数

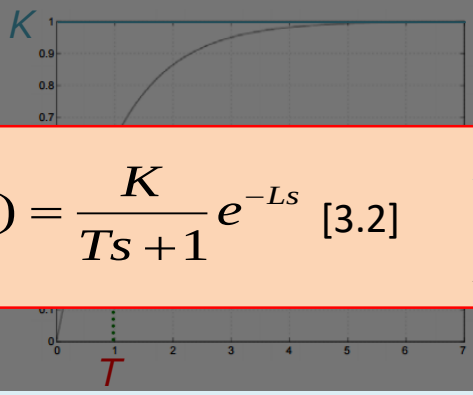
伝達関数の算出(一次遅れ+むだ時間系要素)



K :出力されたステップ応答の定常値
T :$y(t)$ の定常値K の63.2%に達するまでの時間
L :入力を与えて出力に変化が出始めるまでの時間

補足. 伝達関数

伝達関数の算出(一次遅れ+むだ時間系要素)



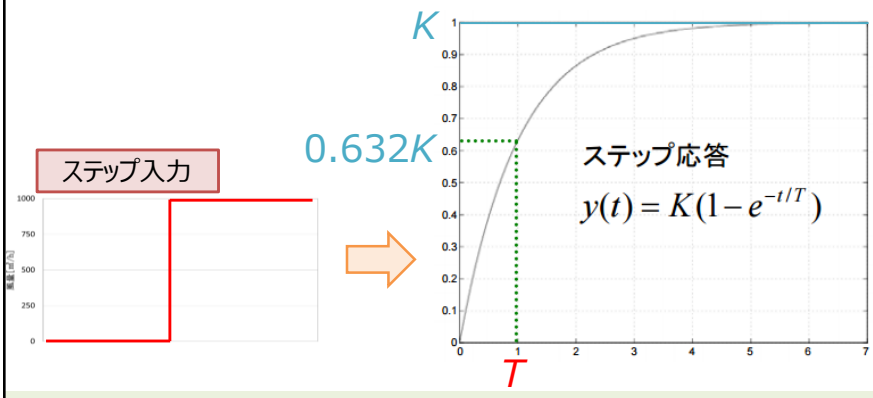
$$G(s) = \frac{K}{Ts+1} e^{-Ls} \quad [3.2]$$

K:定常ゲイン
T:時定数
L:むだ時間

K :出力されたステップ応答の定常値
T :$y(t)$ の定常値*K* の63.2%に達するまでの時間
L :入力を与えて出力に変化が出始めるまでの時間

4.1解析・制御手法概要

伝達関数の算出（一時遅れ+むだ時間系要素）



K :出力されたステップ応答の定常値
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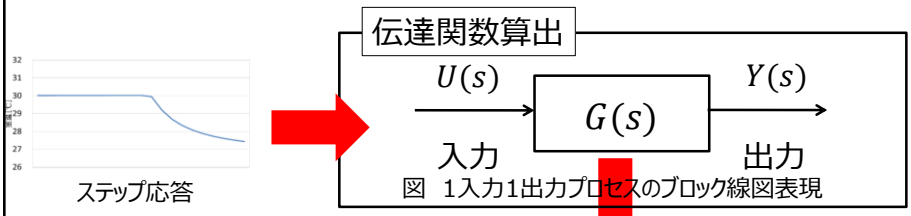
L :入力を与えて出力に変化が出始めるまでの時間

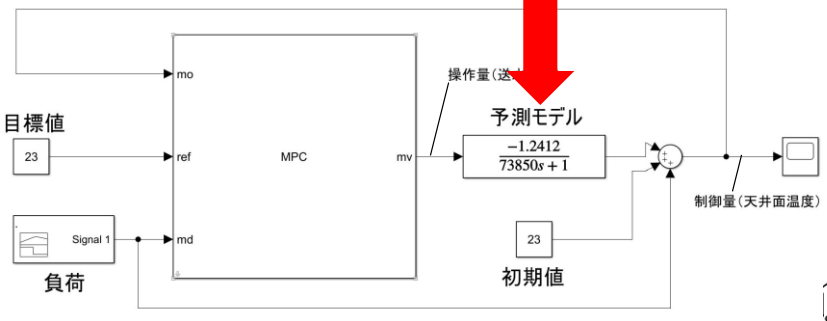
4.1解析・制御手法概要

予測モデルの作成



ステップ応答

図　1入力1出力プロセスのブロック線図表現



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Two Case Studies on Ventilation for Indoor Radon Control

Justin Berquist MASc, Peng

Liang Grace Zhou, Jeffrey Whyte, Yunyi Ethan Li, Mark Vuotari, and Gang Nong

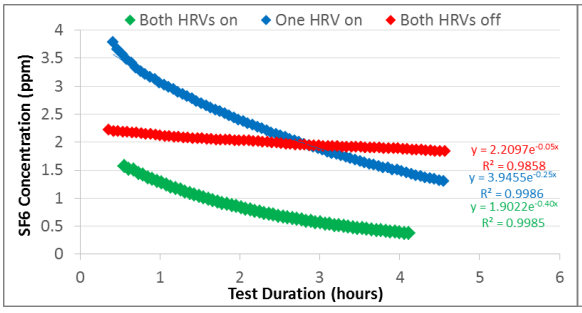
The 40th AIVC Conference
Ghent October 15-16, 2019

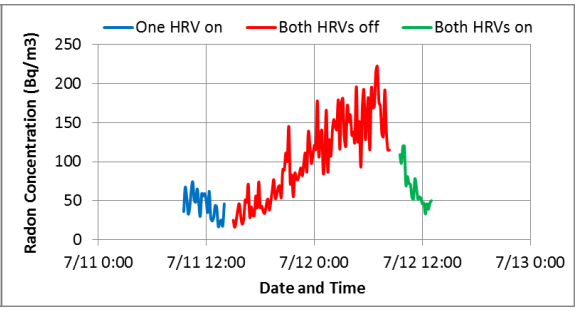


Introduction

- **Radon overview**
  - naturally occurring radioactive gas
  - gives off alpha particle radiation during decay
  - second leading cause of cancer, after smoking[1]
- **Radon risks in buildings**
  - Canadians spend over 90% of their time indoors[4]
  - 7% of Canadian homes contain radon levels above the Canadian guideline[3]
  - responsible for approximately 16% of Canadian deaths annually[2]
- **Radon prevention methods**
  - increase overall ventilation rates
  - active/passive soil depressurization
  - avoid depressurization inside the building
  - seal gas entry routes into the building

Results – Home #1

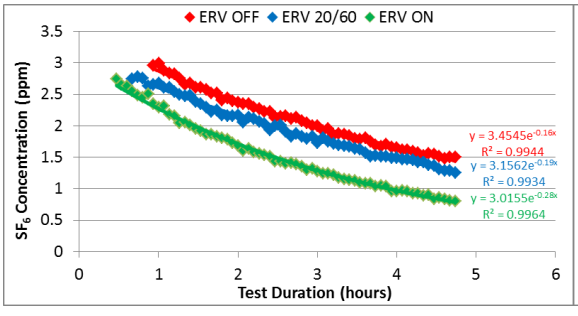


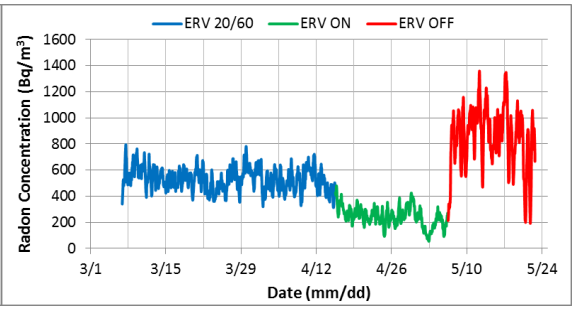


Control Strategy	Average (Bq/m³) AlphaGUARD	Minimum (Bq/m³) AlphaGUARD	Maximum (Bq/m³) AlphaGUARD	ACH (h^{-1})
Both HRVs off	106	16	222	0.05
1 HRV on	44	17	74	0.24
Both HRVs on	66	33	120	0.40

3

Results – Home #2





Control Strategy	Average (Bq/m³) Corentium	Minimum (Bq/m³) Corentium	Maximum (Bq/m³) Corentium	ACH (h^{-1})
ERV 20/60	537	314	767	0.19
ERV On	242	58	424	0.28
ERV Off	872	193	1359	0.16

4

Summary & Conclusion

- **Summary**
  - ventilation rates in two homes were mechanically varied
  - radon reduction was measured
- **Findings**
  - studies using a larger number of homes would be beneficial for evaluating ventilation as a solution for radon control
  - both the initial radon concentration and the natural ventilation rate of the home should be considered when deciding whether to use ventilation to mitigate against radon
- **Future Work**
  - long-term radon monitoring in a larger sample of air tight and leaky homes with elevated radon levels

References

1) American Cancer Society. 2015. “Radon and Cancer.”
2) Chen, J., Moir, D., and Whyte J. 2012. Canadian Population Risk Of Radon Induced Lung
3) Cancer: A Re-Assessment Based On The Recent Cross-Canada Radon Survey. Radiation Protection Dosimetry (2012), Vol. 152, No. 1–3, pp. 9–13.
4) Khan, Selim M., Daniel Krewski, James Gomes, and Raywat Deonandan. 2018. “Radon, an Invisible Killer in Canadian Homes: Perceptions of Ottawa-Gatineau Residents.” *Canadian Journal of Public Health*.
5) Shammas, Nazih K. and Lawrence K. Wang. 2009. “Shammas 2009.Pdf.” in *Handbook of Advanced Industrial and Hazardous Waste Treatment*.

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THANK YOU

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National Research Council Canada | Conseil national de recherches Canada

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Influence of ventilation on Radon Concentration

A case study in Spain

Sonia García-Ortega Eduardo Torroja Institute for construction sciences ETcc - CSIC
Pilar Linares-Alemparte Eduardo Torroja Institute for construction sciences ETcc - CSIC

Motivation

Part of the proyect BIA2014-58887-R. Optimization of mitigation solutions against indoor radon and development of a design method for protective measures.

We collaborate with Ministerio de Fomento (Development Ministry) to elaborate an inforce section about radon to be include in the Spanish Building Code.



This study helps us to improve the knowledge about existing real buildings in Spain and how ventilation influences radon concentration. (Ventilation is also inforce in Spain according with Building Code).

Existing building

The case study is a social centre that belongs to the City Council of Torrelodones, Madrid (Spain). The building is placed above granite rock which is common in the area.





Figure 1. Entrance and lateral (from GoogleMaps)

Existing building

A mechanical ventilation system with heat recovery was installed: supply in more usable areas to increase pressure and reduce radon inlet.
The monitored rooms were the kitchen and the fireplace room. The kitchen presents an acceptable level of airtightness whereas the fireplace room does not.

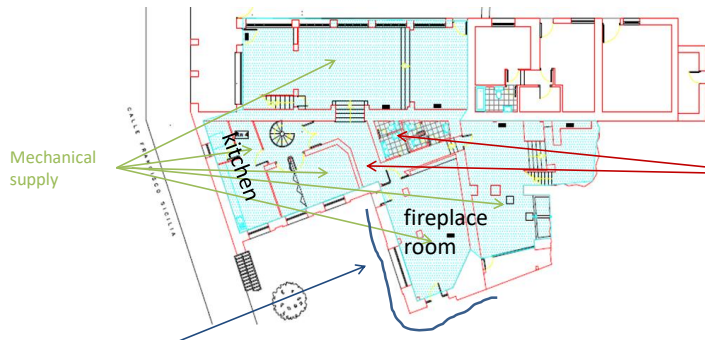


Figure 2. Main floor of the building (in light blue)

Test of ventilation solutions

Constant ventilation flow: 75 m³/h

It was observed a marginal change in radon concentration in the fireplace room, however it was relevant in the kitchen, perhaps because of the higher level of air tightness of the envelope of the kitchen.

Table 1. Initial average radon concentration (Bq/m³) during November 2017

Room	No ventilation	Constant ventilation 75 m³/h
Fire place room	566	547
Kitchen	437	370

Test of ventilation solutions

Constant ventilation flow: 200 m³/h

Table 3. Average radon concentration (Bq/m³) with constant ventilation flow of 200 m³/s

	Fireplace room		Kitchen	
Period of time	No ventilation	Constant vent. 200 m³/h	No ventilation	Constant vent. 200 m³/h
02/10-17/10		341		140
18/10-30/10	495		359	
31/10-15/11[1]		338		260
16/11-02/12		390		364
03/12-21/12	329		364	
Average	**412**	**356**	**361**	**254**

[1] An accidental disconnection of the ventilation system occurred at this period of time.

Ventilation and not ventilation periods were alternated to reduce the effect of occupants behaviour and climatic and seasonal variations.

Test of ventilation solutions

Constant ventilation flow: 350 m³/h

Table 2. Average radon concentration (Bq/m³) with constant ventilation flow of 350 m³/s

Period of time	Fireplace room		Kitchen	
	No ventilation	Constant vent. 350 m³/h	No ventilation	Constant vent. 350 m³/h
05/03 -19/03	171		81	
20/03 - 24/04		168		68
25/04 - 02/05	258		245	
03/05 - 16/05 (1)		206		66
17/05 - 03/06	414		196	
20/06 - 01/07(2)		341		63
02/07 - 17/07	473		319	
18/07 - 01/08		351		62
02/08 - 13/08	543		207	
14/08 - 30/08		469		44
Average	**372**	**307**	**209**	**60**

(1) An accidental disconnection of the system occurred at this period of time.

(2) On 05/06/2018 an opening above the doorway between fireplace room and corridor was covered.

7

Test of ventilation solutions

Constant ventilation flow: 350 m³/h

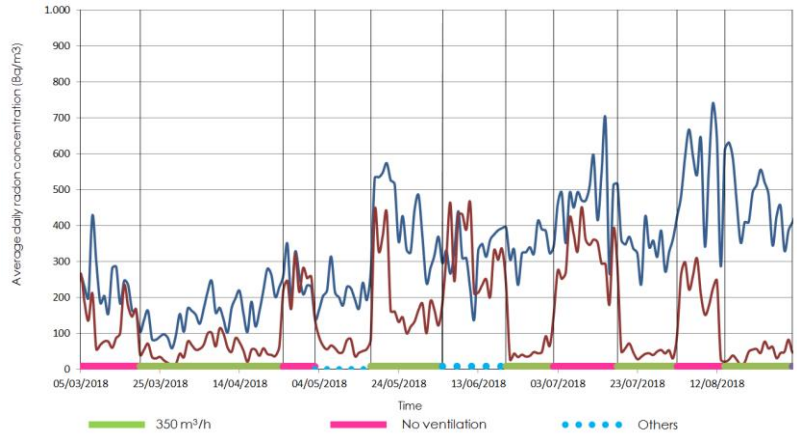


Fig. 3. Average daily radon concent. levels (Bq/m³) in fire place room (blue) and kitchen (red)

8

Results

Ventilation ratio of 75 m^3/h, a marginal change in radon concentration was observed in the fireplace room, and a relevant change in the kitchen, perhaps because of higher air tightness of the envelope of kitchen.

Ventilation ratio of 200 m^3/h , reduction of 13.5% in the fire place room and 30% in the kitchen. Even with a smaller ventilation flow, the kitchen keeps providing the better results due to its higher airtightness and the pressurization.

Ventilation ratio of 350 m^3/h, reduction of 17% in the fire place room and 71% in the kitchen. The bigger reduction in the kitchen could be explained because of the airtightness of this room that is probably contributing to create a pressurization that prevents radon gas from penetrating from soil.

Radon concentration is always lower with ventilation, sometimes enough to reduce the concentration of radon to acceptable levels.
Other ventilation options and occupant roles have been studied but not included in this communication.

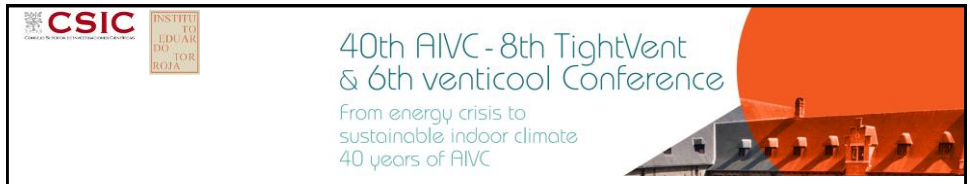
Conclusions

Even little ventilation can lower radon concentration up to acceptable levels.

The air supply was particularly efficient in the kitchen, because of its airtightness that helped to create a pressurization preventing radon from entering the building from the soil. In the fire place room was more efficient to have a less airtight room, ventilating to other parts of the building.

Mechanical ventilation system helped reducing moderate levels of indoor radon in an existing building. The reduction was more efficient with a higher ventilation rate, as expected.

Control ventilation could be used to reduce moderate radon concentration, but it is important to control the airtightness of the building.



Thanks for your attention
Any question?

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Linares-Alemparte, Pilar plinares@ietcc.csic.es

Building Quality Department. Eduardo Torroja Institute for construction sciences ETcc - CSIC

Acknowledgements:

BIA2014-58887-R. Optimization of mitigation solutions against indoor radon and development of a design method for protective measures.

Francisco Saro (Torrelodones Council), Alberto Rodríguez (Siberzone) and Borja Frutos (IETcc-CSIC).

Energy and Indoor Air Quality Analysis of MA, DV and RDV Systems

Walid Chakroun, PhD
Sorour Alotaibi, PhD
Kuwait University

Nesreen Ghaddar, PhD
Kamel Ghali, PhD
American University of Beirut

1

Background

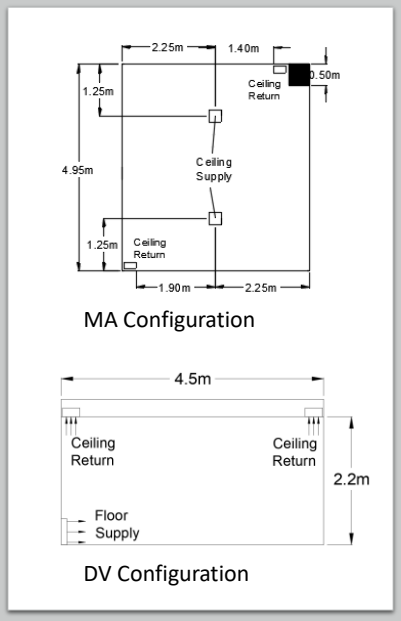
Indoor pollutants and particles pose a threat to human health as people spend 90% of their time in indoor spaces.

A proper ventilation system should remove indoor air pollutants, reduce particle depositions, while saving energy.

Three ventilation systems were analyzed:

- Displacement Ventilation (DV)
- The mixed air conventional ceiling supply and return (MA),
- Reversed Displacement Ventilation (Reversed DV)

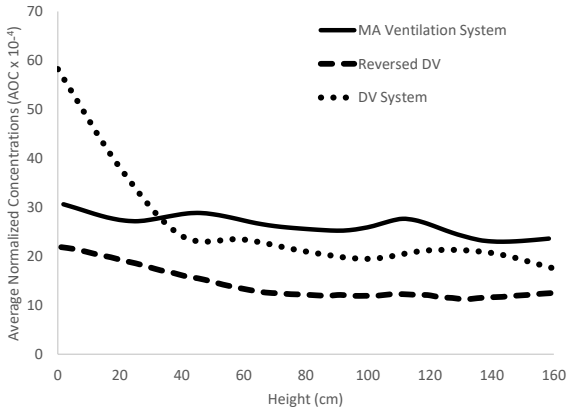
2



Experimental Setup

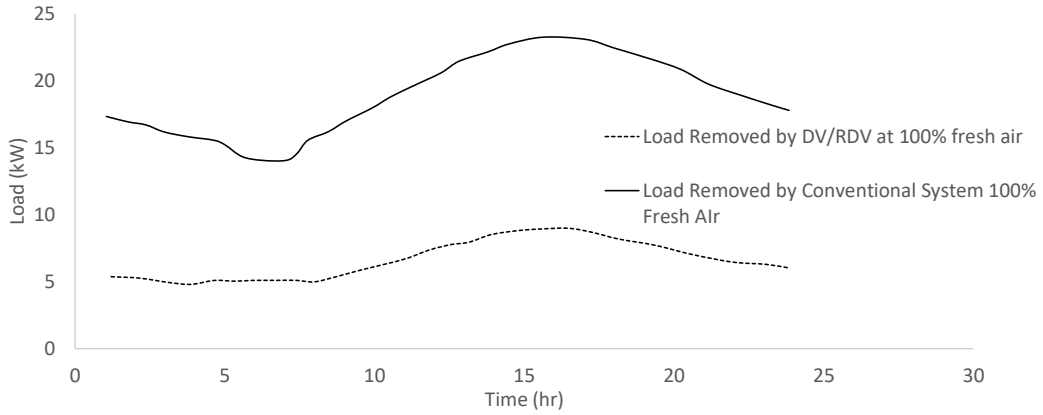
- Two system were tested experimentally:
  1. MA
  2. DV
- Particles of 2.5 μm were generated near the floor level
- Particle Concentrations were measure in several positions
- The Average normalized particle concentrations (AOC) were computed by:
- $AOC = \frac{\text{particle concentrations at a given position}}{\text{the total particle concentration generated}}$

Particle Concentrations for MA, DV and RDV



- DV system confined more particles to the floor, which can be dangerous for toddlers
- The Reversed DV had the lowest AOCs in the room as more particles were removed

Coil Load Analysis



The DV/RDV coil load was lower by 53% than the MA ventilation system, at 100% fresh air

5

Conclusions

A proposed Reversed DV system was able to remove far more particles, providing a better IAQ than both the DV and MA system

The Reversed DV will additionally contribute to reducing the energy consumption by almost 53% that the MA system.

6

The Influence of Indoor Air Stability and Ventilation on Pollutant Transport in the Breathing Microenvironment

Xiaorui Deng, and **Guangcai Gong***

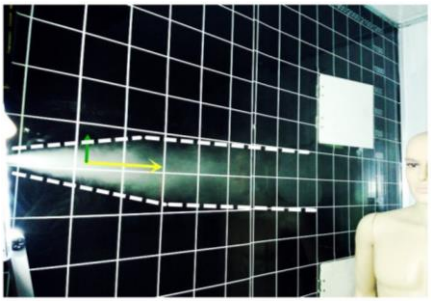
College of Civil Engineering, Hunan University, China

10/15/2019

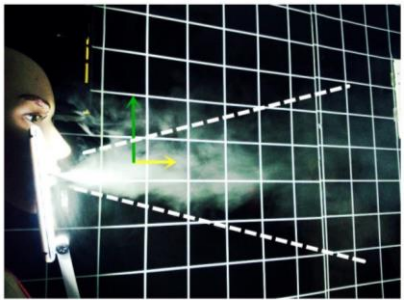
0

Introduction

What is indoor air stability?

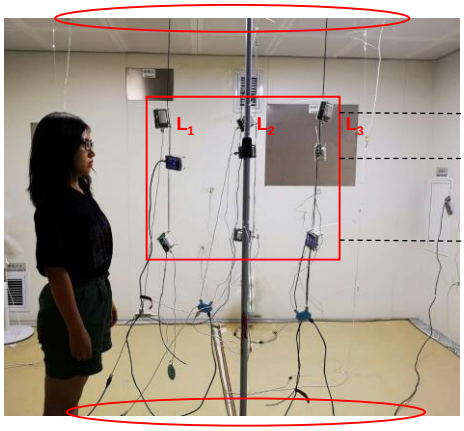


Stable (dT/dy > 0)



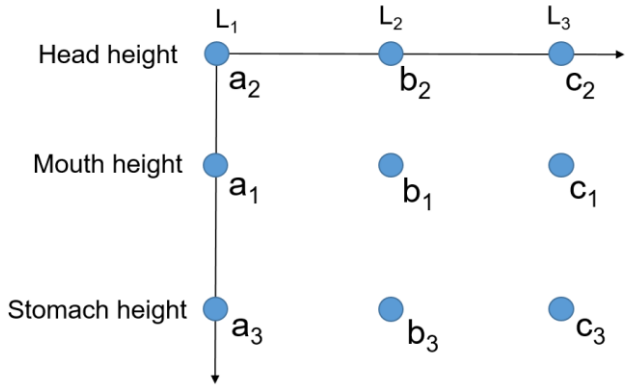
Unstable (dT/dy < 0)

Experimental setup



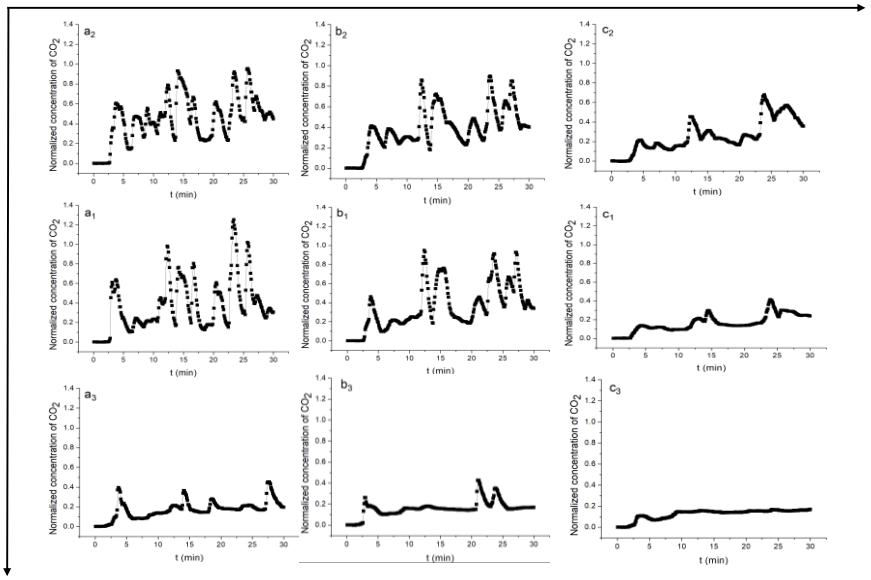
2

The relative positions of measuring points in the breathing microenvironment



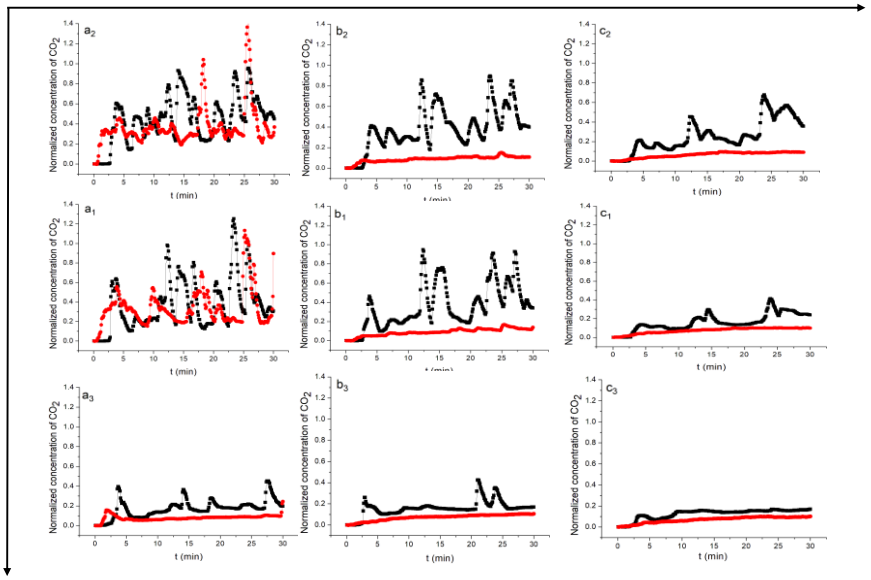
3

Results — Stable



4

Results — Stable — Unstable



5

Conclusion

- Indoor air stability plays a stronger role in air distribution and pollutant transport in the displacement ventilated room.
- Stable condition will lead to air stagnation and heavy pollutant accumulation in the breathing microenvironment.
- Unstable condition removes pollutant effectively and is suggested to be considered by architects or engineers when designing buildings.

5

Acknowledgements
We thank Prof Gary R. Hunt for his thoughtful advice and generous help on this presentation.

CO_2 concentrations were normalized as follow

$$C=\frac{C_i-C_0}{C_0}$$

In (1) C_i is the instantaneous concentration of CO_2 (ppm), C_0 is the background concentration of CO_2 of each experiment (ppm).

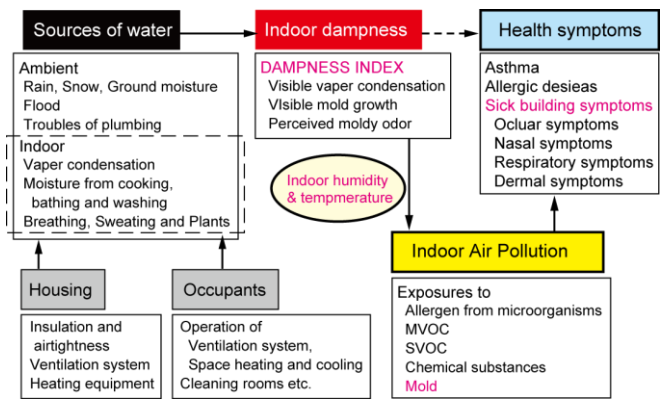
Indoor Environment and Adverse Health Symptoms among Children under Home Damp Conditions

K. Hasegawa (Akita Prefectural University)
N. Kagi, N. Kanazawa, J. Sakaguchi,
N. Shinohara, Y. Shiraishi, T. Mitamura

Akita Prefectural University
秋田県立大学

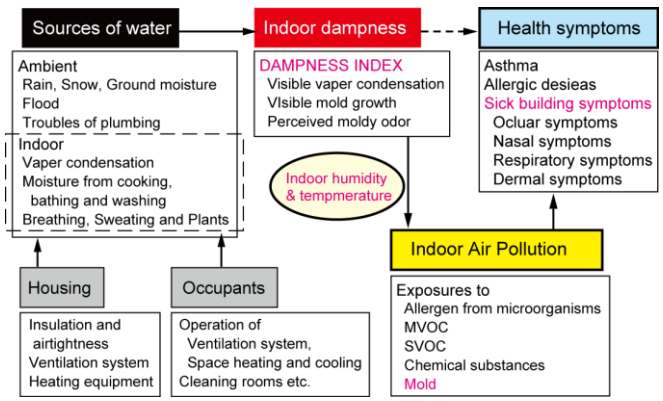
INTRODUCTION(1/2)

- INDOOR DAMPNESS is associated with adverse health symptoms among children.
- INDOOR ENVIRONMENT related to indoor dampness has not been revealed yet.



INDOOR DAMPNESS INDEX(1/2)

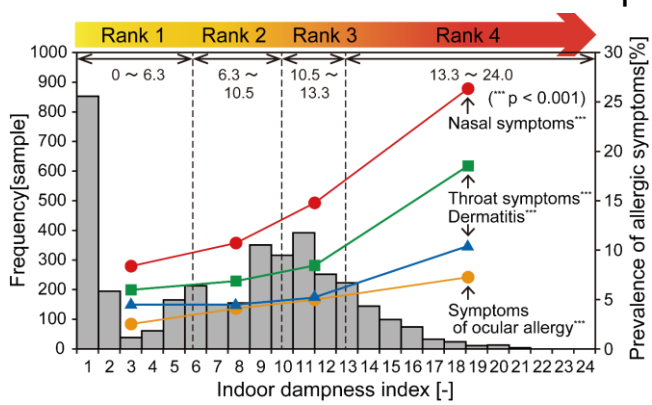
- In this paper, Firstly, DAMPNESS INDEX
- The estimation method for home dampness using occupants self-reported answers about dampness(vapor condensation, mold growth...)



3

INDOOR DAMPNESS INDEX(2/2)

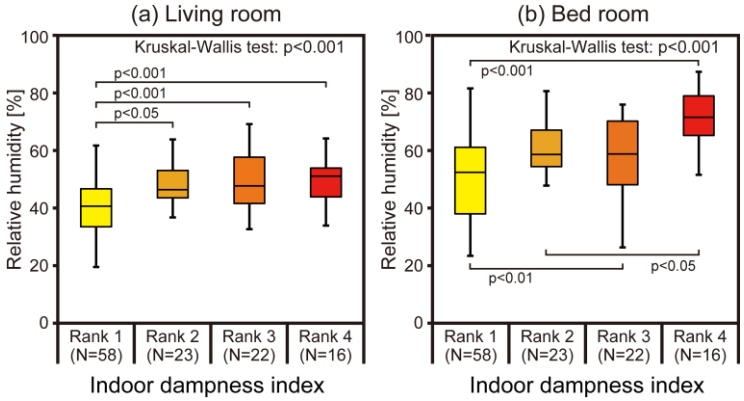
- In this paper, Firstly
  - DAMPNESS INDEX ranges from 0 to 24, and its values were classified into four ranks.
  - Rank 4 indicates serious status for dampness.



4

INDOOR ENVIRONMENT(1/2)

- In this paper, Secondary
  - Indoor temperature, humidity and fungal species were compared with rank of DAMPNESS INDEX. (N=120 houses surveyed)



5

5

INDOOR ENVIRONMENT(2/2)

- In this paper, Secondary
  - Microorganismas included in floor dust were genetically analyzed to evaluate the population diversity of fungal species using metagenomic analysis. (N=120 houses surveyed)
  - Following fungal species were detected in houses at Rank 4 of DAPMNESS INDEX
    - *Wallemia* spp.
    - *Rhodotorula glutinis*
    - *Aspergillus* spp.
    - *Trichosporon* spp.

6

6

DAMPNESS AND HEALTH

- In this paper, Finally
  - The associations between indoor dampness and health-related symptoms were analyzed
  - AOR of nasal symptoms was statistically significant in rank 4
  - The dose-response relationships between indoor dampness and nasal symptoms

Factors	Frequency	Adjusted OR[a] (95%CI)			
		Ocular symptoms	Nasal symptoms	throat symptoms	Dermal symptoms
Rank of dampness Index					
Rank 1	71	1.00 (*Ref.*)	1.00 *(Ref.)*	1.00 *(Ref.)*	1.00 *(Ref.)*
Rank 2	28	2.03 (0.51-8.14)	1.42 (0.47-4.28)	1.57 (0.39-6.29)	1.51 (0.32-7.20)
Rank 3	19	1.92 (0.43-8.66)	2.16 (0.62-7.59)	2.82 (0.68-11.7)	4.26* (1.02-17.7)
Rank 4	27	3.39† (0.96-12.0)	5.25** (1.88-14.7)	1.69 (0.26-2.00)	3.23 (0.82-12.7)
p for trend		0.302	<0.05	0.544	0.166

[a] Adjusted for age, gender and parents health status. CI=confidence interval; †<0.1, * <0.05, **<0.01

7

CONCLUSIONS

This paper presented DAMPNESS INDEX, which authors already have been proposed.

And this paper revealed

1. the indoor environment related to DAMPNESS could be represented by indoor humidity as well as several fungal species
2. children who are living in damp home could be at significant risk for adverse health symptoms such as nasal symptoms and dermal symptoms.

8

Relationship between indoor allergen and occupants' allergic symptoms before and after moving in the house with the countermeasure against allergy

Teruaki Mitamura[1], Kunio Dobashi[2] and Hiroki Harasawa[3]

1 Maebashi Institute of Technology, Japan;
2 Jobu Hospital for Respiratory Diseases, Japan;
3 Harasawa Homes Co., Ltd., Japan

1

INTRODUCTION

- This study introduces a central air-conditioning system integrated with an electrical dust collector developed as a countermeasure against allergy.
- The purpose is to elucidate the relationship between indoor allergens and occupants' allergic symptoms.

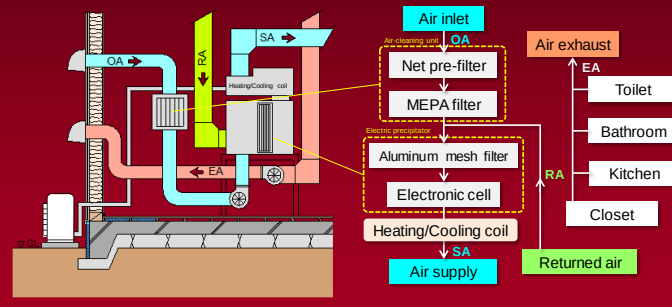


Figure 1: Central air-conditioning, ventilation and air-cleaning system

2

METHODS

- A total of 40 family units and 107 houses were subjected to the investigation and measurements.
- Indoor allergens and occupant's allergic symptoms were compared before and after the subject occupants moved into the house installed with an air-cleaning system.



Before moving
Apartment, old house

After moving
The house with the countermeasure against allergy

Figure 2: *Investigated method*

3

RESULTS AND DISCUSSION

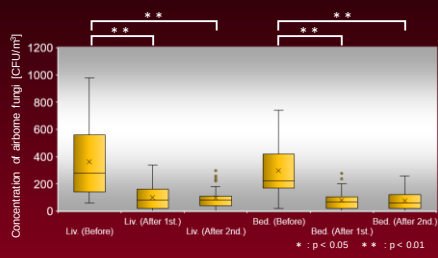


Figure 4: *Concentration of airborne fungi*

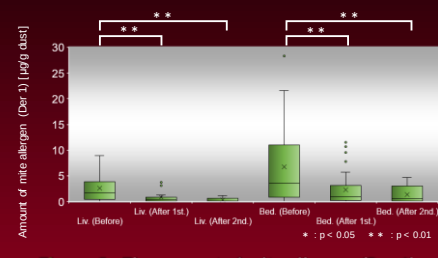


Figure 5: *The amount of mite allergen (Der 1) in household dust*

- After the occupants moved into the house with a countermeasure against allergy, concentrations of airborne fungi and the amount of mite allergen became significantly lower ($p < 0.01$).

4

RESULTS AND DISCUSSION

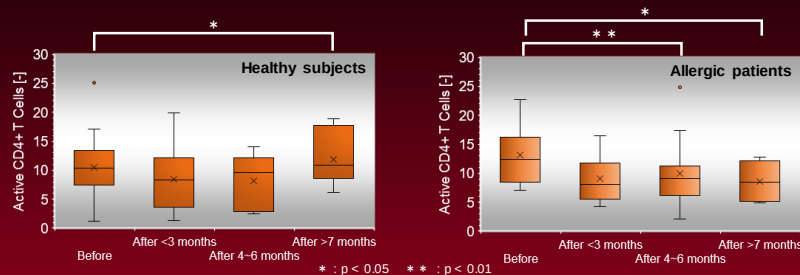
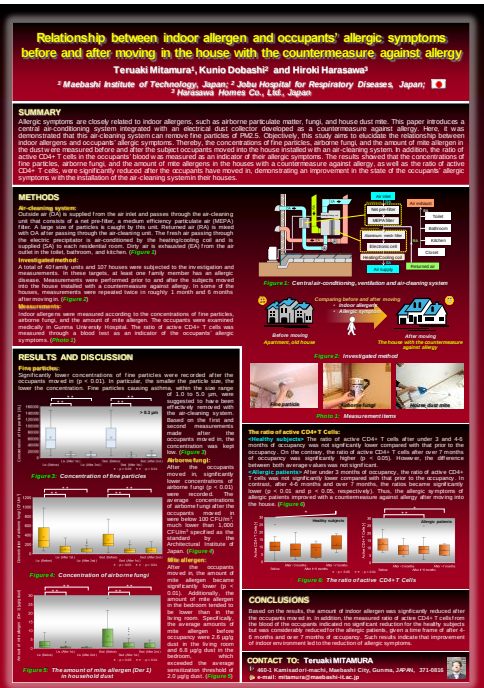


Figure 6: ***The ratio of active CD4+ T Cells***

- Improvement of the allergic symptoms of healthy subjects was not clear comparing before and after moving in.
- The symptoms of allergic patients improved after moving into the house with a countermeasure against allergy.

5



Relationship between indoor allergen and occupants' allergic symptoms before and after moving in the house with the countermeasure against allergy

Teruaki Mitamura[1], Kunio Dobashi[2] and Hiroki Harasawa[3]

[1] Maebashi Institute of Technology, Japan; [2] Jobu Hospital for Respiratory Diseases, Japan; [3] Harasawa Homes Co., Ltd., Japan

SUMMARY

Allergic symptoms are closely related to indoor allergens, such as airborne particulate matter, fungi, and house dust mite. This paper introduces a central air-conditioning system integrated with an electrical dust collector developed as a countermeasure against allergy. Here, it was demonstrated that this air-cleaning system can remove fine particles of PM2.5. Objectively, this study aims to elucidate the relationship between indoor allergens and occupants' allergic symptoms. Thereby, the concentrations of fine particles, airborne fungi, and the amount of mite allergen in the dust were measured before and after the subject occupants moved into the house installed with an air-cleaning system. In addition, the ratio of active CD4+ T cells in the occupants' blood was measured as an indicator of their allergic symptoms. The results showed that the concentrations of fine particles, airborne fungi, and the amount of mite allergens in the houses with a countermeasure against allergy, as well as the ratio of active CD4+ T cells, were significantly reduced after the occupants have moved in, demonstrating an improvement in the state of the occupants' allergic symptoms with the installation of the air-cleaning system in their houses.

METHODS

RESULTS AND DISCUSSION

CONCLUSIONS

CONTACT TO: Teruaki MITAMURA

6

Learning Performance in Odor Environment with aroma oils

Influence of Odor of Essential Oils on Learning Performance in Classroom

Aya ETO, Toshio YAMANAKA, Narae CHOI, Akihisa TAKEMURA, Tomohiro KOBAYASHI

Osaka University, Setsunan University

1

INTRODUCTION

To evaluate the IEQ

Temperature Humidity Pollutant + Odor

Workplace Productivity | Learning Performance

In workplace — Related to economic benefit — In school — Fewer studies

2

PURPOSE

In This Research,



1. Whether the odor environment has positive effects on learning performance?



2. How students feel about studying in an environment fragranced by essential oils?

In this paper,



Rosemary
Essential oil

Improving Memory & Concentration

3

METHODS

1. Odor environment x **Learning performance**



Learning Performance Test



Reading Task



Verbal Memory Task

2. Odor environment x **Impression**



Subjective Evaluation

- ✓ Odor intensity
- ✓ Pleasantness
- ✓ Acceptability
- ✓ Preference

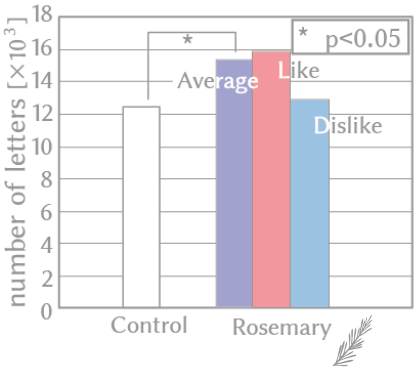
etc...

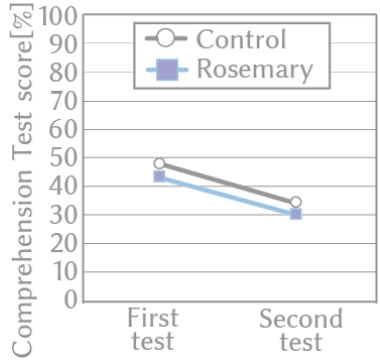


4

RESULTS in Learning Performance Test

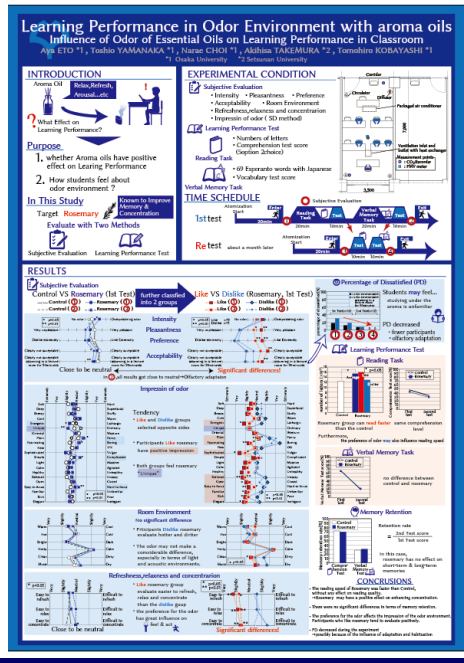
Reading Task





the Rosemary group could read faster
without decreasing the comprehension level

5



Please see the poster for details.

6



1

INTRODUCTION

- IEQ requires larger datasets due to the complex nature of the built environment
- Research-grade IEQ instruments places constraints on long-term monitoring
- Customer-grade sensors offers a unique opportunity to gather large-scale data
- Longitudinal studies could overcome, the traditional uncertainties associated with occupant behaviour and short-term changes
- Evaluate conditions under which consumer-grade monitors can optimally perform large-scale data collection

2

REVIEW FACTORS

- Remote data transmission protocols
- Monitoring Parameters / Sampling Resolution
- Power Supply
- Internal storage / Cloud base storage / Access to the raw data
- Position / Mounting
- Dimensions / Weight
- Restricted access

3

A SAMPLE OF IEH DEVICES







4

Sample outputs



5

THANK YOU



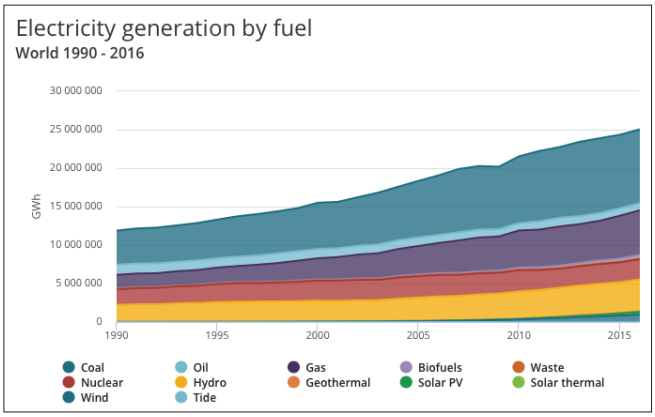
6

"Forget "climate neutral" and clever accounting. Our emissions must start their way to zero. Now."

(Quote: Greta Thunberg, 2019)

"An argument for a reality check in the ventilation industry: We still have an energy crisis, in practice, and are not generally, in practice, achieving better indoor climate." [1]

Sergio George Fox, C.Eng, MCIBSE. AWE Consulting Engineers. sergio@sergio.dk



World electricity use is rising all the time, and our ventilation industry is a **major** contributor. In **theory** ventilation can save energy and provide good indoor climates, but in **practice** it is too often the opposite.

[1] Paper number 1562935103 at the AIVC Conference in Ghent, Belgium, 15th and 16th October 2019

Paper & project scope and conclusion

- The Danish project *"Avoiding energy waste in ventilation systems"* measured and optimized the energy use, as well as the resulting indoor climate, over a **two year** period, in **10** properties (118.000 m²), with **96** ventilation systems.
- The overall **conclusion** of this study is that most of the ventilation systems in the study had degenerated within a short period of time into systems with high energy costs providing low indoor climate quality.
- Major **improvements** were possible and cost effective, although there were many barriers.

Examples of typical system defects

1



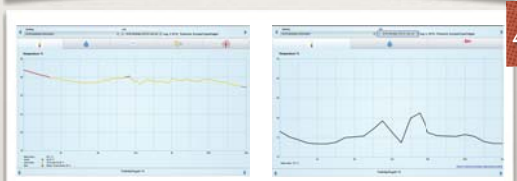
2

m³/h - SYSTEM	
2017:	8.746 / 2.824
2018:	9.200 / 5.400
2019:	9.800 / 9.700
2009:	22.000 /21.700

3

m³/h - ROOM	
2017:	79 / 9
2018:	135 / 45
2019:	189 / 72
2009:	265 / 265

4



5



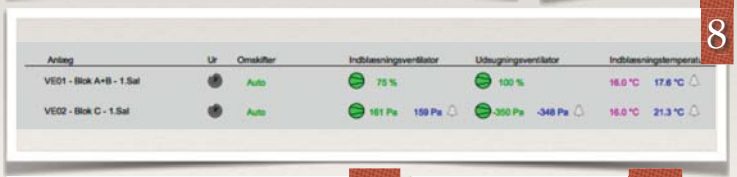
6



7



8



9



10



11



12



13



FROM energy crisis … ??



*Don't we have **more** of an "energy crisis" now than ever before?*

What is the real status of our ventilation industry?

?

“Forget “climate neutral” and clever accounting. Our emissions must start their way to zero. Now.”



To my colleagues in the ventilation industry:

Our children need us to STOP contributing to the **growth** in electricity use.

We should focus on **saving** electricity. We know we can!

AIVC2019



Statistical analysis on **Air Filters** characteristics and energy efficiency by EUROVENT

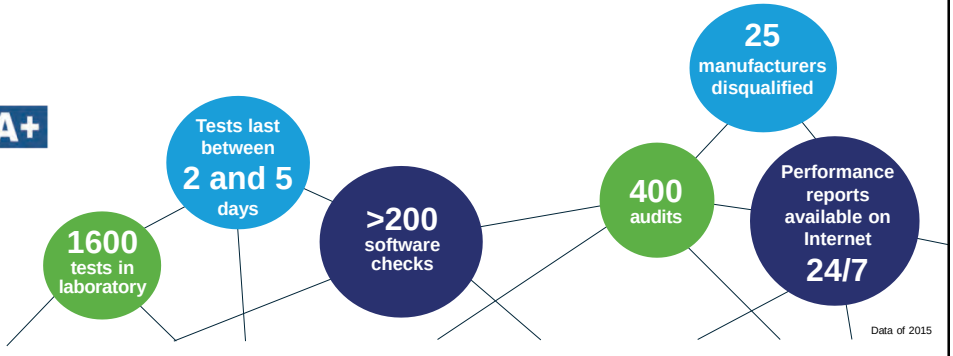
Kiyan VADOUDI

Introduction





A leading European certification body in the field of HVAC-R



Introduction

VENTILATION & INDOOR AIR QUALITY


Air Handling Units (+ higienic option)

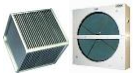

RECENT Ventilation ducts

Air Filters


RECENT Residential Air Filters


RECENT Fans


RECENT Air Cleaners


Air to air heat exchangers


Residential AHU

INDOOR CLIMATE


Variable refrigerant flow


NEW Liquid-to-liquid plate heat exchangers


Chilled beams


Fan coils


Rooftops


Air conditioners

PROCESS COOLING & FOOD COLD CHAIN

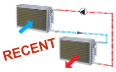

Refrigerated Display Cabinets


Drift eliminators


Chillers & Heat-Pumps


NEW Evaporative cooling


Heating & Cooling Coils


RECENT Heat Recovery Systems with intermediate heat transfer medium

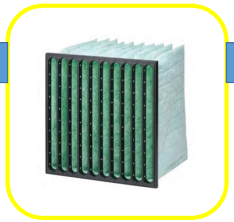

Cooling towers


Heat Exchangers for refrigeration

3

Methodology

RESULTS



Declared

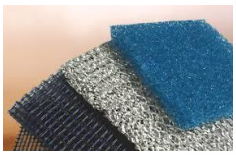
Measured

4

Poster Presentation



Product Characteristics





Energy Efficiency



5

AIVC2019

THANK YOU
FOR YOUR ATTENTION

Kiyan VADOUDI

Email: k.vadoudi@eurovent-certification.com

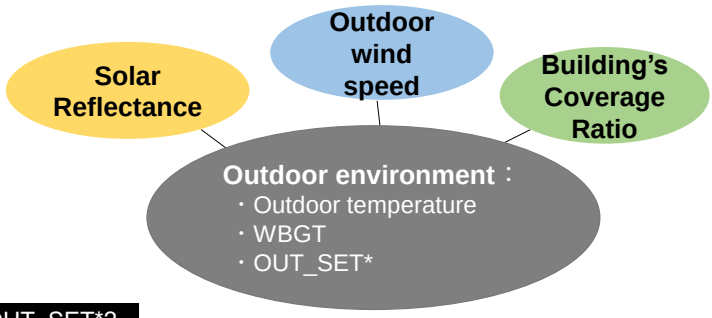
6

Influence of Building Envelope's Solar Reflectance, Wind Speed and Building Coverage Ratio on Urban Heat Environment

Haruto KITAKAZE, Jihui YUAN,
Toshio YAMANAKA, Tomohiro KOBAYASHI

1. BACKGROUND

The aim of research



What's OUT_SET*?

Outdoor thermal index calculated using MRT considering solar radiation

$$OUT\_MRT = \left[\frac{f_p(1-\alpha_{cl})S\downarrow}{F_{eff}\sigma} + \frac{(1-\alpha_{cl})\{D\downarrow + (D\downarrow + S\downarrow)\alpha_{GND}\}}{\sigma} + T_{MRT,L}^4\right]^{0.25}$$

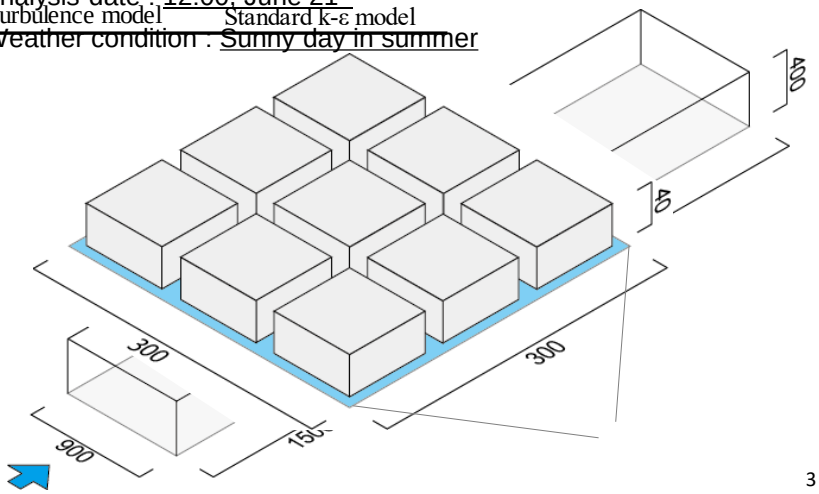
2. ANALYSIS OVERVIEW

■Analysis target

- Target area : Buildings in Osaka City of Japan
- Analysis date : 12:00, June 21st
- Weather condition : Sunny day in summer

CFD code: STREAM V14(RC2)

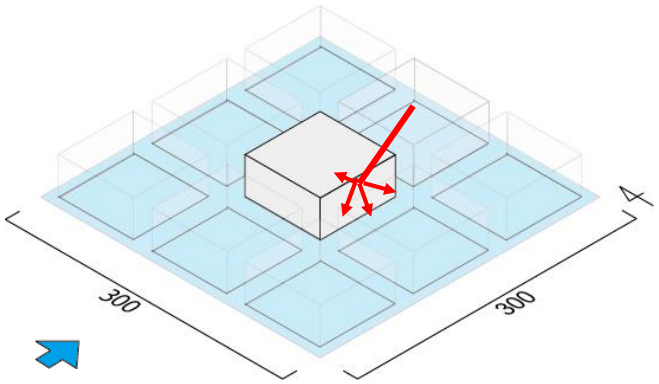
Turbulence model: Standard k-ε model



2. ANALYSIS OVERVIEW

■Analysis case and parameter

- Analysis parameters
  - Envelope's solar reflectance
  - Outdoor wind speed
  - Building coverage ratio
- We set basic case and change only one parameter from that case



3. RESULT OF ANALYSIS

Thank you for your attention !

If you want to know more,

Please come to my poster session !!!

The influence of external environment characteristics on the heating and cooling load of super-tall residential building

2019. 10. 15.

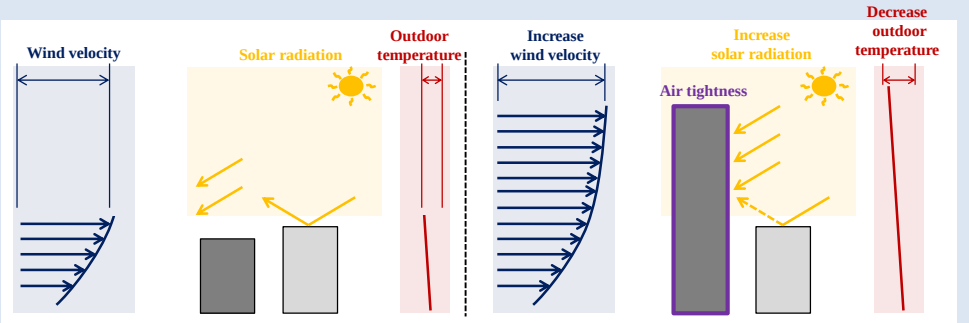
○Hyeong-Tae Kim Hee-Gang Kim Chang-Ho Jeong Myoung-souk Yeo

Architectural Environmental Planning Research Laboratory, Seoul National University

1

BACKGROUND AND OBJECTIVE

- Upper floors of super-tall residential buildings have different characteristics of external environment with respect to outside temperature, solar radiation and wind speed as compared to their low floors because of high-rise
- They have higher level of airtightness because of increased wind speed with high-rise than low-rise residential buildings
- Therefore, upper floors of super-tall residential buildings are expected to have different heating and cooling load influence factors and characteristics as compared to their low floors and low-rise residential buildings
- In this study, the influence of external environment characteristics due to the high-rise on the heating and cooling loads of super-tall buildings were analysed for determining architectural and mechanical alternatives suitable for super-tall residential buildings



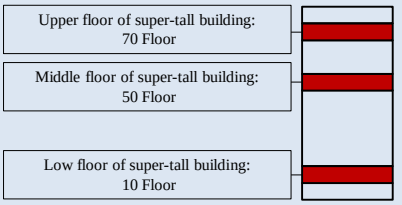
2

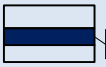
SCOPE AND METHODOLOGY

- Influence factors on the heating and cooling load
  - External environment
    - **Wind speed**: increase with high
    - **Solar radiation**: influence of reduction of adjacent shading buildings and reflections from adjacent rooftops
    - **Outdoor temperature**: decrease with high
  - Airtightness
    - **Super-tall building have high level of airtightness** and difficulty for ventilation due to change of exterior environment

- For the analysis of heating and cooling load, super-tall building and low-rise building were selected satisfying the building code in Korea

- It was selected the upper floor, middle floor, and low floor of super-tall building to analyze the load characteristics according to the height. The same height of the low floor of super-tall building was selected in the low-rise building





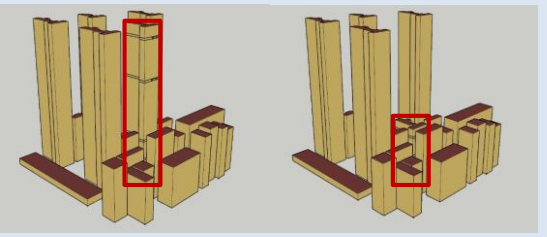
	Super-tall building	Low-rise building
Floors(Height)	74 Floors(222m)	24 Floors(72m)
Airtightness (Effective Leakage Areas) [㎠/㎡]	1.4	2.8
Ventilation	No ventilation	Window open according to temperature in May, September and October (18℃~26℃)

Super-tall residential building and low-rise residential building for simulation

SCOPE AND METHODOLOGY

- Considering layout of city, high density of buildings, adjacent buildings were placed around the selected buildings

- It was assumed the super-tall building and the low-rise building were built in the same location



Layout of super-tall residential building and low-rise residential building

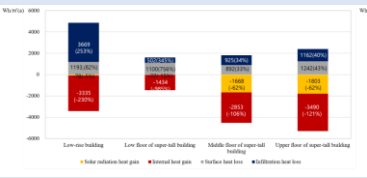


Plan for the simulation model

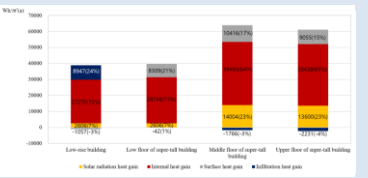
- Floor plan and material properties of typical residential building in Korea was used for simulation

- EnergyPlus, a heat balance based simulation program, was used for analysing heating and cooling load with respect to transient characteristics of the dynamic load

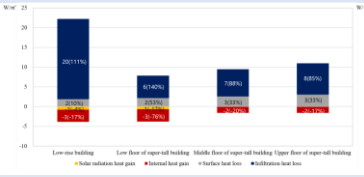
INFLUENCE OF SOLAR RADIATION AND INFILTRATION



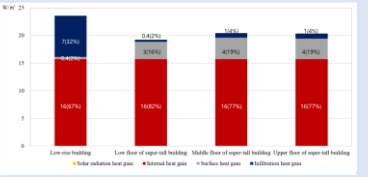
Annual Heating Energy components



Annual Cooling Energy components



Peak Heating Load components

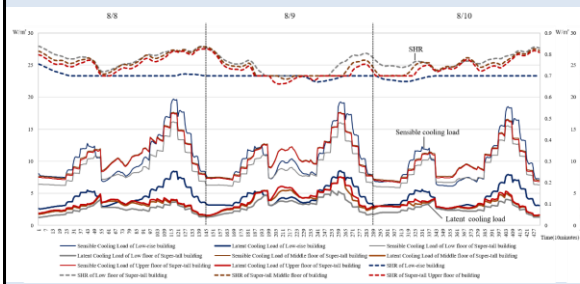


Peak Cooling Load components

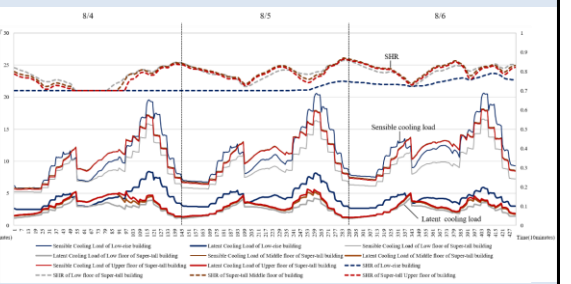
- The result shows the annual cooling energy is larger in the upper floor of super tall building than its low floor and low-rise building. Moreover, the upper floor of super-tall building has larger annual cooling energy than annual heating energy
- The upper floor of super-tall building has larger influence of solar radiation, resulting in lower annual heating energy and larger cooling energy than its low floor and the low-rise building
- The upper floors of super-tall building has larger influence of infiltration than its low floors, resulting in larger peak heating and cooling load, but has smaller influence of infiltration than low-rise building, resulting in lower peak heating and cooling load

INFLUENCE OF SOLAR AND INFILTRATION

- With respect to change of solar radiation and infiltration, difference sensible heat ratio(SHR) appeared in the super-tall building and the low-rise building
- During daytime, the upper floor of super-tall building has larger sensible cooling load than its low floor and low-rise building due to solar radiation, but at nighttime, it has lower sensible and latent cooling load than the low-rise building but larger than its low floor due to infiltration
- The change of sensible heat ratio(SHR) of the upper floor of super-tall building appeared to be greater than the low-rise building



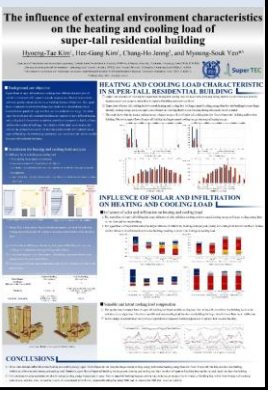
Cooling load and SHR when Peak Cooling load appeared in upper floor of super-tall building



Cooling load and SHR when Peak Cooling load appeared in low - rise building

CONCLUSION

- Since solar radiation affect the annual heating and cooling energy, upper floor of super-tall building has larger annual cooling energy and smaller heating energy than low floor of super-tall building and low-rise building
- Infiltration affect the peak heating and cooling load. Therefore, upper floor of super-tall building has larger peak heating and cooling load than low floor of super-tall building but smaller the peak loads than low-rise building
- It is considered mechanical operation plan for annual cooling energy is necessary in upper floor of super-tall building because cooling load more occurs in upper floor of super tall building than in low floor of super-tall building and low-rise building. Also, for cooling system, it is considered upper floor of super-tall building has larger SHR and variation of the SHR than low-rise building



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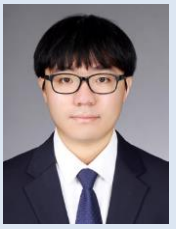

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Improvement Method of Thermal Environmental Near Windows During Heating Period

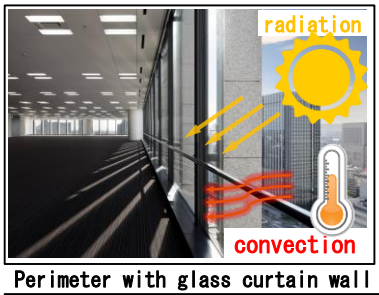
Thermal and Air Flow Characteristics of
Two-Dimensional Jet from Breeze Line Diffuser in Free Field

○Shaoyu Sheng, Toshio Yamanaka, Tomohiro Kobayashi,
Jihui Yuan, Masahiro Katou and Saori Yumino

大阪大学
OSAKA UNIVERSITY

1

■ Research Background

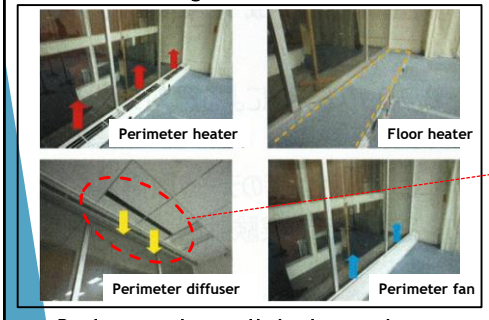


Perimeter with glass curtain wall

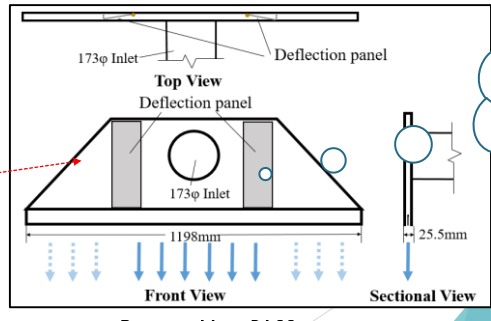
The window area of office buildings, hotels, residential, etc. is increasing

Perimeter zone is easily affected by heat transfer and radiation from windows.

Breeze line (Slot line) diffusers are widely used in Japan as the terminal equipment of air conditioning and ventilation systems



Perimeter air-conditioning equipment

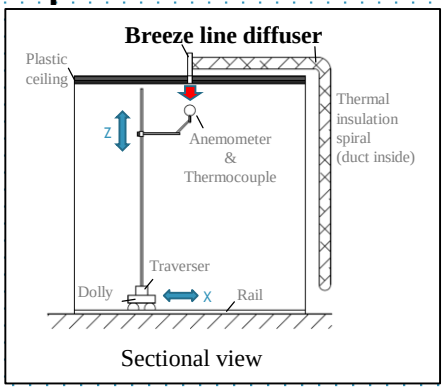


Breeze line Diffuser

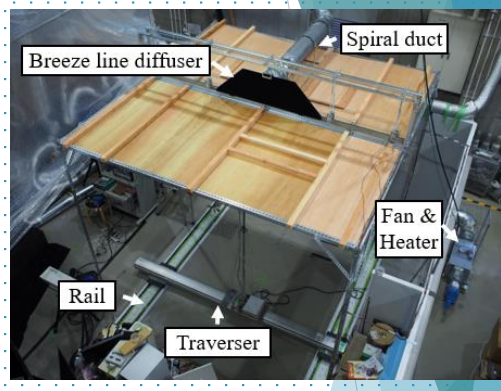
Deflection panel
ON: Heating
OFF: Cooling
& isothermal

2

■ Experiment with breeze line diffuser



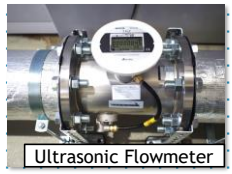
Experiment System



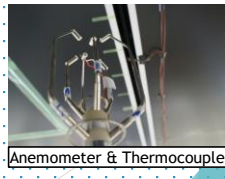
Photograph of laboratory







Air flow system

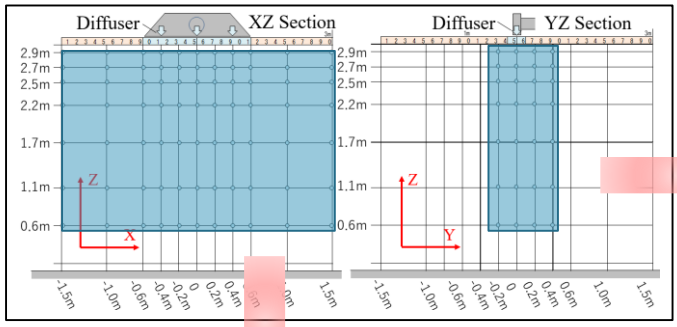




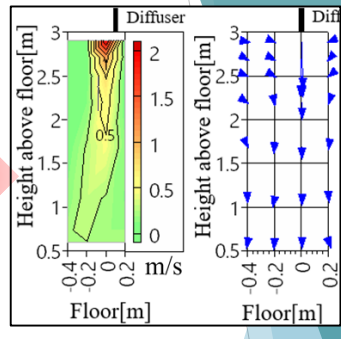
Measurement System

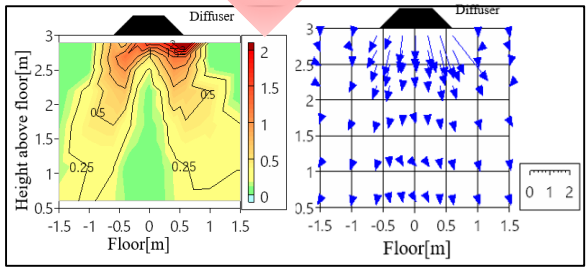
3

■ Principles and methods of experiment



Overview of measurement point

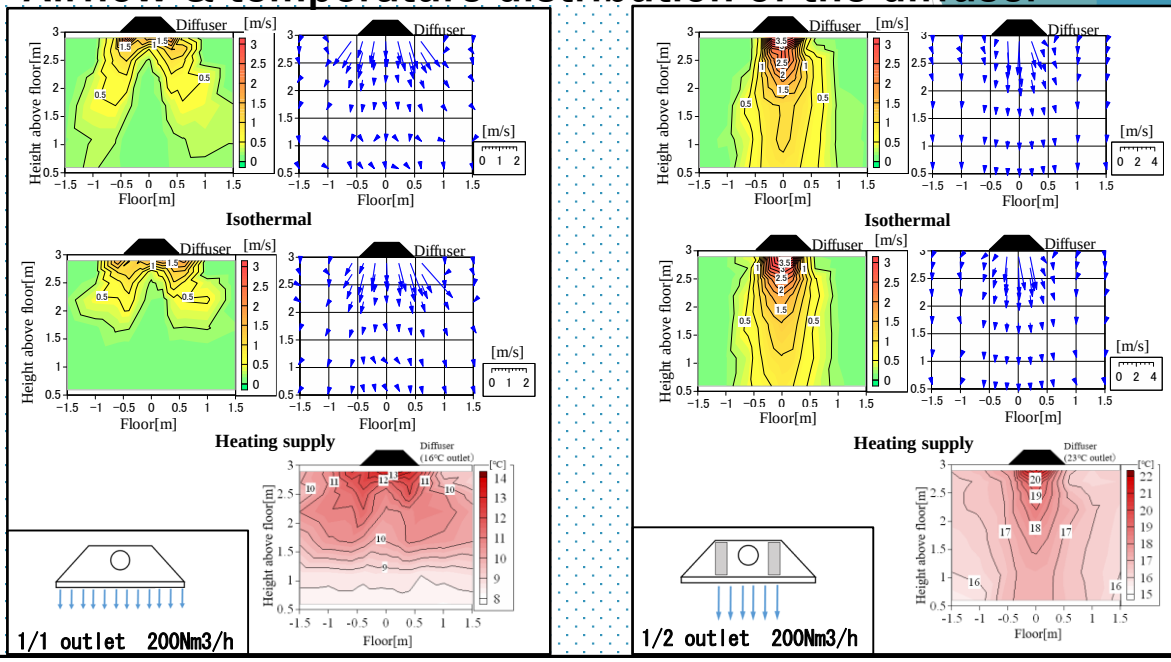




Scalar wind speed
&
Vector velocity distribution

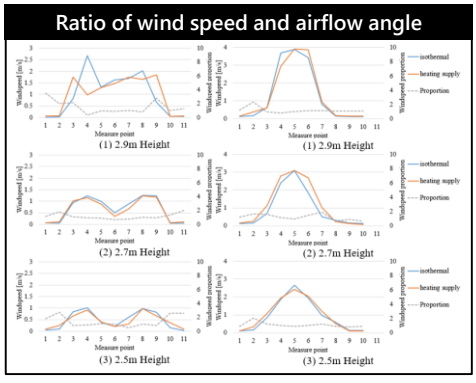
4

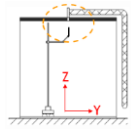
■Airflow & temperature distribution of the diffuser



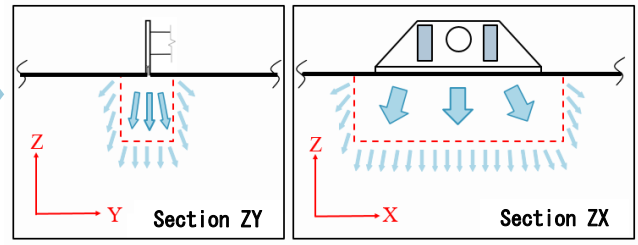
5

■ Effect of buoyancy on airflow velocity





Location of boundary for the P.V. method



■ Conclusions

- Set deflection panels inside of the breeze line diffuser can enhance diffuser's heating effect.
- The figure of the ratio of wind speed and airflow angle can be used to decide the location of the boundary for the P.V. method.
- Detailed data measuring from this boundary will be used to built the CFD model of this kind of diffuser.

6

Universidad de Valladolid

Airtightness and energy impact of air infiltration in residential buildings in Spain

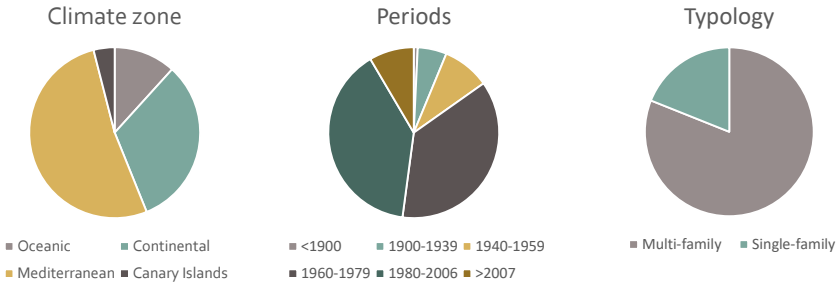
Irene Poza-Casado, Alberto Meiss, Miguel Ángel Padilla-Marcos and Jesús Feijó-Muñoz

40th AIVC – 8th TightVent & 6th venticool Conference, 2019. Ghent, Belgium

1

1 Introduction

- No airtightness requirements in national building regulations
- Sample: 400 cases
  - Multi-family and single-family
  - Different periods of construction
  - 9 locations: Continental, Mediterranean and Oceanic climates



2 Testing method and energy impact assessment

- Fan pressurization method. ISO 9972
- $n_{50} > n_{nat}$

$$n_{nat} = \frac{n_{50}}{N}$$

- Energy load

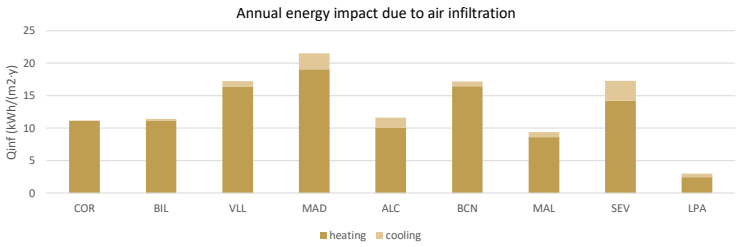
$$Q_{inf} = C_p \cdot G_t \cdot V_{inf}$$

Where:

Q_{inf}:annual energy loss [kWh/y] for heating $Q_{inf\ -H}$ and cooling $Q_{inf\ -C}$
C_p: volumetric heat capacity of the air
G_t : annual degree days [kKh/y]



3 Results & Conclusions



Airtightness results and energy impact due to air infiltration

Parameter	unit	COR	BIL	VLL	MAD	ALC	BCN	MAL	SEV	LPA
n_{50}	h^{-1}	4.61	4.67	4.99	7.29	7.78	9.73	6.89	8.88	5.43
q_{50}	$m^3/(h \cdot m^2)$	3.58	3.47	3.76	5.93	6.26	7.49	5.16	6.81	4.60
n	-	0.62	0.62	0.64	0.61	0.61	0.59	0.60	0.58	0.59
G_{t-H}	kKh/y	54.89	56.86	80.09	63.48	33.24	44.90	34.46	38.50	9.86
G_{t-C}	kKh/y	0.12	1.32	3.91	8.21	5.30	1.99	3.12	8.30	
$Q_{inf\ -H}$	$kWh/(m^2 \cdot y)$	11.10	11.15	16.41	19.07	10.02	16.44	8.61	14.21	2.43
$Q_{inf\ -C}$	$kWh/(m^2 \cdot y)$	0.02	0.26	0.80	2.47	1.60	0.73	0.78	3.06	0.54

Thank you!

Acknowledgements

The test campaigns that allowed this work were supported by the Spanish Ministry of Economy and Competitiveness (BIA2015-64321-R) under the research project *INFILES: Repercusión energética de la permeabilidad al aire de los edificios residenciales en España: estudio y caracterización de sus infiltraciones*. The attendance to this conference has been possible thanks to the program Movilidad de Doctorandos UVa 2019.

Exist'air: a campaign of airtightness measurement and ventilation evaluation in 117 (pre-2005) existing dwellings in France





Sylvain Berthault, Lucille Labat
Cerema - Centre-Est, France

1

Evaluation of Airtightness and ventilation of residential buildings pre-2005





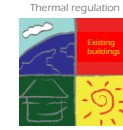






- **Context**
  - Very little data are available on airtightness and ventilation dwellings built before 2005, but the literature review showed that:
    - existing dwellings are less airtight that new buildings,
    - the airtightness level and the kind of ventilation vary according to the year of construction buildings,
    - Leakages locations/characteristics are also quite different from those found in new buildings.
- **Problem**
  - Data available on airtightness and ventilation:
    - are not representative of the French residential buildings,
    - do not give information on building characteristics and/or the retrofitting works carried out,
    - do not provide combined information on airtightness and ventilation. Therefore the air change rate in French existing buildings is unknown.
- **Objective**
  - The energy performance improvement of existing buildings is a priority in France. The Exist'air project should improve:
    - knowledge about airtightness and ventilation of residential existing buildings,
    - the thermal regulation of the residential existing buildings.

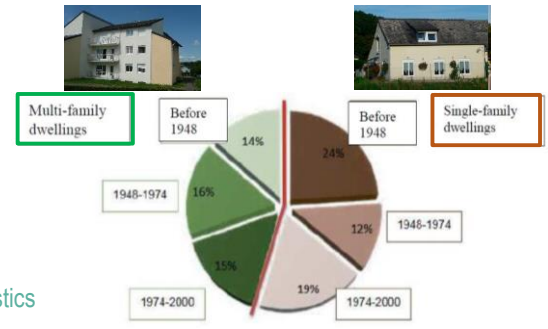
Thermal regulation



2

Evaluation of Airtightness and ventilation of residential buildings pre-2005

- **Method**
  - 117 dwellings selected on the whole territory in France to constitute a representative panel
  - Development of a diagnostic protocol to assess:
    - the alteration of the building
    - the ventilation performance
    - the building airtightness
  - Study of the correlations between:
    - air leakages and dwelling characteristics
    - air leakages and airtightness values
    - airtightness values and dwellings characteristics
  - Evaluation of the global air change rate in dwellings:
    - with a survey to the occupant for aeration
    - with a description of the installation of ventilation system
    - by measuring the airtightness



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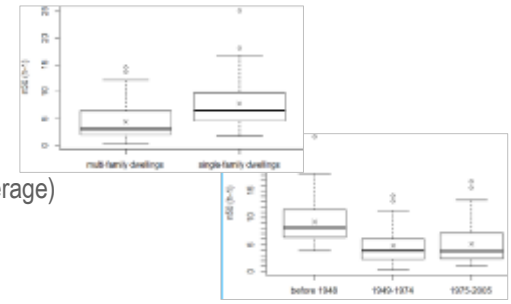
Evaluation of Airtightness and ventilation of residential buildings pre-2005



- **Main results and conclusion**
  - Airtightness value
    => Apartment tighter that single dwellings (in average)
    => Dwellings are 50% tighter after 1948.
  - No correlation between the air leakages and dwelling characteristics but the presence of:
    => sliding windows, roller shutter box, false ceiling, hatches trapdoor, open fires, no sealed combustion appliances tend to increase the air permeability
  - Correlation between airtightness values and dwelling characteristics change the value of n_{50} :
    => For houses: the nature of the wall (hollow concrete) + an insulation of walls and ceilings give a better airtightness
    => For apartments: the type of separation (light) walls between apartments increases the air permeability. The nature of the wall (concrete wall) + an insulation give a better airtightness.

4

Evaluation of Airtightness and ventilation of residential buildings pre-2005

- **Main results and conclusion**
  - Evaluation of the global air change rate
    => Evaluation of the global air change rate through three data:
    - Aeration (A) = windows openings or closings
    - Ventilation (V) = type of compliance and number of compliance
    - Permeability (P) = measurement of airtightness

    three levels for each data:
    - "3" = high value
    - "2" = average value
    - "1" = low value

  - The study shows that dwellings are:
    => well aerated (A3 value)
    => highly permeability (P3 value)

    Those parameters induce a good air change rate

Criteria \ Assessment level	High (3)	Average (2)	Low (1)
Aeration (A)	83	18	16
Ventilation (V)	10	19	88
Permeability (P)	80	26	11

  - For the ventilation parameter, it doesn't not comply: box no connected or ventilation system stopped and/or exhaust and air terminal devices no present and/or airflow absent, bad implementation exhaust and supply air terminal devices

=> **Conclusion**: those results should be used for the evolution of the thermal French regulation for existing buildings including A+ V+ P- method, the new airtightness values and the development of a qualitative method/protocol to evaluate the airtightness.

5

Cerema

AIVC TightVent Europe venticool

Thanks

Sylvain Berthault
Cerema - Centre-Est, France

6


New findings on **measurements** of
very airtight buildings and apartments
Stefanie Rolfsmeier
2019 © BlowerDoor GmbH

1



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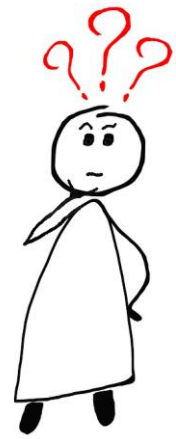

3

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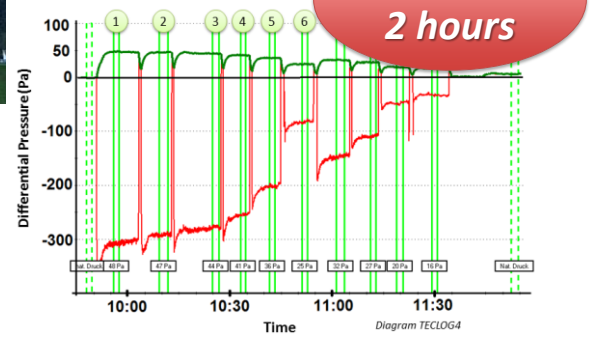
Airtightness Test of Warehouse (Volume = 46000 m³)



n_{50} = 0.03 h^{-1}

Test Time 2 hours



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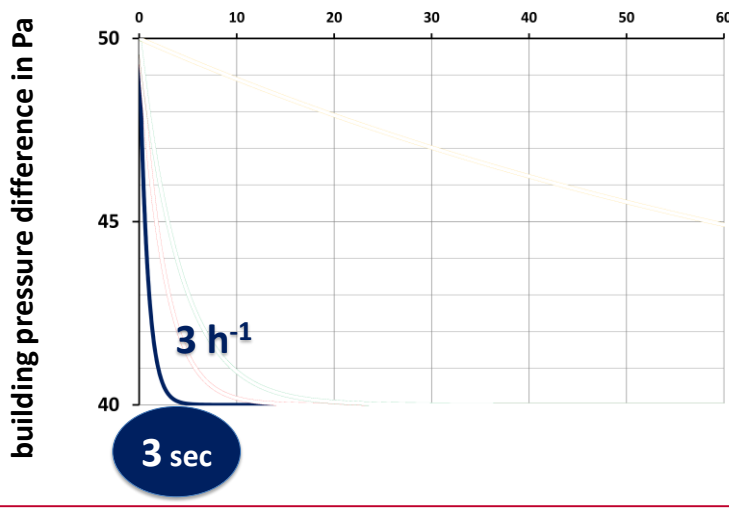
4

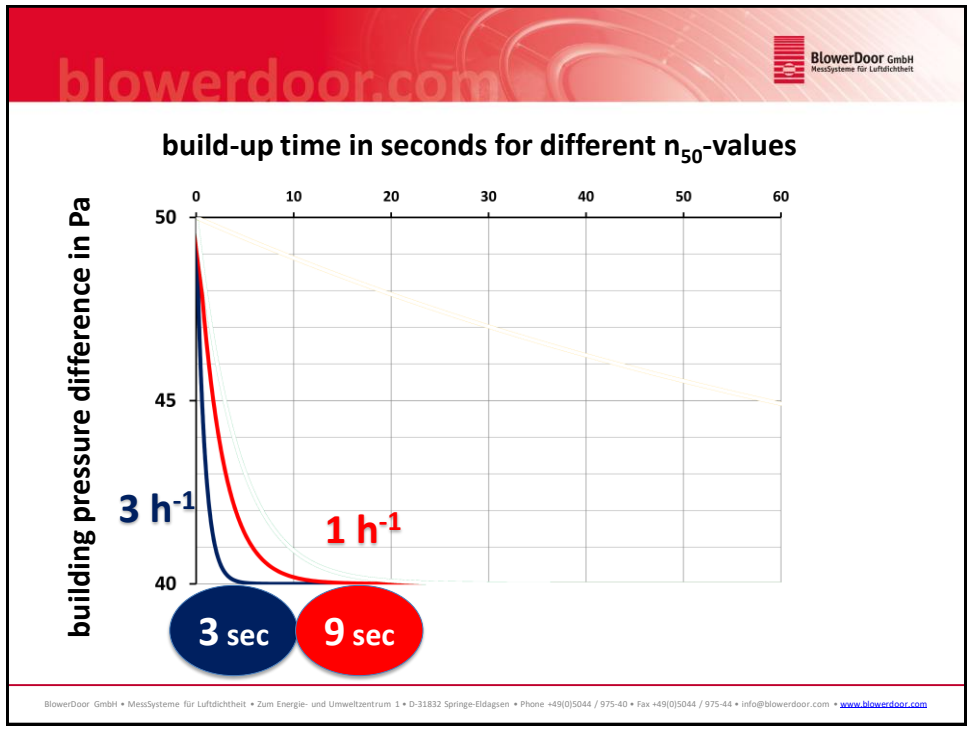
Study from Dipl.-Phys. Joachim Zeller

The lower the air change rate at 50 Pa, the longer takes the airtightness test.

The time required to achieve a stable pressure difference ("**build-up time**")
is inversely proportional
to the air change rate at 50 Pa (n_{50}).

build-up time in seconds for different n_{50}-values

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build-up time in seconds for different n_{50}-values
building pressure difference in Pa
0
10
20
30
40
50
60
50
45
40
3 h-1
1 h-1
3 sec
9 sec
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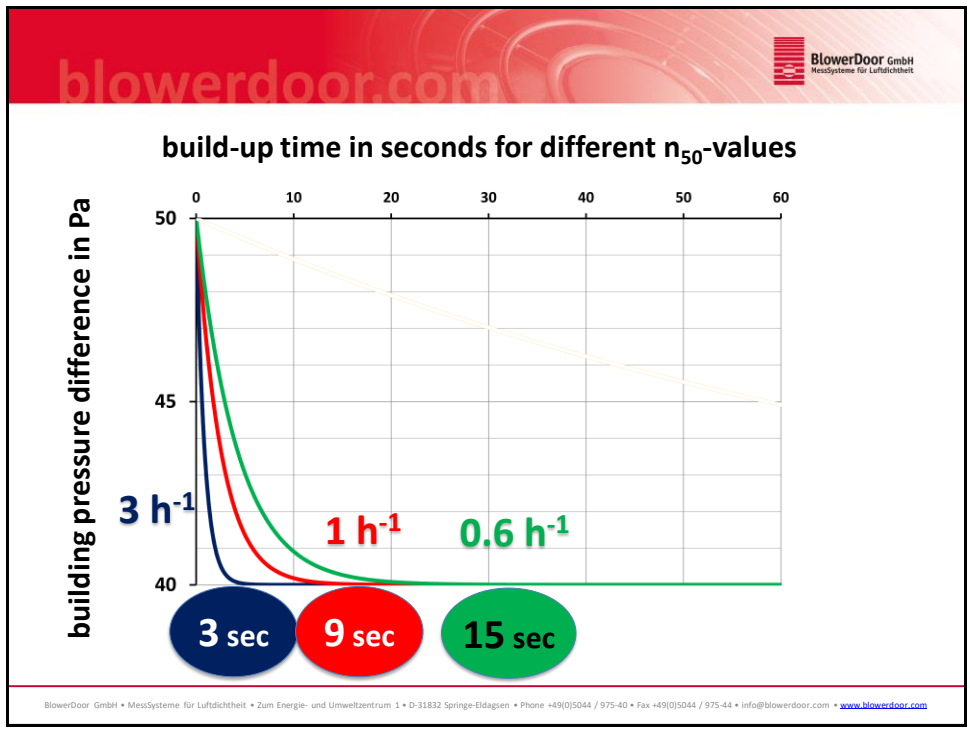
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build-up time in seconds for different n_{50}-values
building pressure difference in Pa
0
10
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45
40
3 h-1
1 h-1
0.6 h-1
3 sec
9 sec
15 sec
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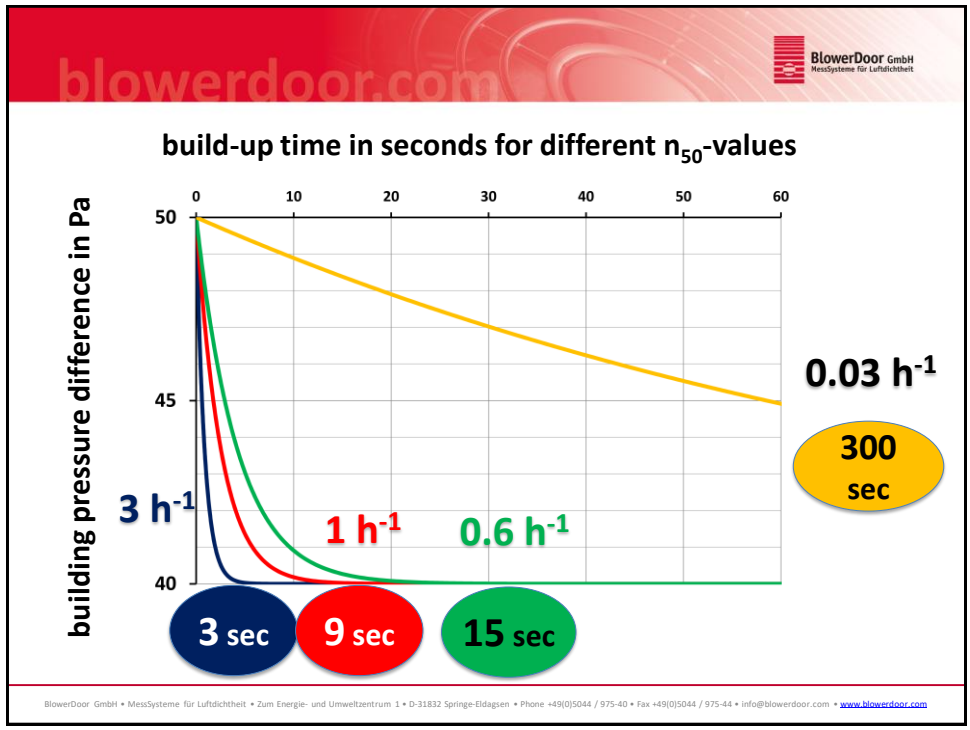
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build-up time in seconds for different n_{50}-values
building pressure difference in Pa
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1 h-1
0.6 h-1
0.03 h-1
300 sec
3 sec
9 sec
15 sec
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Thank you for your attention
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Paul Simons
Collin Olsen
Gary Nelson
Valérie Leprince

10

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Comparison between infiltration rate predictions using the divide-by-20 rule of thumb and real measurements.

Alan Vega Pasos, Xiaofeng Zheng, Mark Gillott, Christopher Wood

40th AIVC - 8th TightVent & 6th venticool Conference
From energy crisis to sustainable indoor climate
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Introduction

2

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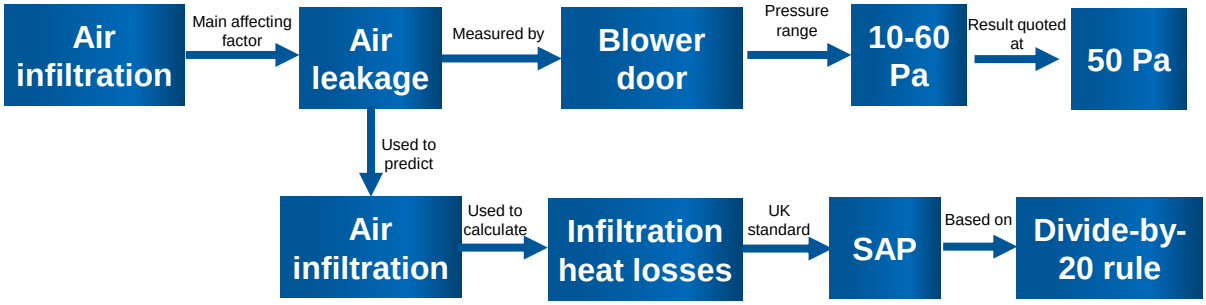
Introduction



Leakage-infiltration ratios $n_{50}/n_1 = N$

The divide-by-20 rule of thumb $n_{50}/20 = n_1$

The British divide-by-20 rule of thumb $q_{50}/20 = n_1$

n_{50} → air leakage rate @50 Pa (h^{-1})
N → Ratio constant
n_1 → air infiltration rate (h^{-1})
q_{50} → air permeability @ 50 Pa ($m^3h^{-1}m^{-2}$)

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Introduction

Objective: To assess the UK building regulation's method of predicting air infiltration heat losses, which utilises the divide-by-20 rule of thumb.

The divide-by-20 rule of thumb $n_{50}/20 = n_1$

The British divide-by-20 rule of thumb $q_{50}/20 = n_1$

n_{50} → air leakage rate @50 Pa (h^{-1})
N → Ratio constant
n_1 → air infiltration rate (h^{-1})
q_{50} → air permeability @ 50 Pa ($m^3h^{-1}m^{-2}$)

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Method & Test dwellings

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Method

Airtightness: Pressurisation tests → q_{50} and n_{50}

→

Air infiltration: Tracer gas concentration decay tests → n_1

→

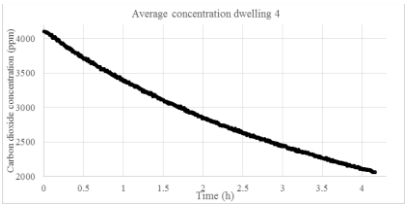
Divide-by-20 rule: $q_{50}/20=n_1$ or $q_{50}/n_1=N$

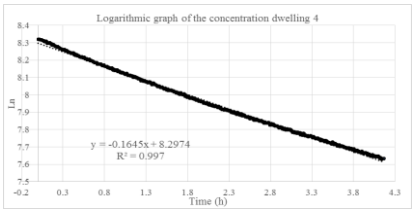
→

SAP (British standard) calculations

New ratio?







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Test dwellings











Dwelling	Date of test	Form	Main construction type	Volume (m^3)	Envelope area (m^2)
1	25/04/2018	Detached	Cavity	278	269
2	03/08/2018	Detached	Timber frame	188	227
3	16/08/2018	Detached	Solid	478	435
4	07/06/2018	Semi-detached	Solid	264	252
5	18/01/2018	Detached	Cavity	285	290

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Results

Results

	Air infiltration h^{-1} n_1	Air Permeability @50 Pa $m^3h^{-1}m^2$ q_{50}	$q_{50}/20$	Error	q_{50}/n_1	ACH @50 Pa h^{-1} n_{50}	$n_{50}/20$	Error	n_{50}/n_1
1	0.1484	7.88	0.3938	165%	53.07	0.1484	0.3810	157%	51.35
2	0.1241	4.40	0.2200	77%	35.46	0.1241	0.2656	114%	42.81
3	0.0787	3.86	0.1930	145%	49.05	0.0787	0.1756	123%	44.63
4	0.1645	6.04	0.3020	84%	36.72	0.1645	0.2883	75%	35.05
5	0.3618	7.60	0.3798	5%	21.00	0.3618	0.3865	7%	21.37
				Average	**39.06**			Average	**39.04**
				Min	21.00			Min	21.37
				Max	53.07			Max	51.35
				Std dev	11.32			Std dev	10.25
				Std error	5.06			Std error	4.58

New rule: divide-by-39?

Results

What about SAP predictions?

Dwelling	SAP n_1 during test month	SAP n_1 annual average	N SAP during test month	N SAP annual average	ACH, tracer gas	Error SAP during test month	Error SAP annual average
1	0.6000	0.6000	13.1256	13.1261	0.1484	304%	304%
2	0.5150	0.5212	0.5444	8.4428	0.1241	315%	320%
3	0.5161	0.5228	7.4792	7.3838	0.0787	**556%**	**564%**
4	0.5352	0.5472	11.2852	11.0380	0.1645	225%	233%
5	0.6174	0.5873	12.3050	12.9340	0.3618	71%	62%

Minimum infiltration 0.5 h^{-1} → Overestimation

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Conclusions

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Conclusions

- Measurements: Average air permeability of 5.96 $m^3h^{-1}m^{-2}$ (@50 Pa), and air infiltration rate 0.1755h^{-1}
- Large error when using the divide-by-20 rule between 5% and 165%
- A new proposed rule fitting the data is a divide-by-39 rule
- SAP over-predicts infiltration, errors larger than 500%
- Suggestion: testing more properties and using infiltration predicting models rather than leakage-infiltration ratios

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THANK YOU


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On the experimental validation of the infiltration model DOMVENT3D.

Alan Vega Pasos, Xiaofeng Zheng, Benjamin Jones, Mark Gillott, Christopher Wood

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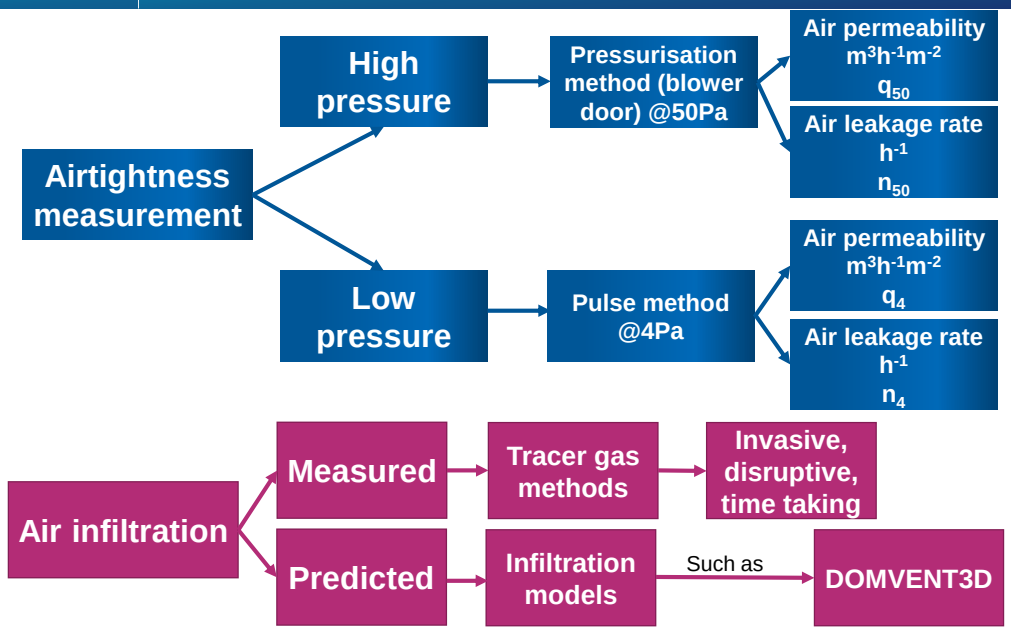
Introduction



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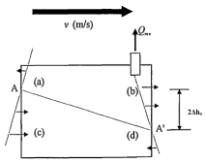
Introduction

DOMVENT3D

- *Air infiltration predicting model, originally created by Lowe (2000) based on Lyberg's proposals (1997) and modified by Jones et al. (2013)*
- *Governing equations:*



$$Q = C\Delta P^b \quad (1)$$

$$Q_1 = \frac{E\alpha W\varepsilon(\rho_0-\rho_i)}{b+1}\{|(\rho_0-\rho_i)|g\}^b \begin{bmatrix} +h_0^{b+1}|_{h_0>0} \\ -(h_0-H)^{b+1}|_{h_0>H} \end{bmatrix} \quad (2)$$

$$Q_2 = \frac{E\alpha W\varepsilon(\rho_0-\rho_i)}{b+1}\{|(\rho_0-\rho_i)|g\}^b \begin{bmatrix} +(H-h_0)^{b+1}|_{h_0<H} \\ -(-h_0)^{b+1}|_{h_0<0} \end{bmatrix} \quad (3)$$

- Only two of those equations are needed for each facade.

Objective: The objective of this paper is to field validate the predictions made by DOMVENT3D from measurements of airtightness quoted at 50 Pa. In addition, DOMVENT3D will be calibrated to give predictions from airtightness measurements quoted at 4 Pa.

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Method & Test dwellings

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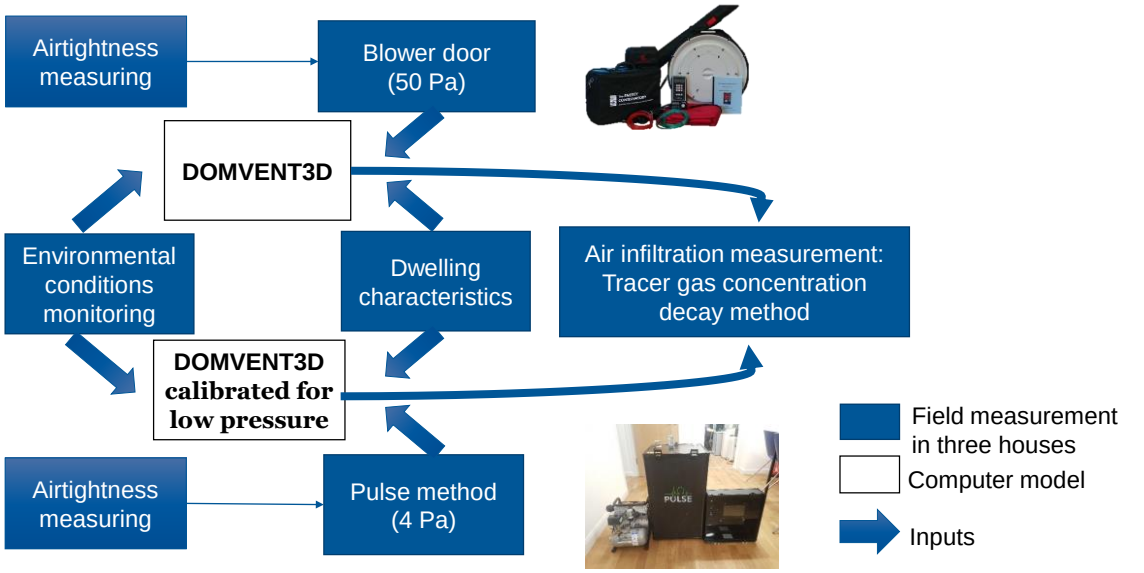
Method



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Results

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Results

DOMVENT3D Model inputs

	Shield.	Terrain	Wind (m/s)	Wind dir. (°)	ΔT (K)	Dwelling type	Exposed Facades			
							0°	90°	180°	270°
1	Light	Suburban	1.080	250	3.69	Detached	✓	✓	✓	✓
2	Mod.	Suburban	0.712	216	3.40	Detached	✓	✓	✓	✓
3	Light	Suburban	1.700	195	1.71	Semi detached	✓	✗	✓	✓

Air infiltration (n_1) and airtightness results from blower door (n_{50}, b_{50}) and Pulse (n_4, b_4), b represents the flow exponent

	Air infiltration, n_1 (h^{-1})	Air infiltration uncertainty (h^{-1})	Pressurisation		Pulse	
			n_{50} (h^{-1})	b_{50}	n_4 (h^{-1})	b_4
1	0.1241	0.0019	5.3128	0.659	1.0098	0.707
2	0.0787	0.0036	3.5310	0.596	0.7167	0.675
3	0.1645	0.0020	5.7654	0.626	1.2267	0.604

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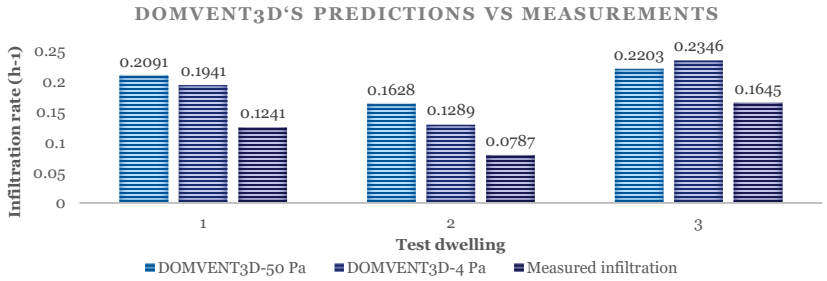
Results

DOMVENT3D air infiltration rate predictions (DVn_1) and percentage difference between measurements of air infiltration and DOMVENT3D's predictions

	Air Infiltration measurements n_1 (h^{-1})	DOMVENT3D predictions from n_{50} (h^{-1})	DOMVENT3D predictions from n_4 (h^{-1})	DVn_1 (ΔP=50 Pa) difference (%)	DVn_1 (ΔP=4 Pa) difference (%)
1	0.1241	0.2091	0.1941	68%	56%
2	0.0787	0.1628	0.1289	107%	64%
3	0.1645	0.2203	0.2346	34%	43%
			Average	**70%**	**54%**



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Conclusions

Conclusions

- DOMVENT3D predictions differed from 34% to 107% when using the blower door's measurements; and, from 43% to 64% when using the Pulse measurements. → Over prediction in all cases
- It cannot be concluded that an airtightness measurement method is better than the other to predict infiltration rate.
- Pulse (low pressure measurement), led to a lower uncertainty, or a more repeatable one.
- More dwellings for more data.
- Infiltration models such as DOMVENT3D are more accurate than leakage-infiltration ratios.

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How Accurate is our Leakage Extrapolation?

MODELING BUILDING LEAKAGE USING THE DARCY-WEISBACH EQUATION

1

Distributions of Leaks

- All Three result in the SAME Power Law Fit: $Q_v = 94.4 * \Delta p^{0.653}$

A

Leak Size	16 mm	7 mm	5 mm	2.2 mm	1.6 mm
Leakage Area (mm^2)	1875	3375	6075	10935	19683
% of Total Leakage @50Pa	*12.6%*	*13.2%*	*21.6%*	*27.7%*	*24.9%*

B

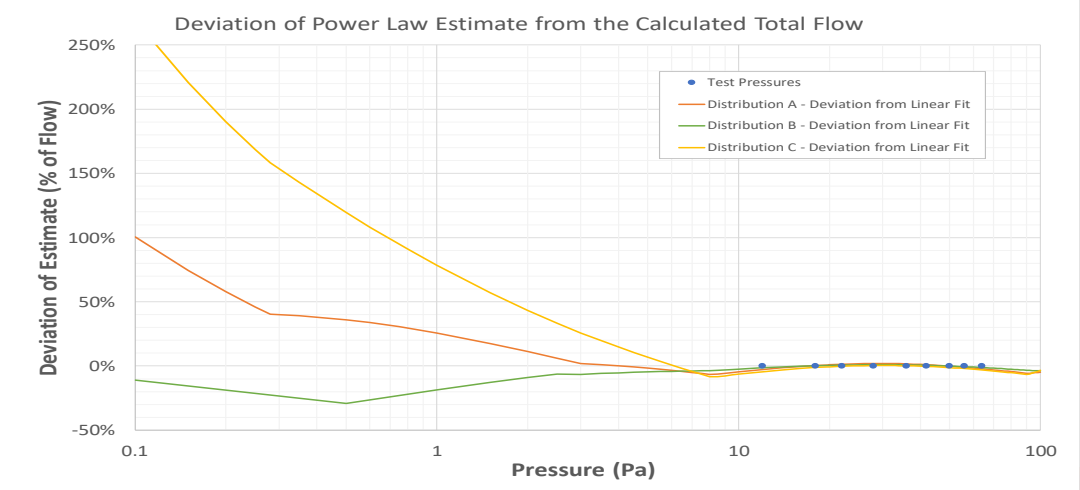
Leak Size	16 mm	7 mm	5 mm	2.2 mm	1.6 mm
Leakage Area (mm^2)	7663	1120	1400	1750	27410
% of Total Leakage @50Pa	*51.4%*	*4.4%*	*5.0%*	*4.4%*	*34.8%*

C

Leak Size	16 mm	7 mm	5 mm	2.2 mm	1.6 mm
Leakage Area (mm^2)	250	250	10764.05016	23175	250
% of Total Leakage @50Pa	*1.7%*	*1.0%*	*39.7%*	*57.3%*	*0.3%*

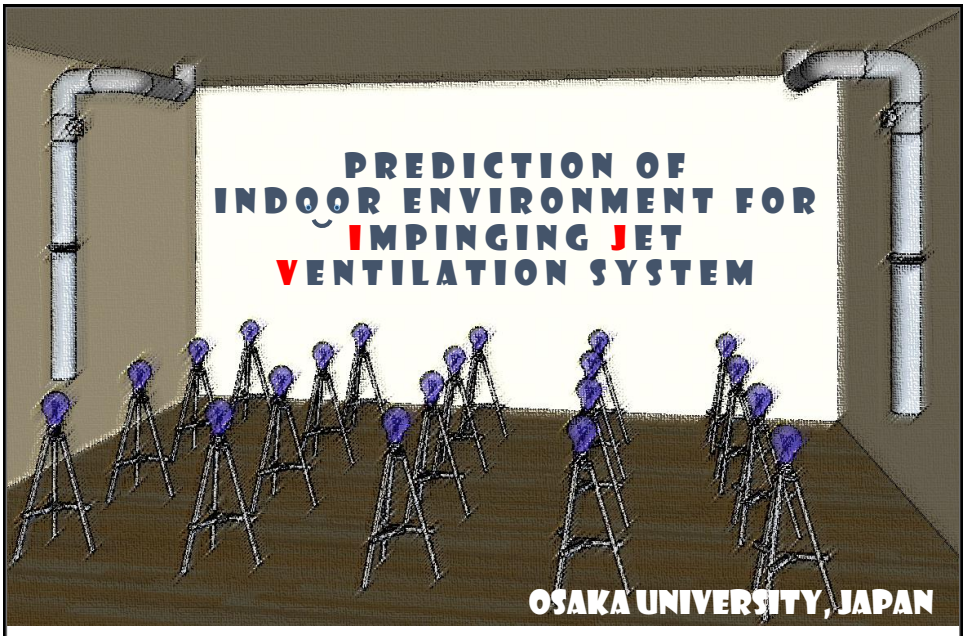
3

Deviation of Each Distribution



Conclusions

- Different distributions of leak sizes can result in the same power law fit
- Extrapolations of leakage rates to low pressures may have large errors
- The errors could be positive or negative
- Empirical studies are recommended to help understand probable errors



MEMBERS

- MATSUZAKI MAKO
- KOBAYASHI TOMOHIRO
- YAMANAKA TOSHIO
- CHOI NARAE
- YAMASAWA HARUNA

1

MECHANISM OF IJV

exhausted near
the ceiling





2

PURPOSE OF RESEARCH

Good

Ventilation efficiency and comfort

But,

To date, few studies have been done about IJV in Japan

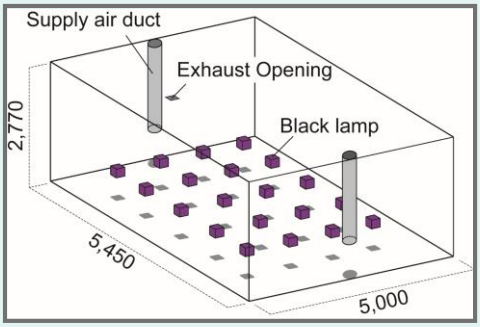
In this study, we investigated the indoor environment in a room with distributed heat load

Full scale cooling Experiment

CFD analysis

3

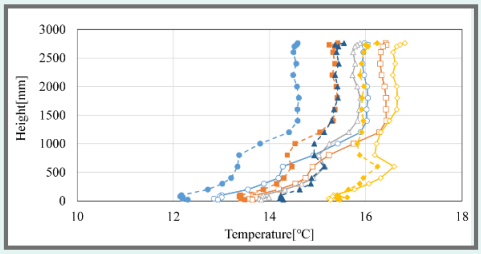
FULL SCALE COOLING EXPERIMENT

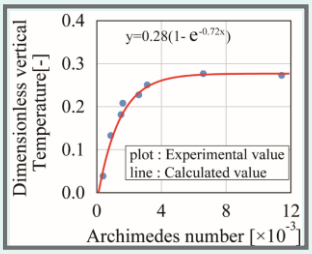


Measurement Item
- ✓ Temperature
- ✓ CO2 distributions

The relationship between
- ✓ Ar number
- ✓ indoor environment

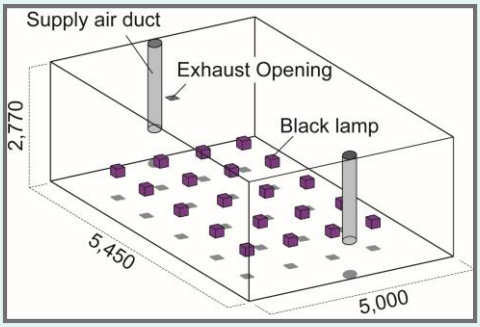
was obtained





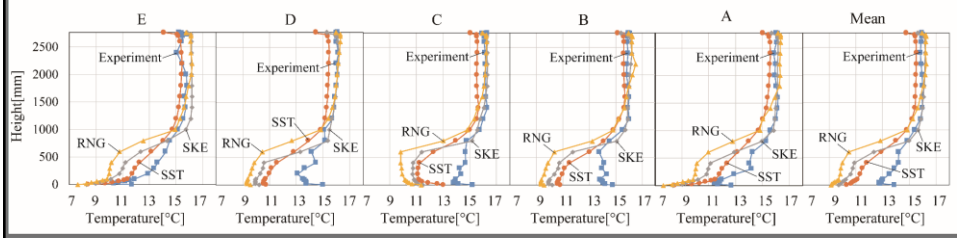
4

ACCURACY VERIFICATION OF CFD ANALYSIS

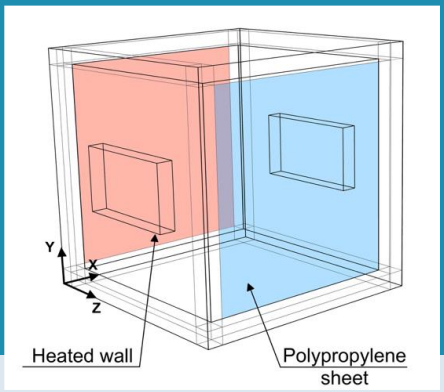


We verified the accuracy of CFD

We examined the dependence of the turbulence model



Analysis of convective heat transfer coefficient correlations for ventilative cooling based on reduced-scale measurements



K Kosutova[1], C Vanderwel[2], T van Hooff[1,3], B Blocken[1,3], JLM Hensen[1]

[1] Building Physics and Services, Department of the Built Environment, Eindhoven University of Technology, The Netherlands
[2] Aerodynamics and Flight Mechanics Research Group, University of Southampton, United Kingdom
[3] Building Physics Section, Department of Civil Engineering, KU Leuven, Belgium

1

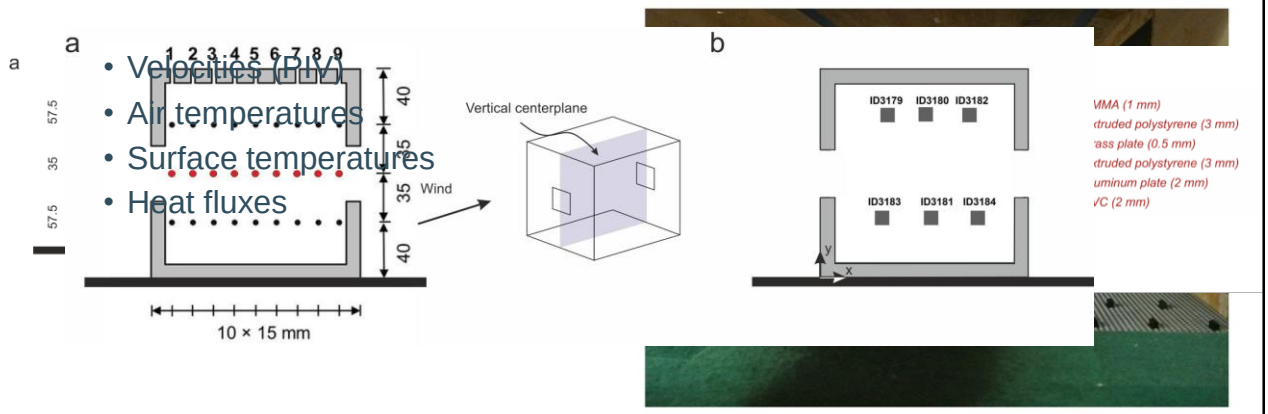
Introduction

- Ventilative cooling can reduce cooling energy demands
- Ventilative cooling potential and energy reduction should be assessed in the design phase
- The majority of convective heat transfer coefficients (CHTC) correlations for building performance simulations are not developed for high velocities/flow rates

2

Experimental setup

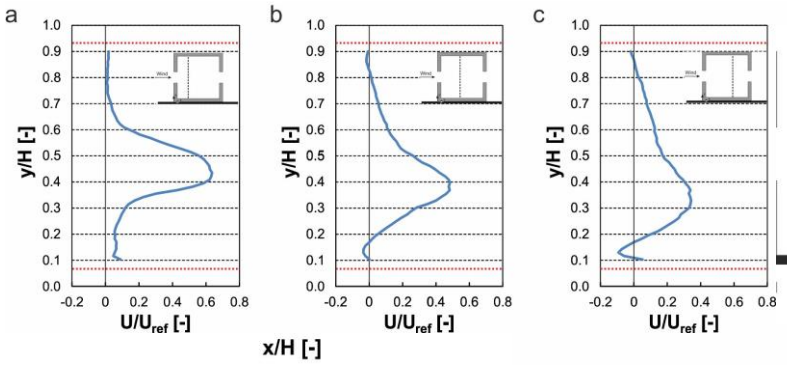
- Wind-tunnel model (scale 1:20) in ABL wind tunnel of University of Southampton
  - Velocities (PIV)
  - Air temperatures
  - Surface temperatures
  - Heat fluxes



KU LEUVEN

Results

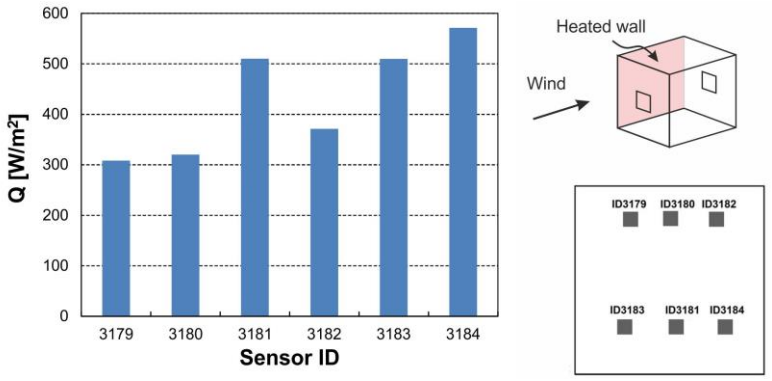
- Velocities
- Air temperatures



KU LEUVEN

Results

- Heat fluxes



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Ongoing research

- Comparison of CHTC correlations with experimental values
- Validation of CFD models for a detailed spatial analysis of CHTC in realistic environments
- Use of realistic CHTC correlations in building performance simulations

KU LEUVEN

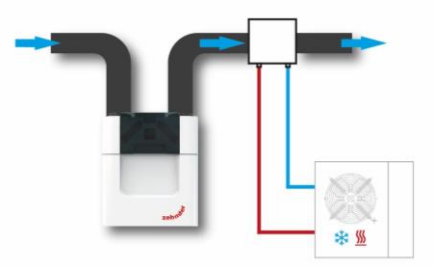
Q&A

Twan van Hooff
Building Physics Section – Department of Civil Engineering
twan.vanhooff@kuleuven.be

KU LEUVEN

Overheating reduction in a house with balanced ventilation and postcooling

Balanced ventilation with postconditioning



NZEB house in Modena, Italy



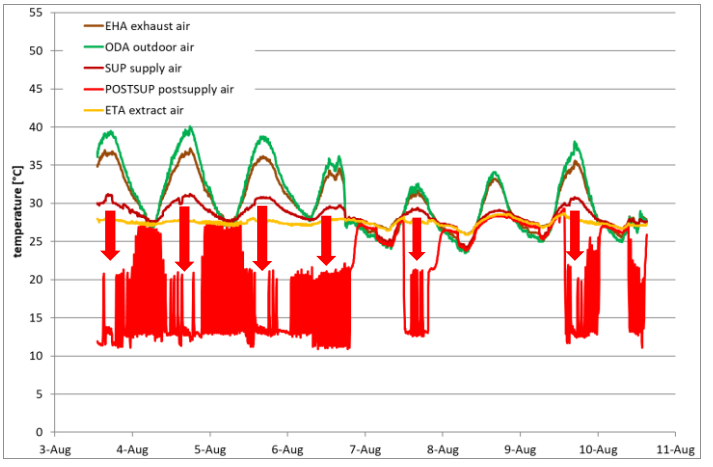
- ComfoAir Q600 ERV, max 600 m³/h (balanced ventilation with enthalpy recovery)
- ComfoPost CW10, max 5 kW (postcooling and postheating)
- Heatpump 4 kW dedicated for heating and cooling the water for the ComfoPost
- ComfoPost is controlled by room thermostat
- No other internal climatization devices
- Monitoring from 3 August 2017 until 8 March 2018

Bart Cremers, Zehnder Group Zwolle, bart.cremers@zehndergroup.com

zehnder
always the best climate

1

Summer week example



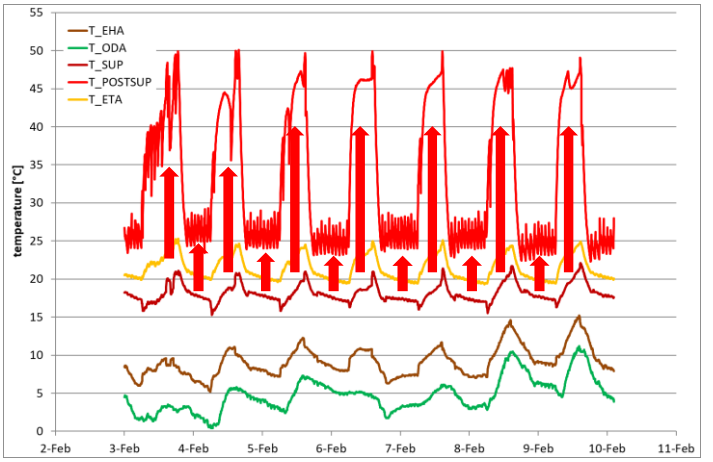
postcooling

- Outdoor temperatures up to 40°C during the day until 25°C at night
- Indoor temperatures stay at 27°C thanks to cold recovery and postcooling

zehnder

2

Winter week example

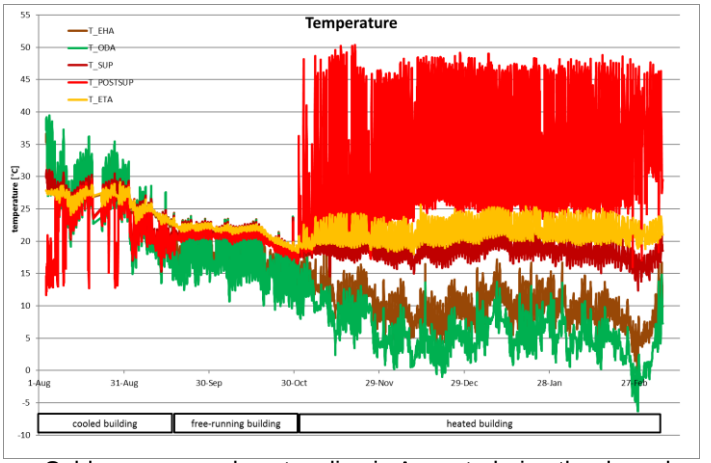


postheating

- Outdoor temperatures between 1°C at night and 11°C during the day
- Indoor temperatures between 20°C at night and 25 °C during the day (thanks to heat recovery and postheating)

zehnder

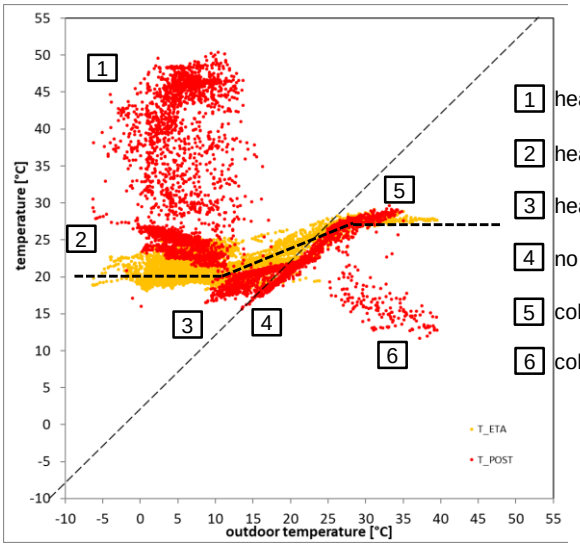
Temperatures from summer to winter



- Cold recovery and postcooling in August, during the day, when requested
- Passive cooling in first half of September
- Heat recovery from mid September to end of October
- Postheating in from November to begin of March

zehnder

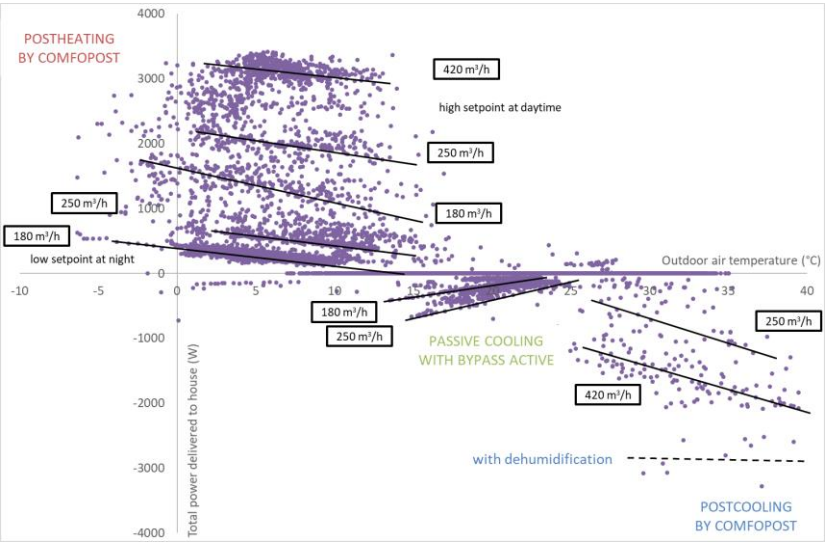
Postsupply temperatures against outdoor temperature



1 heat recovery and postheating
2 heat recovery and postheating
3 heat recovery
4 no recovery
5 cold recovery
6 cold recovery and postcooling

zehnder

Heating and cooling output against outdoor temperature



- Conditioning of the house possible with appr. 3 kW cooling and heating

zehnder

Summary

Balanced ventilation with postconditioning device
is able to maintain comfortable indoor temperatures
in a Nearly Zero Energy Building,
without any other climatization devices!

Indoor temperatures are between 19 and 27 degrees Celsius
with outdoor temperatures between -5 and 40 degrees Celsius

桂林電子科技大學
GUILIN UNIVERSITY OF ELECTRONIC TECHNOLOGY

2019 40th AIVC

Modelling thermal comfort and energy use of a typical mixed-mode cooling apartments in Guilin, China

Presenters: Jie Han
Affiliation: Guilin University of Electronic Technology, China
Email: hanjie@guet.edu.cn

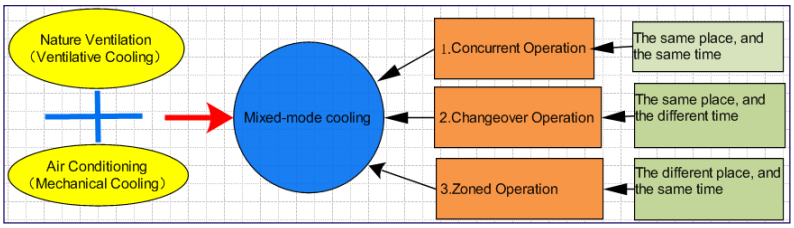
建筑与交通工程学院
School of Architecture and Transportation Engineering

Background



➢Space heating and cooling consume more than half energy in buildings of China (Tsinghua, 2013).The problem is how to reduce energy use for heating and cooling while maintaining indoor air quality and thermal comfort.

➢Many methods are proposed such as high efficient equipments for energy saving, renewable energy utilization, passive technologies and so on. Recently, mixed-mode cooling as an alternative method is attracting public attention. Mixed-mode cooling is a combination of natural ventilation (Ventilative Cooling) and mechanical cooling to provide indoor air quality and thermal comfort (Heiselberg, 2002; Brager, 2006).



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Methods

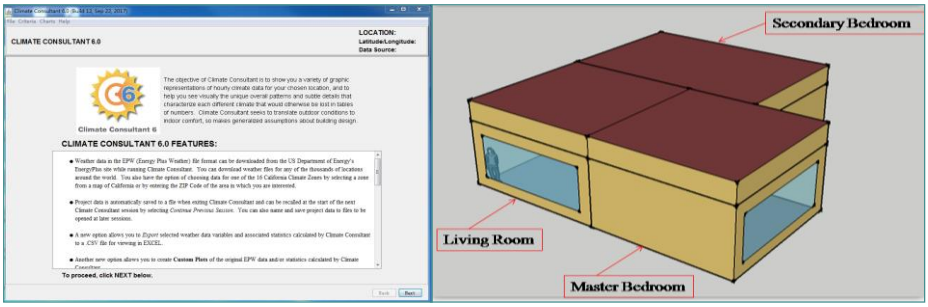
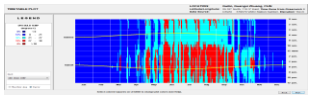


Fig.1. Climate consultant and EnergyPlus softwares are used to simulation.

- A typical apartment with three rooms- a living room, a master bedroom and a secondary bedroom.
- Terminal reheats are applied to the living room and the master bedroom.

Results



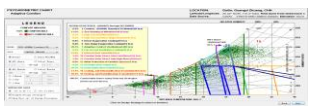


Fig.2 shows that natural ventilation during daytime can run in transition seasons, winter and summer before10:00 A.M.

Fig.3 shows that different design strategies. The main design methods are comfort ventilation, heating with dehumidification, internal heat gains, and dehumidification only.

Results



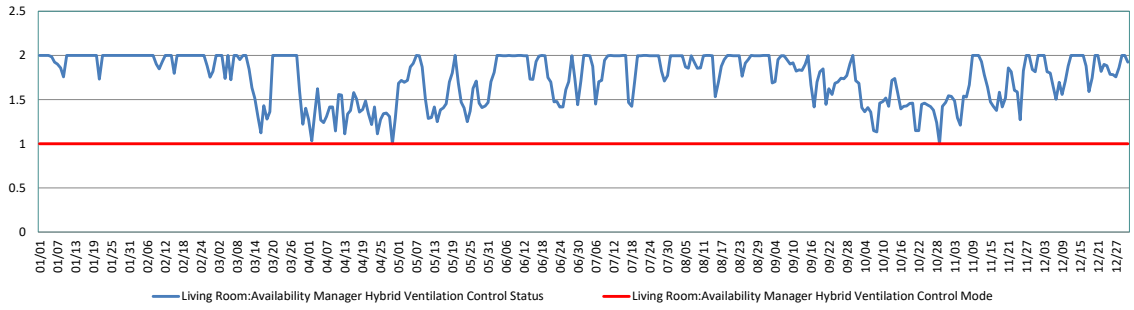


Fig.4. Hybrid control with time (hour)

- A value of 1 (Red Line) shows hybrid control mode.
- Values 1 and 2 (Blue Line) show natural ventilation and mechanical system respectively. Values between 1 and 2 present the switching of natural ventilation and mechanical systems

Results



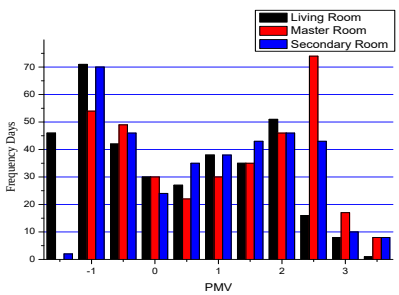


Fig.5. Frequency days of PMV

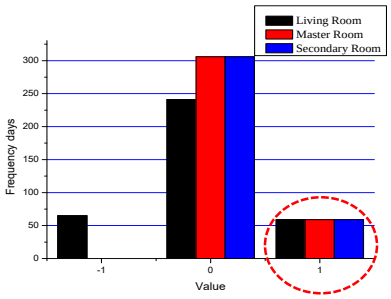


Fig.6. Frequency days of adaptive thermal comfort

Fig.5. shows frequency days of thermal comfort based Fanger model, these rooms are 99, 101 and 105, respectively.

Fig.6. shows 80% acceptability limits based adaptive model. A value of 1 means within (inclusive) the limits, a value of 0 means outside the limits, and a value of -1 means not applicable. The number of frequency days satisfying the limits are the same (59).

Results



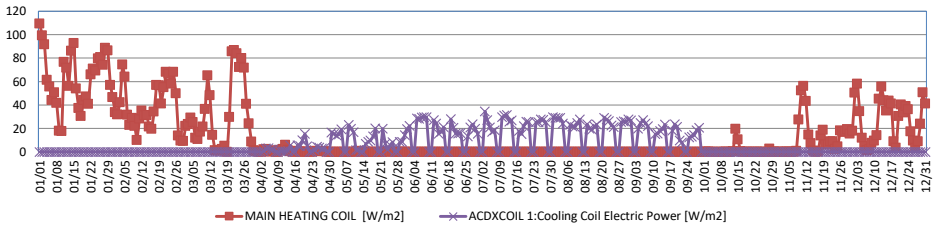


Fig.7. shows the cooling period is about from Apr 1 to Oct 1,the heating period is from Jan 1 to Mar 31 and from Nov 9 to Dec 31.

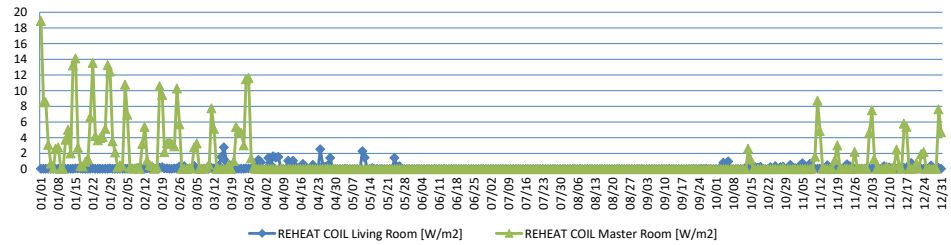


Fig.8. shows the energy use of the reheating in the living room and the master bedroom. The reheating energy use in the master bedroom is much higher than in the living room.

Conclusions



- Natural ventilation can reduce air conditioning load partly, but the running of natural ventilation only is very few, and the mechanical system is needed for most of the year.
- Assessment of thermal comfort in mixed-mode cooling spaces will be different depending on if the Fanger model or the adaptive model is used. To determine which one is the suitable methods need further research.
- Current design parameters of fully air-conditioning and natural ventilation buildings can not be used in mixed-mode cooling design.



建筑与交通工程學院
School of Architecture and Transportation Engineering

Comfort at Hospital Reception Desks





Regina Bokel*, P.J.W. van den Engel, A.M. Eijkelenboom, M.A. Ortiz Sanchez

Faculty of Architecture and the Built Environment, Delft University,

Julianalaan 134, 2628 BL Delft, The Netherlands, R.M.J.Bokel@TUDelft.nl

Types of Receptions

Closed

- Physically separates the personnel and the hall.
- Ensures safety, privacy; increases thermal comfort; decreases noise.

Open

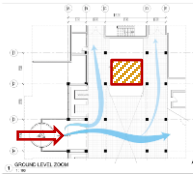
- No physical separation between personnel and patients and visitors.
- Preferred by hospitals because an open reception creates a more welcoming atmosphere for patients and visitors.

Main causes of discomfort from draught:

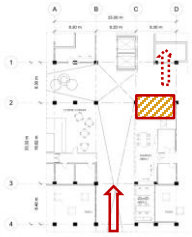
- Hospital 1:
  - Revolving door



- Hospital 2
  - **???**



- Hospital 3
  - Ventilation system
  - Opening and closing of emergency stairway door

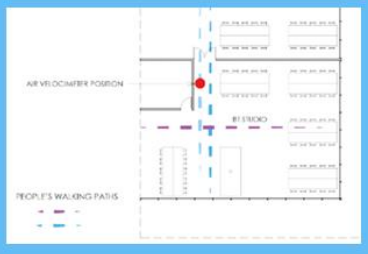


TUDelft

Movement of People

Are people the source of the draught?

Plan of the situation



Acutal situation



TUDelft

Conclusions

The exact cause of draught is difficult to determine.

Scale models or CFD simulations should be used as a guide for designing a reception desk in a hospital or when solving thermal comfort problems.

A **new cause** of **draught** was identified:
people moving past the reception desk

TU Delft

5

DEVELOPING A NEW PASSIVE TRACER GAS TEST FOR AIR CHANGE RATE MEASUREMENT

PhD project
Sarah L. Paralovo

VITO promoter: dr. Marianne Stranger
UGent promoter: prof. dr. Jelle Laverge

1

UNIVERSITEIT GENT vito

INTRODUCTION

Motivation:

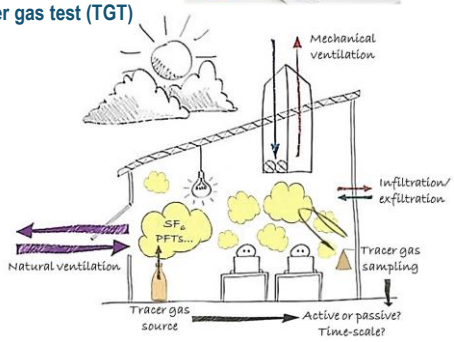
- IAQ, health and ventilation;
- Ventilation is often ignored;
- Need for an accessible method to quantify ventilation.



Most ventilation assessments use **a tracer gas test (TGT)** to measure total ACH:

Focus:
Large-scale studies

Best option:
- Constant injection method;
- Passive techniques.



Major shortcomings:
- Differing timescale between IAQ and ventilation data;
- Inadequate substances as traces;
- Perfect-mixing assumption bias.

Aim:

Develop new TGT to measure total ACH

- Different substance as tracer;
- Tracer is passively co-captured and co-analyzed with IAQ pollutants;
- Implementation of a pre-test planning phase to avoid bias from imperfect mixing;

2

METHODS

Selecting a substance better suited for use as tracer:

Deep literature review and definition of 6 criteria for a suitable tracer gas:

1) It can be quantified by passive air sampling commonly used in IAQ surveys;
2) It has insignificant background concentration;
3) It is safe for human health (use during occupancy);
4) It can be co-analyzed with common IAQ pollutants;
5) It is not susceptible to physical and chemical parameters of the indoor environment;
6) It is financially adequate.

Two substances under consideration:

- 2-butoxuethyl acetate (**EGBEA**)
- Deuterated decane (**D-decane**)

Tracer source design and testing:

- Chamber tests in steel and glass chambers: Determination of appropriate source design under constant standard conditions (T = 23°C, RH = 50%, ACH = 0.5 h^{-1});
- Gravimetric tests with micro-balance: Determination of sources emission rates under varying RH conditions.



Source design based on Shinohara et al. (2010)

Evaluation of perfect-mixing-bias via simulation modelling:

Most ventilation studies do not describe TGT positioning

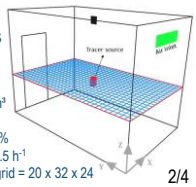
Perfect-mixing assumption

Severe bias

Proposed solution

Planning phase: simulate the spatial distribution of tracer concentration

Preliminary simulations with CONTAM-CFD0:



V = 30 m³
T = 23 C
RH = 50%
ACH = 0.5 h^{-1}
(X,Y,Z) grid = 20 x 32 x 24

2/4

3

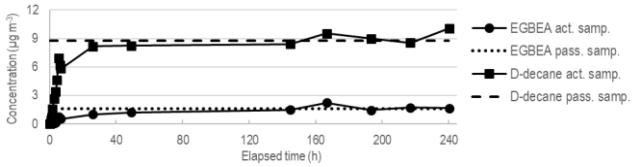
RESULTS

Chamber testing:

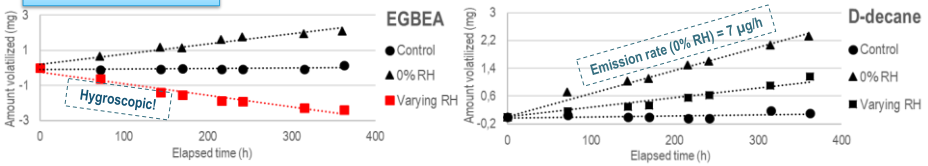
Estimated emission rates:

EGBEA = 0.8 µg/h

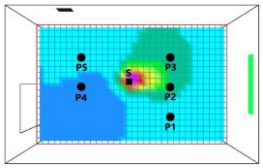
D-decane = 4 µg/h

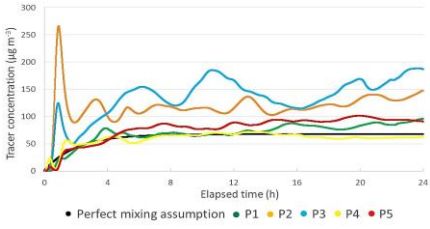


Gravimetric testing:



Simulation modeling:





Uneven tracer distribution

Best placement = **P4**

3/4

4

CONCLUSIONS

- A new TGT may encourage researchers to include ventilation assessments in their IAQ studies;
- This project proposes to tackle 3 major shortcomings of current TGTs:
  - Differing timescale between ACH and IAQ data → Employment of commercial passive samplers
  - Inadequate substances used as tracers → Propose alternative substance
  - Perfect-mixing-assumption bias → Implement planning phase for sources/samplers positioning via simulation modeling.
- Ongoing work on pursuit of new tracer substance and suitable source design:
  - Chamber testing
  - Gravimetric tests
- D-decane shows suitability for use as tracer, unlike EGBEA (hygroscopic);
- Simulation models demonstrate the effects of imperfect mixing and can assist on TGT positioning planning.

London-Loughborough EPSRC CDT
Centre for Doctoral Training in Energy Demand

Vision and leadership for a sustainable built environment

Measuring the ventilation rate in occupied buildings: adapting the CO_2 tracer gas technique

Jessica Few

Jessica.few.16@ucl.ac.uk

UCL Loughborough University EPSRC Pioneering research and skills

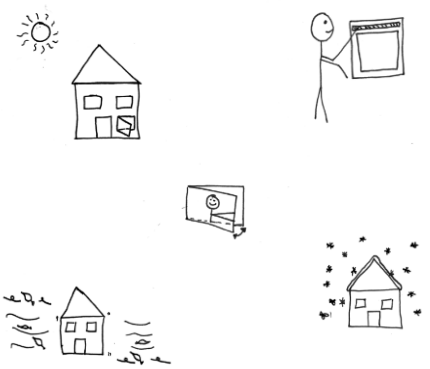
1

London-Loughborough EPSRC CDT
Centre for Doctoral Training in Energy Demand

Ventilation measurement in occupied homes

Several issues arise when measuring ventilation in occupied buildings:

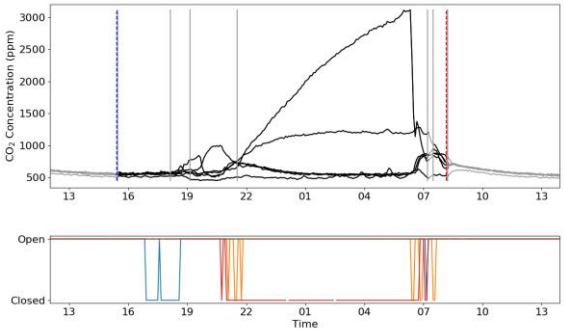
- Time scale of measurement
- Spatial scale of measurement
- Inconvenience to occupants
- Knowledge of internal conditions



2

London-Loughborough EPSRC CDT
Centre for Doctoral Training in Energy Demand

Developing an Occupancy Algorithm



- The algorithm uses door and CO_2 measurements to determine when the building is occupied.
- 87% agreement with occupant records.

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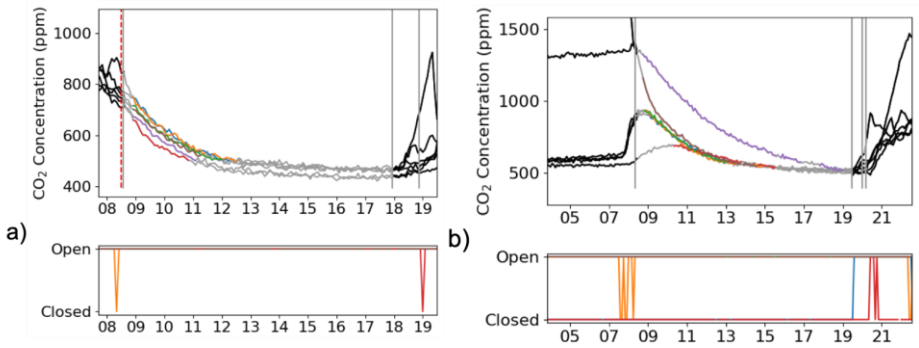
Centre for Doctoral Training in Energy Demand

Evaluating the ventilation rate



- Since all rooms and internal doors are measured, greater insight into the ventilation conditions is gained.
- This can help us to understand the ventilation conditions that occupants experience.

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Thank you for listening!

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Centre for Doctoral Training in Energy Demand

Vision and leadership for a sustainable built environment

Airtightness and non-uniformity of ventilation rates in a naturally ventilated building with trickle vents

Jessica Few

Jessica.few.16@ucl.ac.uk

UCL Loughborough University EPSRC Pioneering research and skills

1

London-Loughborough EPSRC CDT
Centre for Doctoral Training in Energy Demand

Investigating ventilation in a naturally ventilated dwelling with trickle vents







2

London-Loughborough EPSRC CDT
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Ventilation: trickle vents and spatial scale of measurement

	Whole house	Individual room
Trickle vents open 	0.8 ach	0.3 ach
Trickle vents closed 	0.7 ach	0.2 ach

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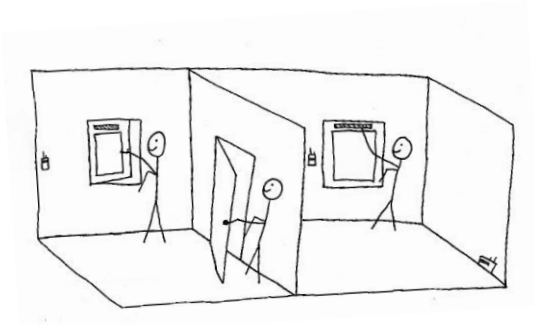
Implications of findings



- Cracks in the building fabric are unlikely to be evenly distributed. This is likely to have a significant impact on the ventilation rate.
- Further work is required to understand more about the ways that occupants use internal spaces; this may have a major impact on the ventilation rates they experience.

London-Loughborough EPSRC CDT
Centre for Doctoral Training in Energy Demand

Thank you for listening!

Prediction Method of Natural Ventilation Rate Based on Successive Calculation of Indoor Air Pressure Variation

Haruna Yamasawa, Toshio Yamanaka,
Tomohiro Kobayashi, Jihui Yuan

Doctor course student in Osaka university, Japan

1

Natural Ventilation II

Uses renewable energy when ventilating

So, Saves energy of

Heat source Air conveyance Ventilation

50% of the energy consumption in an office

Accurate, long-term prediction method is needed

But, Performance easily affected by

Wind Solar radiation Temperature etc...

AIM

to establish the prediction method of NV

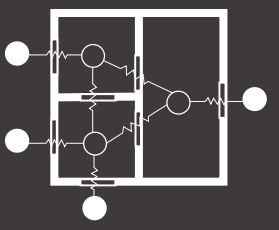
Network model for transient condition

2

Network Model III

Rooms & Outdoor air
→ **Nodes**
with pressure, temp., ⋯

Openings
→ **Branches**
with area, resistance, ⋯



Common method
✓ Steady calc.
✓ Balance eq.
& Iterative calc.

Method in this paper
✓ Transient calc.
Time series results

✓ Iterative calc.
is **not** needed
Simple Algorithm

3

Calculation Method IV

Setting
Initial condition & Boundary condition

Calc.
Differential pressure & Airflow rate

$\Delta p = P_1 - P_2 - P_{Loss}$ $\quad F = C_D A\sqrt{2/\rho|\Delta p|}$

Air density
$\rho_i^{j+1} = \rho_i^j + \Sigma\rho^j F^j / V_i$

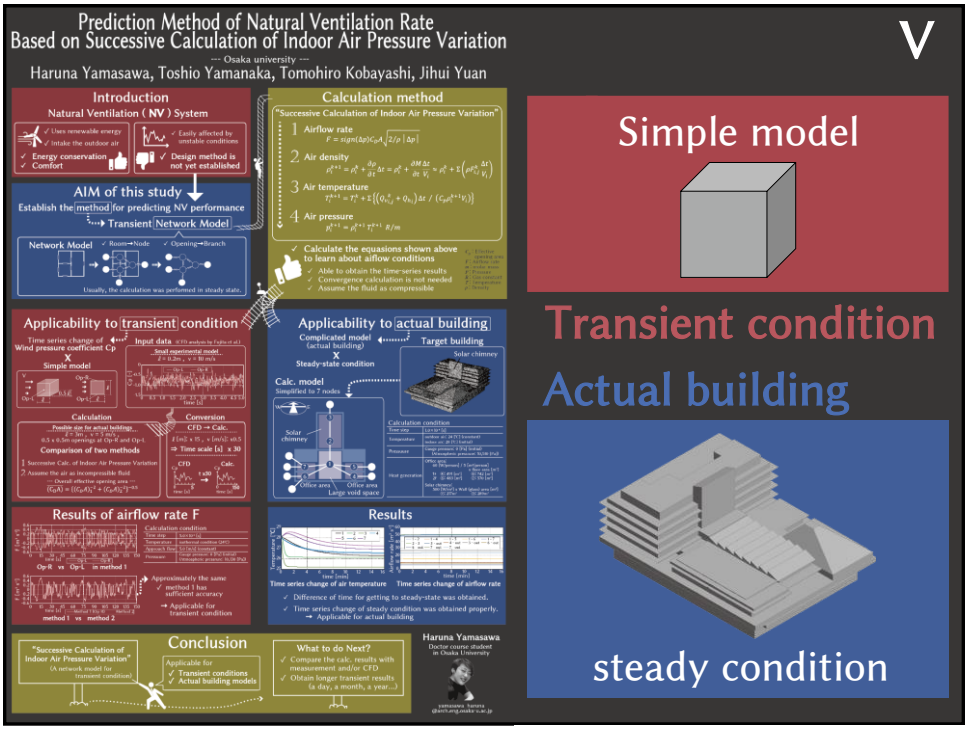
Air temperature
$T_i^{j+1} = T_i^j + \Delta T$

Air pressure
$P_i^{j+1} = \rho_i^{j+1} R T_i^j / m$

t = t + Δt

$C_D A$: Effective opening area
F : Airflow rate
m : molar mass
P : Pressure
R : Gas constant
T : Temperature
ρ : Density

4


Prediction Method of Natural Ventilation Rate
Based on Successive Calculation of Indoor Air Pressure Variation
--- Osaka university ---
Haruna Yamasawa, Toshio Yamanaka, Tomohiro Kobayashi, Jihui Yuan
V
Introduction
Natural Ventilation (NV) System
Uses renewable energy
Intake the outdoor air
Energy conservation
Comfort
Easily affected by unstable conditions
Design method is not yet established
AIM of this study
Establish the method for predicting NV performance
Transient Network Model
Network Model
Room→Node
Opening→Branch
Usually, the calculation was performed in steady state.
Calculation method
"Successive Calculation of Indoor Air Pressure Variation"
1 Airflow rate
2 Air density
3 Air temperature
4 Air pressure
Calculate the equasions shown above to learn about aiflow conditions
Able to obtain the time-series results
Convergence calculation is not needed
Assume the fluid as compressible
Applicability to transient condition
Time series change of Wind pressure coefficient Cp
Input data
Simple model
Calculation
Conversion
CFD → Calc.
Comparison of two methods
Applicability to actual building
Complicated model (actual building)
Target building
Steady-state condition
Solar chimney
Calc. model
Simplified to 7 nodes
Office area
Large void space
Calculation condition
Results of airflow rate F
Op-R vs Op-L in method 1
Approximately the same
method 1 has sufficient accuracy
→ Applicable for transient condition
method 1 vs method 2
Results
Time series change of air temperature
Time series change of airflow rate
Difference of time for getting to steady-state was obtained.
Time series change of steady condition was obtained properly.
→ Applicable for actual building
Conclusion
"Successive Calculation of Indoor Air Pressure Variation"
(A network model for transient condition)
Applicable for
Transient conditions
Actual building models
What to do Next?
Compare the calc. results with measurement and/or CFD
Obtain longer transient results (a day, a month, a year...)
Haruna Yamasawa
Doctor course student
in Osaka University
Simple model
Transient condition
Actual building
steady condition



antoine.leconte@cea.fr

EXPERIMENTAL STUDY OF THE COMBINATION OF A POSITIVE INPUT VENTILATION AND ACTIVE AIR VENTS ON THE AIR CHANGE RATES OF A HOUSE

Antoine Leconte, Clément Lafféter, Thomas Fritsch, Nicolas Giordano, Julien Escaich and Ophélie Ouvrier Bonnaz

1

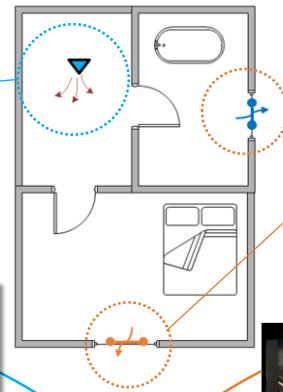
OBJECTIVES

Positive Input Ventilation

- Mechanical ventilation
- Draws, filters and pre-heats fresh air
- Supplies into living areas







Active Air Vents

- Motorized dampers (windows of damp & living rooms)
- Electronic cards (controls, measurements and communication with the other Active Air Vents)





What is the impact of the different possible configurations on the Air Change Rate of the rooms ?

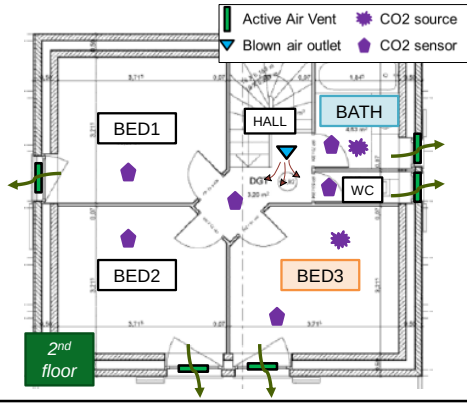
→ ***Quantitative evaluation of the Air Change Rate in a real size environment***

2

METHODOLOGY

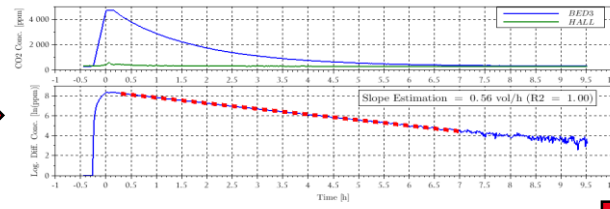
EXPERIMENTAL SETUP

- Fully equipped experimental house
- Use of CO2 as a trace gas in the studied rooms



AIR CHANGE RATE ESTIMATION

Analysis of the decrease of the CO2 concentration



TESTED CONFIGURATIONS (Steady sate)

Multiple combination the tested rooms

BATHROOM, BEDROOM, KITCHEN

- [REF] = With a classical static air vent (self-regulation units)
- [MIN] = With all the AAVs of the room at the "Minimal position"
- [MAX] = With all the AAVs of the room at the "Maximal position"

→ 52 characterization tests to evaluate possible scenarios

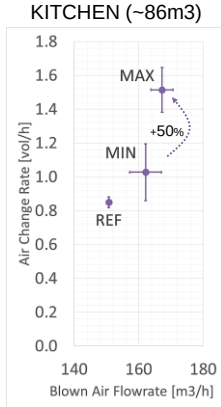
3

RESULTS AND OUTLOOKS

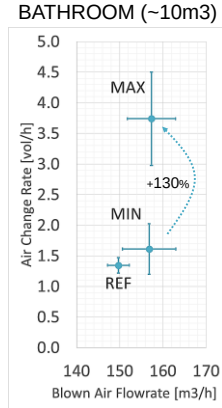
AUTONOMOUS OPERATION

- *Significant raise of the Air Change Rate when the Active Air Vent is open*

KITCHEN (~86m3)

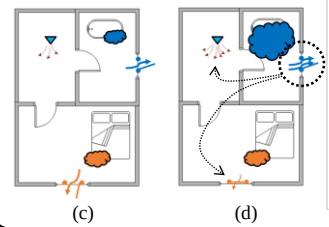


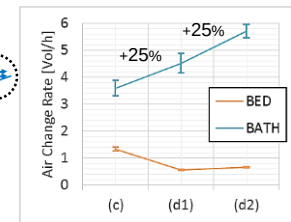
BATHROOM (~10m3)



CONCERTED OPERATION

- *Additional Air Change Rate potential when the Active Air Vents communicate between them and with the Positive Input Ventilation*





To go further…

- Numerical studies to generalize the results
- Development of a **global controller to smartly modulate the ACR of each room** (damp room as well as living room) according to the pollution levels throughout the house

4

antoine.leconte@cea.fr

MERCI POUR VOTRE ATTENTION

THANKS FOR YOUR ATTENTION

Commissariat à l'énergie atomique et aux énergies alternatives
150 avenue du lac Léman | 73375 Le Bourget-du-Lac
www-liten.cea.fr

Établissement public à caractère industriel et commercial | RCS Paris B 775 685 019

Leonie Scheuring
Technical University of Dresden
Institute of Building Construction

An investigation of ventilation control strategies for louver windows in different climate zones

AIVC - Ghent // 15.10.2019

1

Motivation
Mechanical ventilation vs. natural ventilation

Mechanical ventilation

↓

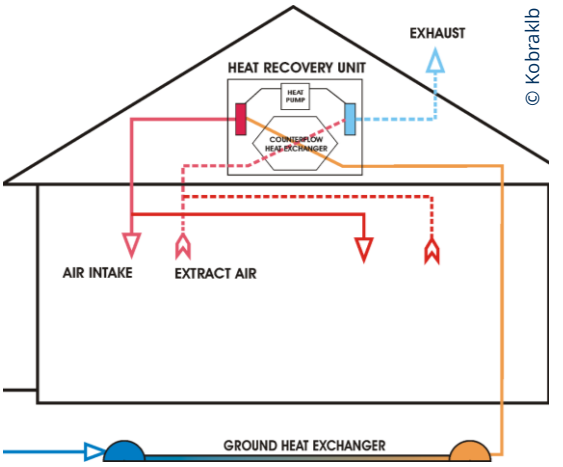
Potential of functionality in every environment

↓

Risk to evoke Sick Building Syndrome
High installation costs
Energy demand for ventilation fan

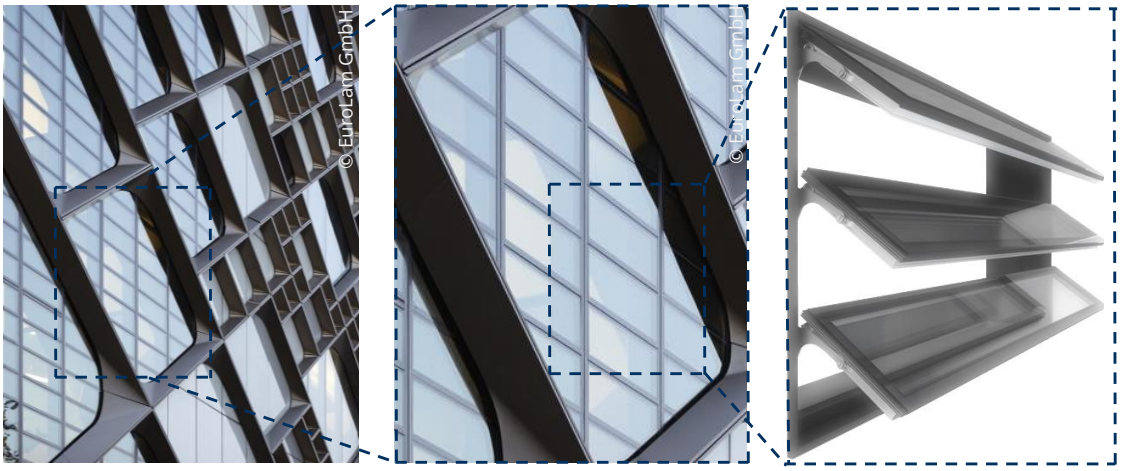
↓

Low tech - natural ventilation?



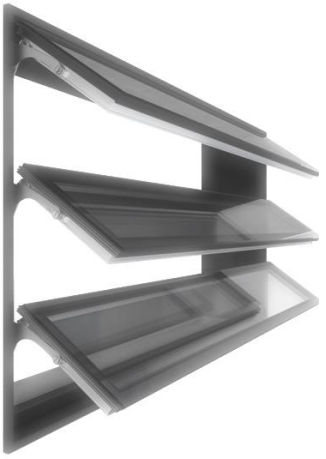
2

System
Principles



3

System
Functionality



CONTROL STRATEGY

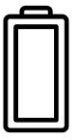




SELF-SUFFICIENCY



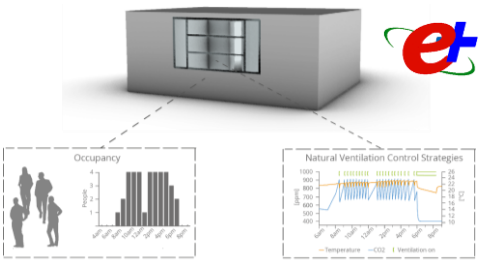
PHOTOVOLTAICS



BATTERY

4

Studies
Concept



	Internal gains	Reference
People	126 W/person	DIN EN 15251
Lighting	10.63 W/m²	DIN 18599-10
Electric equip.	7 W/m²	DIN 18599-10
CO_2-production rate	$3.82 \cdot 10^{-8}$ m³/s·W	ASHRAE Standard 62.1-2007

Construction Element	U-Value	Solar Heat Gain coefficient (SHGC)	Material and thickness of the structural element
External wall	0.28 W/(m²K)	-	25 cm concrete
Louver window and non operable windows	1.27 W/(m²K)	0.54	-
Ceiling	adiabatic	-	20 cm concrete
Internal walls	adiabatic	-	11.5 cm sand-lime brick

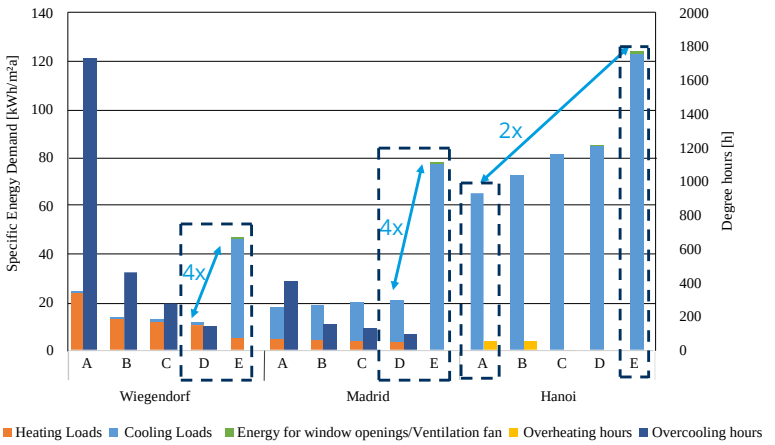
5

Evaluating control strategies
Varying CO_2 thresholds

Natural ventilation
A. 900 - 500 ppm
B. 900 - 600 ppm
C. 900 - 700 ppm
D. 900 - 800 ppm

Mechanical ventilation
E. 900 ppm

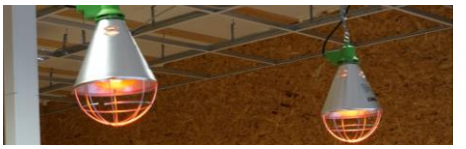
➢ Natural ventilation is more energy efficient.



6

Outlook









Cooling Performance of Air-Conditioning System with Ceiling Suspended Packaged Air Conditioning Unit over Divided – Type Membrane Ceilings in Large Classroom

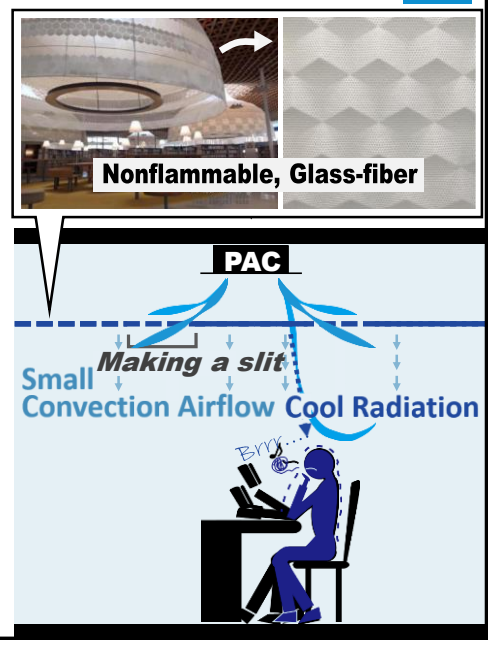
Shogo Ito
Toshio Yamanaka
Tomohiro Kobayashi
Jihui Yuan
Narae Choi

1

2

- **CONVENTIONAL…**
  - Mixing Ventilation
  - ↳ Cold Draft Risk
- **MEMBRANE CEILING**
  - Draft-less environment
  - Good thermal comfort
- **DIVIDED-TYPE MEMBRANE**
  - Increasing convection flow
  - ↑ IAQ
  - ↑ Cooling performance

To Grab the Performance of New System!



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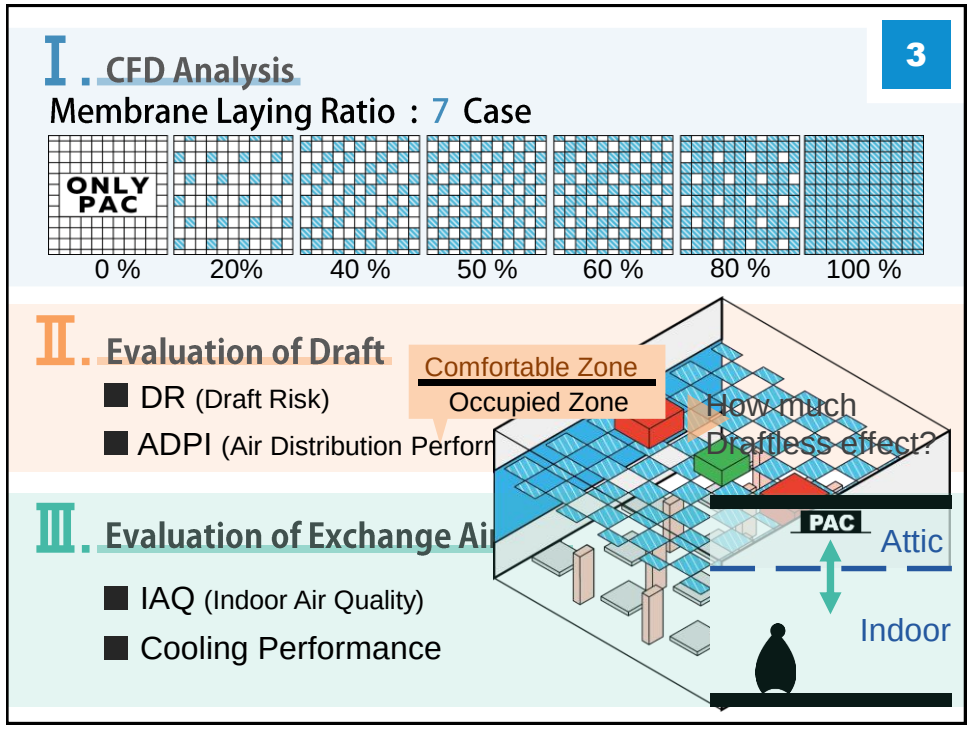
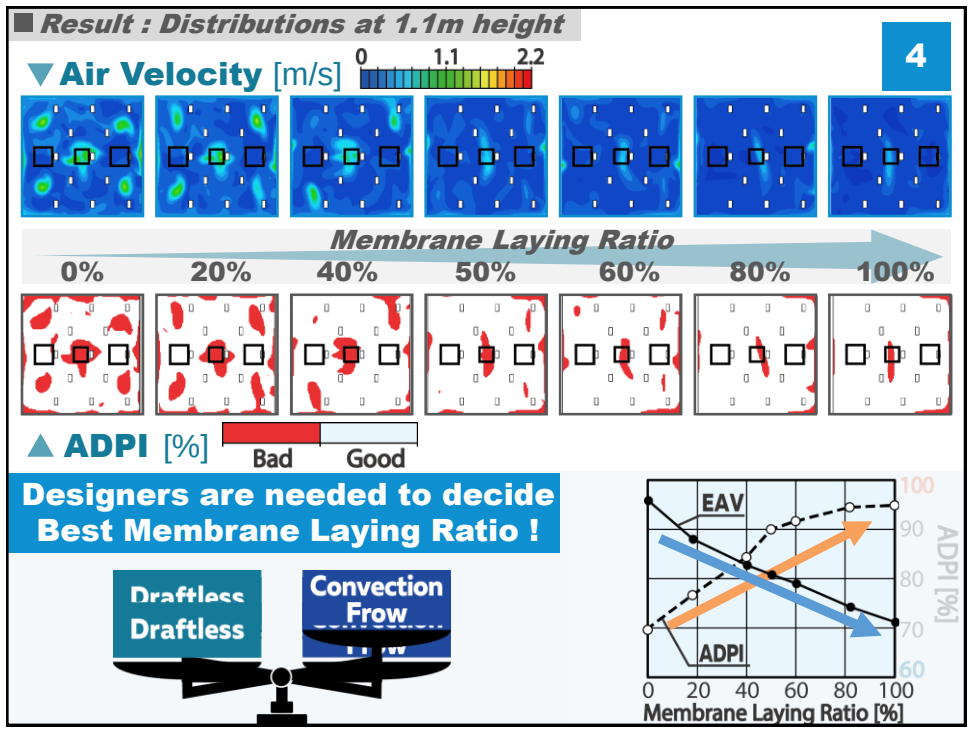
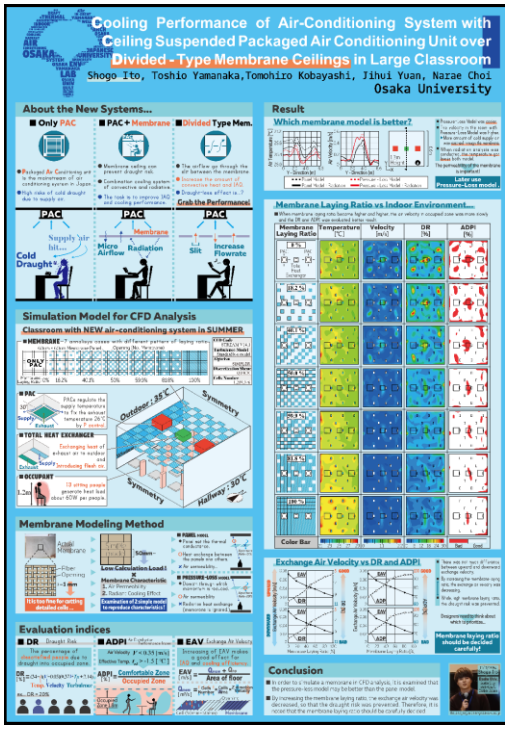

3
Ⅰ. CFD Analysis
Membrane Laying Ratio : 7 Case
ONLY PAC
0 %
20%
40 %
50 %
60 %
80 %
100 %
Ⅱ. Evaluation of Draft
DR (Draft Risk)
ADPI (Air Distribution Perfor
Comfortable Zone
Occupied Zone
How much Draftless effect?
PAC
Attic
Indoor
Ⅲ. Evaluation of Exchange Ai
IAQ (Indoor Air Quality)
Cooling Performance

3


Result : Distributions at 1.1m height
4
Air Velocity [m/s]
0
1.1
2.2
Membrane Laying Ratio
0%
20%
40%
50%
60%
80%
100%
ADPI [%]
Bad
Good
Designers are needed to decide Best Membrane Laying Ratio !
Draftless
Convection Frow
EAV
ADPI
100
90
80
70
60
ADPI [%]
0
20
40
60
80
100
Membrane Laying Ratio [%]

4



Thank you for the attention!
The details are shown on the poster.

AIVC2019

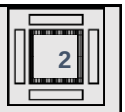
Modelling of Supply Air Jet from Diffusers of Four-way packaged Air-conditioner for CFD Analysis on Unsteady Airflow in Room

大阪大学
OSAKA UNIVERSITY

Norikazu YASUDA
Toshio YAMANAKA
Tomohiro KOBAYASHI
Jihui YUAN
Narae CHOI

1

Purpose





Packaged Air Conditioner (PAC)

・Refrigerator ・Cooling coil ・Ventilator

can change its airflow's

- **Rate**
- **Temperature**
- **Direction**

"Swing mode" needs non-steady analysis

No precise design method

Purpose

Establishing CFD model

・shorten the analysis time
・more precise analysis result

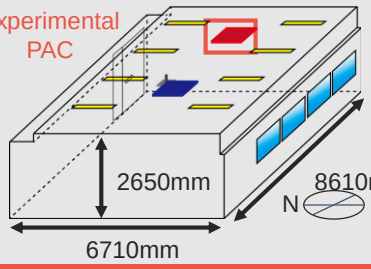
Using
Prescribed Velocity method
(P.V.method)

2

Experiment



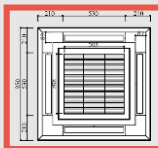
Experimental PAC



Experimental room



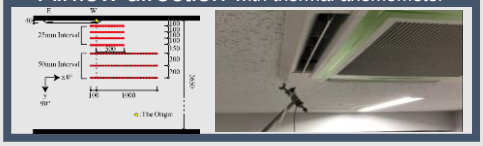
Experimental PAC



4-way PAC

Plan View of PAC

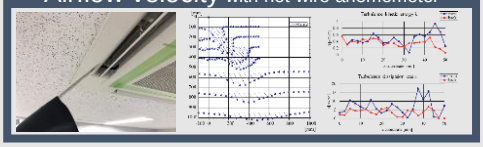
Airflow direction with thermal anemometer



Airflow Rate with card board duct



Airflow velocity with hot-wire anemometer

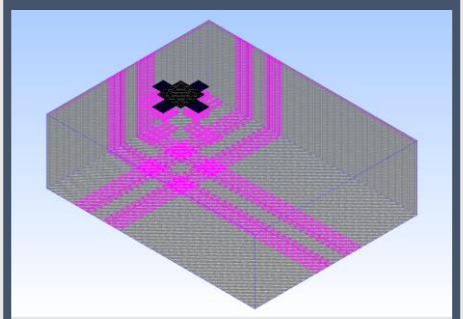


3

CFD Analysis



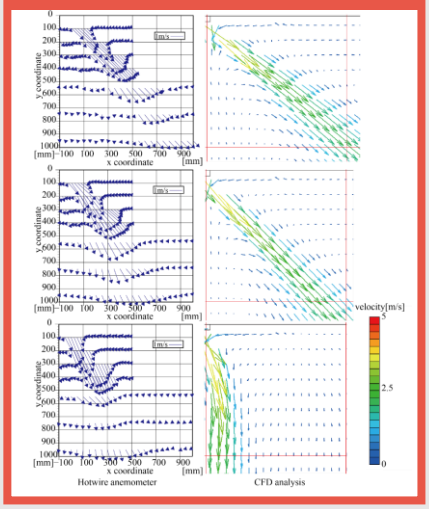
Model



Using P.V. method



Results



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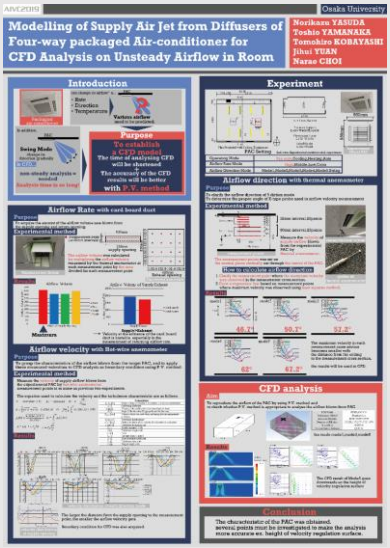
For Further Information...



Please ask me at poster presentation!

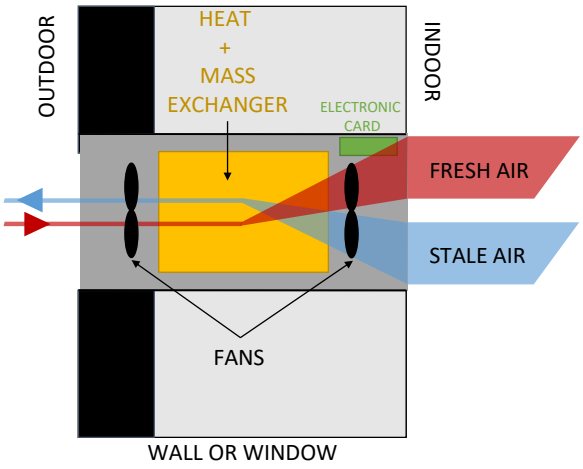
Multi-objective design of single room ventilation units with heat and water recovery

Antoine Parthoens

a.parthoens@uliege.be

15/10/2019

SILENTHALPIC project



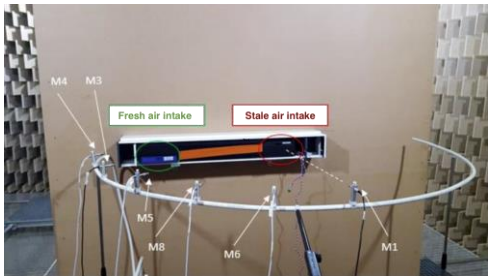
SILENTHALPIC

silence enthalpy

REDUCTION OF NOISE EMISSIONS

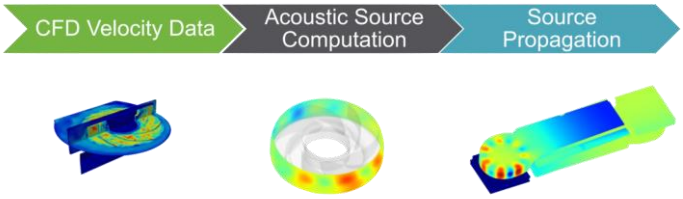
2 kind of investigations :

- Experimental
- Numerical



2 kind of solutions :

- Passive
- Active



Computed by Cenaero

Near the rotor/stator CFD interface

Inside the module and outside

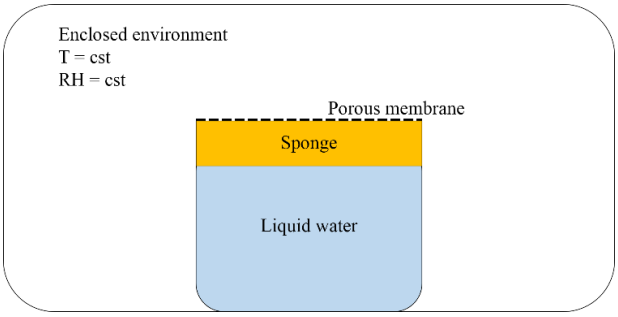
3

3

HEAT + MASS EXCHANGER

Development of modeling of a **new composite membrane** (polymer matrix with artificial defects)

Goal : get the best membrane performance and optimal exchanger geometry



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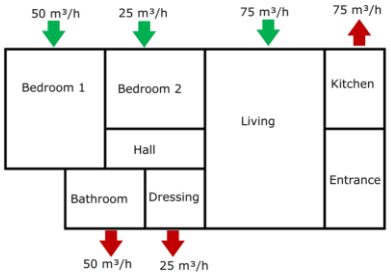
4

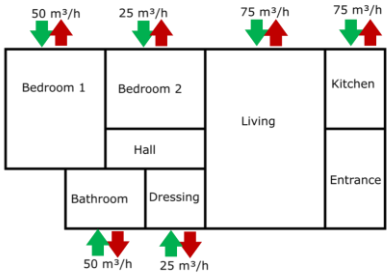
DESIGN AND CONTROL AT BUILDING SCALE

Multizone simulations (CONTAM)

Conventional



Decentralized



Case	Nominal flow rate [m³/h]	Mean flow rate with local regulation and detection [m³/h]
Conventional centralized system	150	63
Fully decentralized system	**300**	86

THANK YOU

REVIEW OF BUILDING SERVICES SOLUTION FITTED FOR A LOW EMISSION BUILDING STOCK IN URBAN AREAS

Matthias Haase

SINTEF Community

Research Centre on ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES

Structure of the paper/poster

Literature review

- Scopus datsbase
- Boolean operators
- + research reports

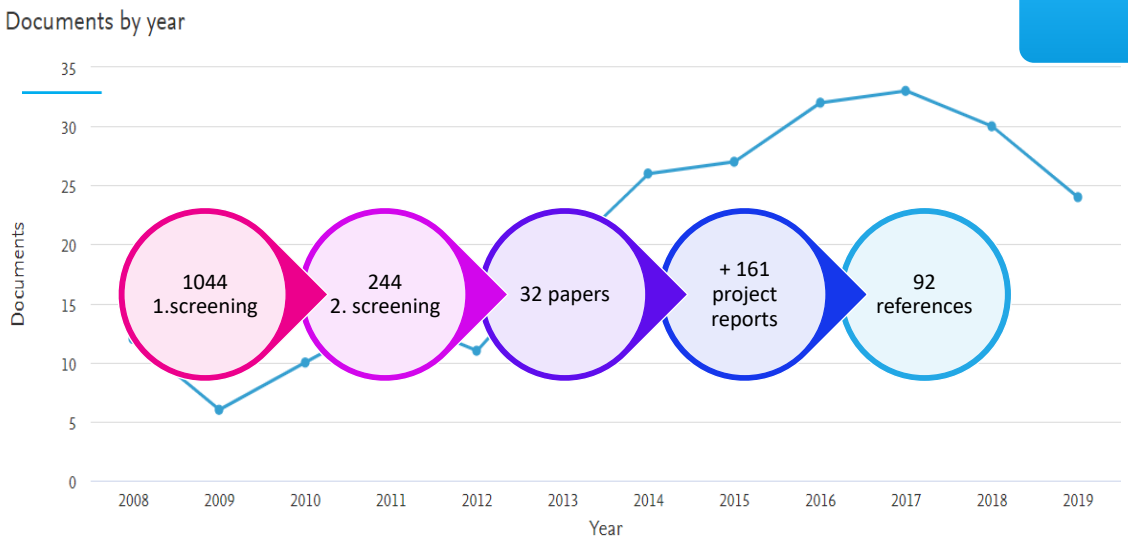
Classification technologies

- Demand-controlled ventilation
- Ventilation-based heating and cooling
- Simplified hydronic heating
- Smart energy control
- Responsive lighting equipment
- Utilizing surplus energy sources

Suitable Building typologies

- New offices
- Renovated offices
- Educational buildings
- Kindergartens
- Residential buildings
- Grocery stores
- Shopping centres

Literature review



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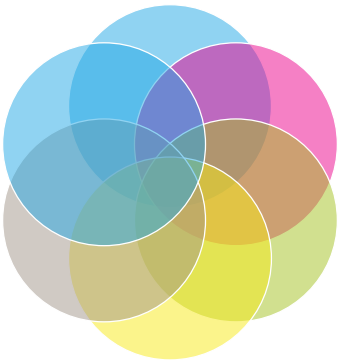
3

Classification technologies

Demand-controlled ventilation

Utilizing surplus energy sources

Ventilation-based heating and cooling



Responsive lighting equipment

Simplified hydronic heating

Smart energy control

4

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4

Building category / Technical solution		New offices	Renovated offices	Educational buildings	Kindergartens	Residential buildings	Grocery stores	Shopping centres
Demand-controlled ventilation		+++	+++	+++	+++	++	0	0
Simplified hydronic heating		+++	0	0	0	+++	0	0
Ventilation-based heating		+++	++	0	0	+	0	0
Ventilation-based cooling		+++	+++	+	+	+	+	+++
Responsive lighting equipment (LED)		++	+++	+++	+++	++	+++	+++
Smart energy control (BEMS)		+++	+++	+++	+++	++	++	++
Utilizing surplus energy sources*	import	+++	+++	+++	+++	+++	+++	+++
	export	++	++	++	+	+	+++	++

5

SINTEF

Teknologi for et bedre samfunn

6

"40th AIVC - 8th TightVent & 6th Venticool Conference 15-16 October, 2019"



Life cycle assessment of CAV, VAV, and ACB systems in a modern Swedish office building

Nadeen Hassan[1]; Saqib Javed[2]
1- Lund University – Energy-efficient & Environmental Building Design
2- Lund University – Building services

1- Life Cycle Assessment · Idaho Forests Products Commission

1

Problem Motivation

HVAC systems

HVAC represent 50% of building's total energy (Pérez-Lombard et al., 2008)

HVAC installations increased due to thermal comfort demand & standards (Coletti & Fano, 2008)

HVAC studies focused on operational energy (Chen, 2011).

HVAC's manufacturing, transportation, installation consume high amount of energy

1-Icon made by Freepik from www.flaticon.com
2-Icon made by Geotatah from www.flaticon.com

2

Case study

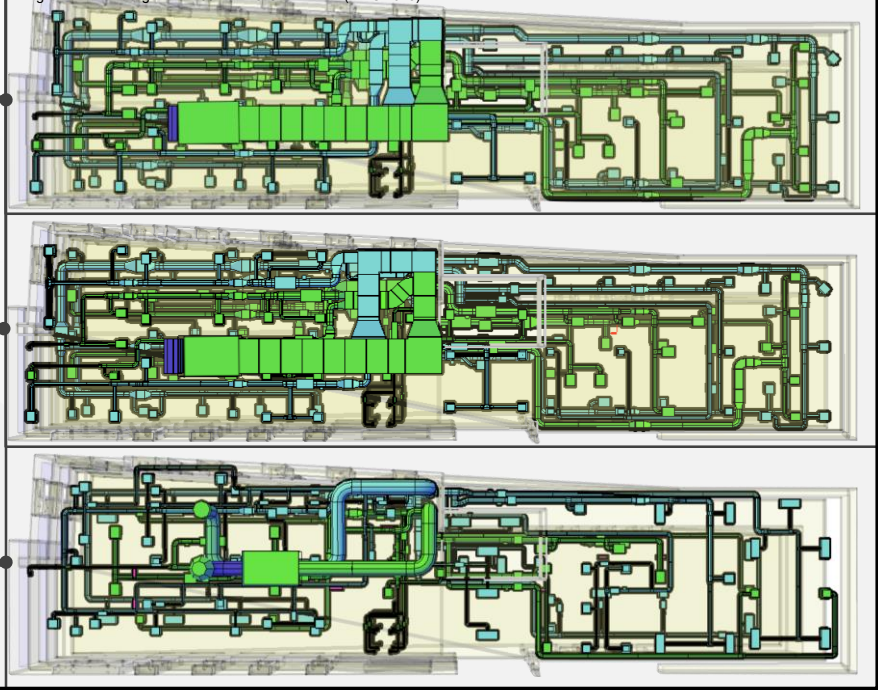
3

1 Constant Air Volume (CAV)

2 Variable Air Volume (VAV)

3 Active Climate Beams (ACB)

"Abugabbara M., Sebesten L., & Behrens J. (2018). Assessing the energy use and IAQ of various HVAC systems during the early design stage. In: Proceedings of the 39th AIVC Conference (AIVC 2018)."



4

Goal & scope

01 To evaluate and compare the life cycles of the CAV, VAV, and ACB systems from Cradle-to-grave

02 FU: 20 years of heating/cooling to maintain an indoor temperature of 26 °C and 22 °C in summer/winter and the minimum required flow rate.

03 LCA modelling system: Attributional method

04 Method of LCIA: CML IA (Baseline); Weighting: Shadow cost method

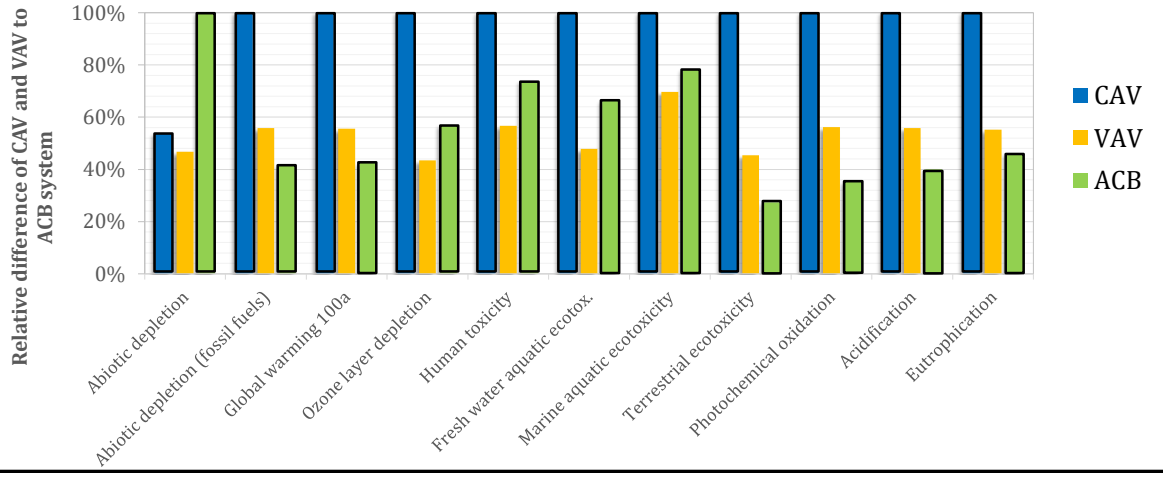
05 Ecoinvent database + SimaPRO LCA software

5

Results & conclusions

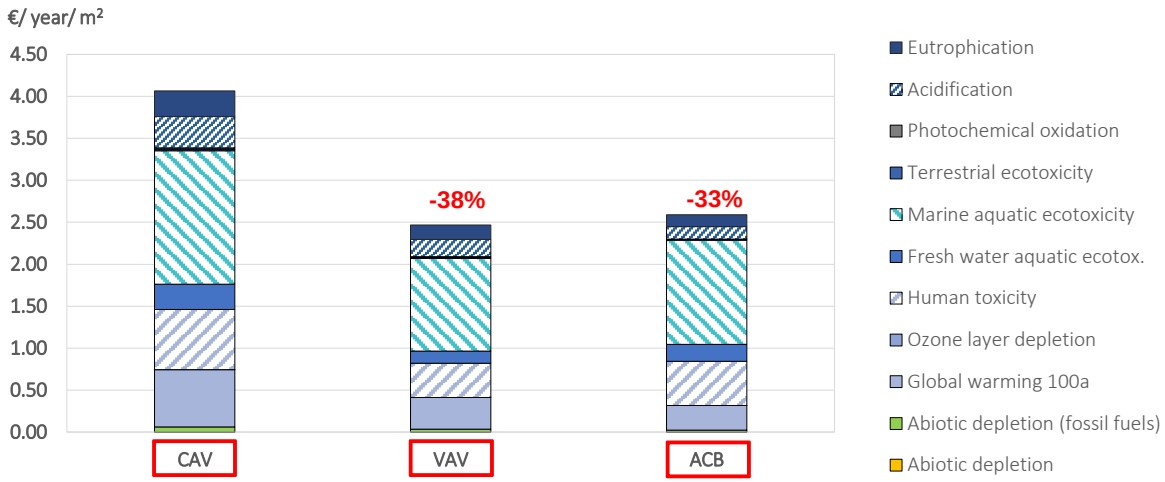
6

Potential Environmental Impacts
Life cycle



7

Shadow cost
Life cycle

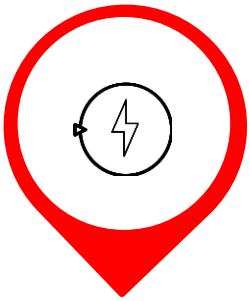


8

Conclusions



Environmental impacts
ACB: Manufacturing
VAV/CAV: Operation



Sources of Impacts
Metals; Zinc coating;
Operational energy



Shadow cost
CAV has the highest shadow cost; VAV system have a better performance than the ACB system

1-Icon made by "pongsakornRed" from www.flaticon.com

10

Thank you

For more information, please visit my poster

Nadeen Hassan

11

1

Enhancing thermal comfort and indoor air quality in Australian school classrooms

Shamila Haddad, Afroditi Synnefa, Miguel Ángel Padilla Marcos, Riccardo Paolini, Deo Prasad, and Mattheos Santamouris

40th AIVC - 8th TightVent & 6th venticool Conference

2

Fresh air

Air quality and ventilation

Thermal comfort

Mould and condensation

Smart monitoring devices

Health and wellbeing

Cognitive performance

Energy use

Sustainability

Awareness

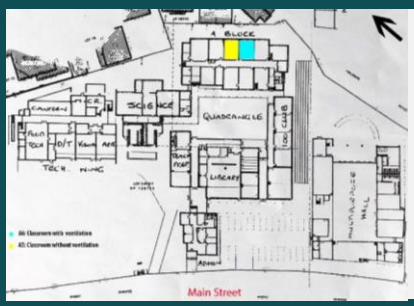


3

Objectives:

- Assessment of the thermal comfort conditions and air quality over 1 year (2018-2019)
- Installation and evaluation of a hybrid ventilation system to improve thermal comfort and air quality





– Achieve thermal comfort conditions

– Enhance wellbeing and performance

– Reduce energy consumption

Healthy, comfortable, and energy efficient school buildings

4

4

Selected school/classrooms:





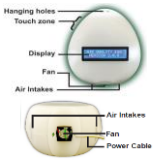
Classroom area: 48 m2
Occupancy: varied
Student age group: 12-18 years
Distance to the coast: 1.5 km
Distance to the main road: 100m
Orientation: NE

5

Method:

- Measurement of Ta, RH, and CO2 in two adjacent classrooms from April 2018 to May 2019 using Air Quality Eggs.

Indoor Air Quality Egg recorder

Air Quality Device Aims to 'Bring Citizen Science into the Classroom'




6

6

Method:

- Measurement of Ta, RH, and CO2 in two adjacent classrooms from April 2018 to May 2019 using Air Quality Eggs.
- Measurement of globe temperature, dry bulb temperature, relative humidity, and air speed simultaneous with questionnaire survey using Heat Shield by LSI.

Indoor Air Quality Egg recorder





LSI Heat Shield



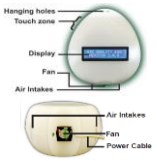
7

Method:

- Measurement of Ta, RH, and CO2 in two adjacent classrooms from April 2018 to May 2019 using Air Quality Eggs.
- Measurement of globe temperature, dry bulb temperature, relative humidity, and air speed simultaneous with questionnaire survey using Heat Shield by LSI.
- Questionnaire survey on right here, right now' basis over one week during midseason 2019 and winter 2018.

Indoor Air Quality Egg recorder





LSI Heat Shield



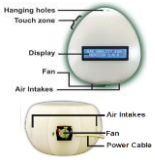
8

Method:

- Measurement of Ta, RH, and CO2 in two adjacent classrooms from April 2018 to May 2019 using Air Quality Eggs.
- Measurement of globe temperature, dry bulb temperature, relative humidity, and air speed simultaneous with questionnaire survey using Heat Shield by LSI.
- Questionnaire survey on right here, right now' basis over one week during midseason 2019 and winter 2018.
- Spot measurements of PM10 and PM2.5, and Formaldehyde using Aeroqual Air Quality Monitor (series 500).

Indoor Air Quality Egg recorder





LSI Heat Shield



Aeroqual



9

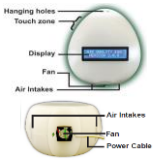
9

Method:

- Measurement of Ta, RH, and CO2 in two adjacent classrooms from April 2018 to May 2019 using Air Quality Eggs.
- Measurement of globe temperature, dry bulb temperature, relative humidity, and air speed simultaneous with questionnaire survey using Heat Shield by LSI.
- Questionnaire survey on right here, right now' basis over one week during midseason 2019 and winter 2018.
- Spot measurements of PM10 and PM2.5, and Formaldehyde using Aeroqual Air Quality Monitor (series 500).
- Measurement of outdoor air temperature every 30 minutes during the long-term monitoring period.

Indoor Air Quality Egg recorder





LSI Heat Shield



Aeroqual



10

LOGTAG temperature recorder





10







11

11

Method:

- Measurement of infiltration and ventilation rates through tracer gas measurements using the decay method over one day in October 2018 from 9:00 to18:00: Innova 1403, and Innova 1412i Photoacoustic Gas Monitor (LumaSense Technology) with Sulphur Hexafluoride (SF6).

- Healthbox 3.0 and window ventilator by RENSON® were installed in one of the selected classrooms before the mid-season survey in February 2019

Tracer gas measurment



Healthbox 3.0



1. Window Vents
2. Ventilative cooling
3. Extraction of air

12

12



Healthbox installed in the ceiling.



INVISIVENT® EVO: Ventilator installed in the window which supplied fresh air



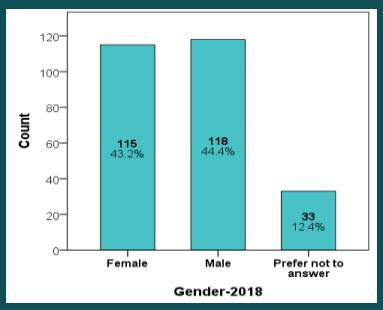
Healthbox 3 with the SmartConnect connection

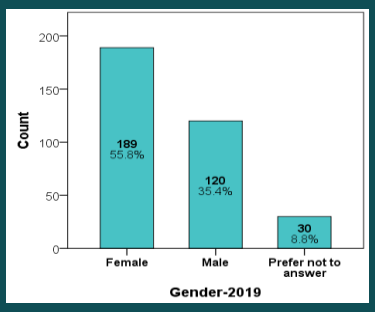
13

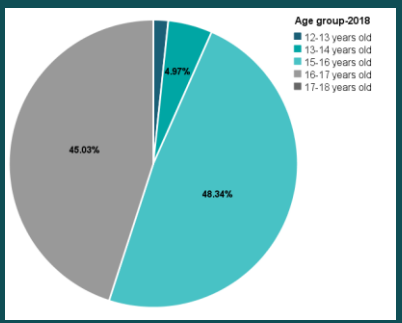
The built-in central sensors continuously monitor
Temperature, humidity, CO2 and VOC

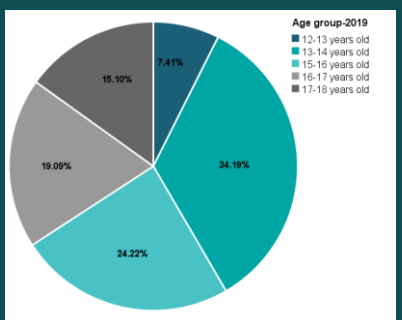
13

Participants





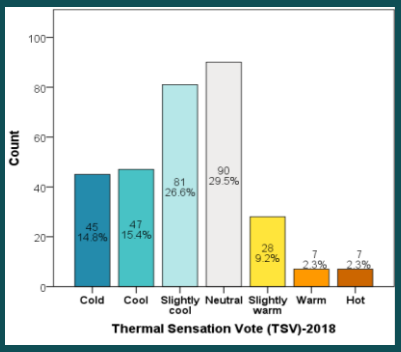


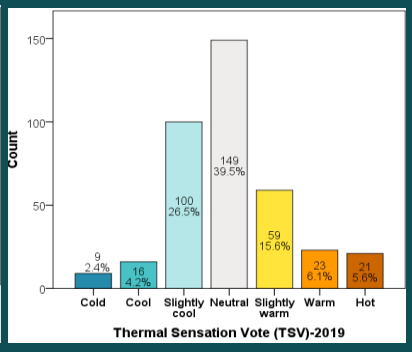


376 (28 class-survey) and 306 questionnaires (27 class-survey) were pooled during winter and summer

14

Seven-point psycho-physical ASHRAE thermal sensation scale



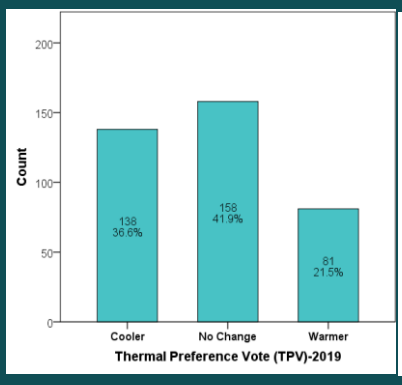


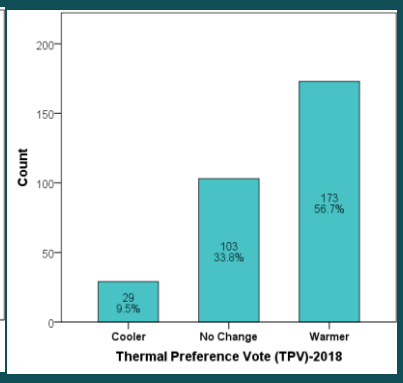
During mid-season survey 2019: over 81% of students feel neutral by voting on the three-central categories of the comfort scale.
During winter 2018: 65 %

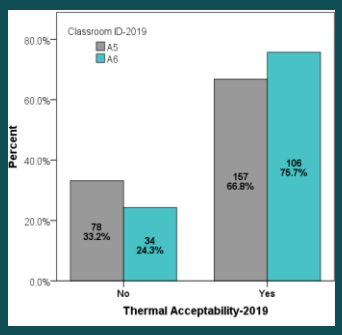
15

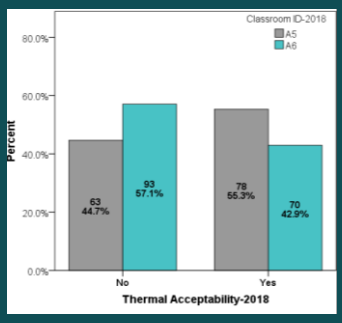
15

Thermal preference votes and acceptability





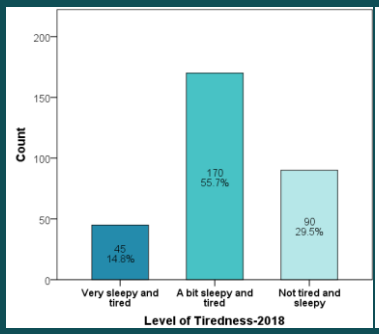


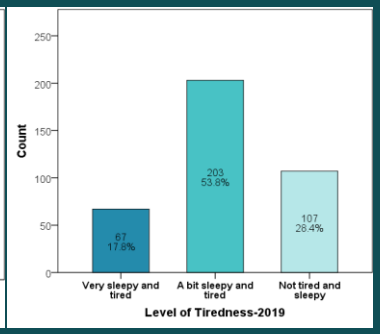


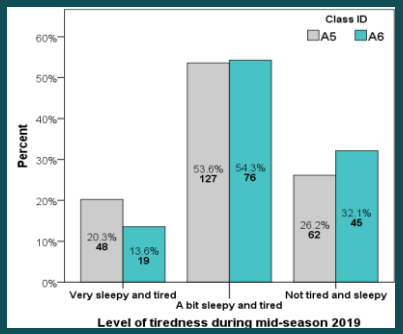
16

16

Tiredness level







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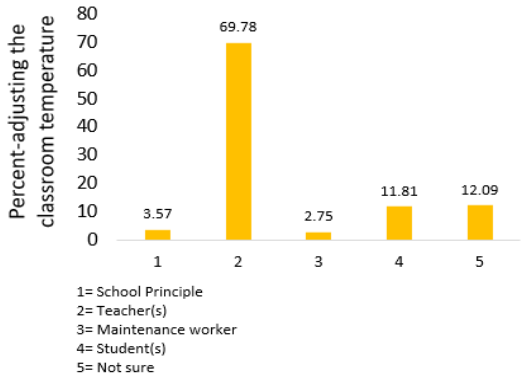
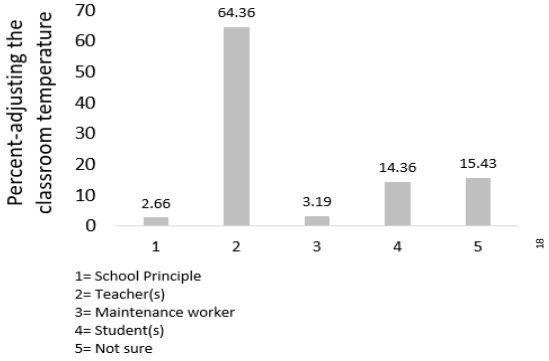




18

18

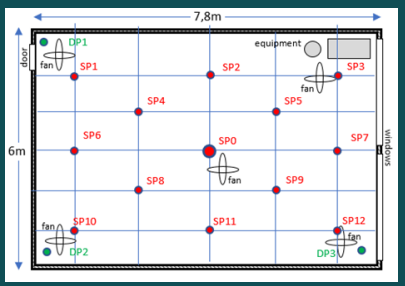
Results

a) all windows closed, b) windows opened, including two sub-cases, namely with one window opened and all windows opened.

When the window was closed:
The mean air exchange rate through the envelope of the classroom was 0.86 ACH at the reference sampling point.

The ventilation rate with one window open was 2.35 ACH in the reference point. When all windows and door were opened, the ventilation rate of 21.07 ACH was obtained.



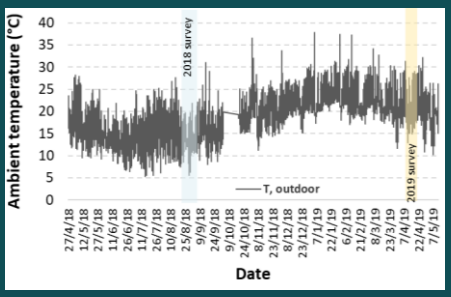


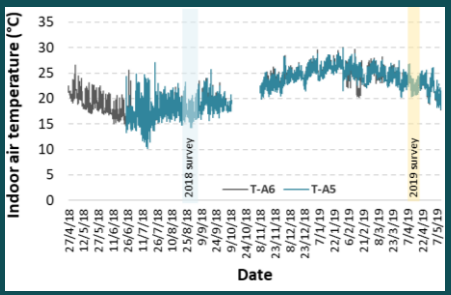
Tracer gas measurement: height 1.2 m
13 SP in 3 steps

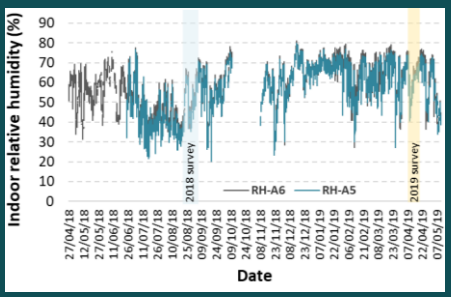
19

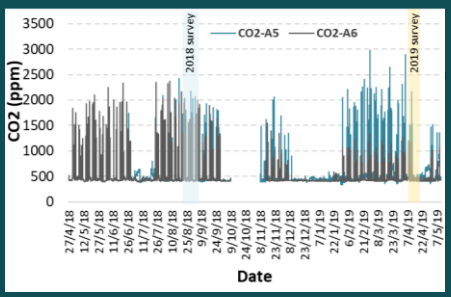
Results

Indoor temperature:
10.2 °C and 30.0 °C,
Outdoor temperature:
5 °C to 37.9 °C
RH: 21-81%
CO2 exceeded 2900 ppm
April 2018 to May 2019



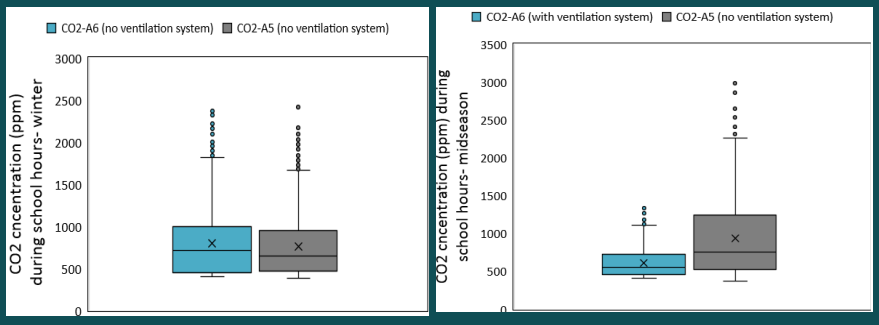


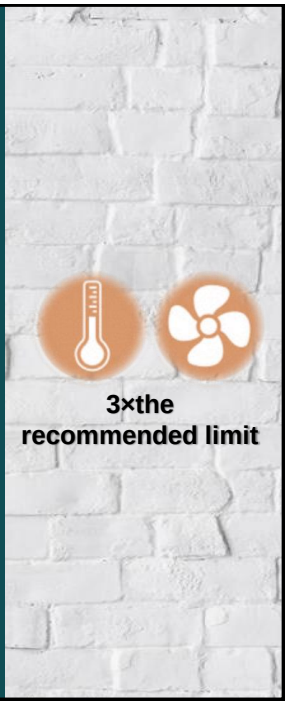




20

CO2 concentrations in classrooms with and without ventilation system





Elevated CO2 levels may lead to headache, changes in respiratory patterns, and concentration loss (Australian Building Codes Board ABCB, 2018).
Use of ventilation system helps to

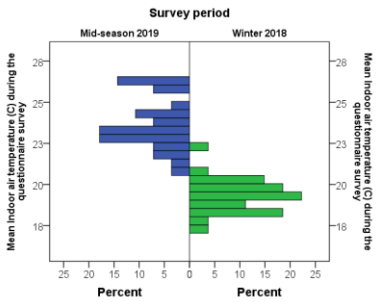
- Enhance wellbeing and learning performance
- Improve respiratory health symptoms
- Achieve thermal comfort conditions
- Reduce energy consumption

21

Survey period				Statistic
Mean CO2 (ppm) during the questionnaire survey	Mid-season	Mean		744.5
		95% Confidence	Lower Bound	639.1
			Upper Bound	849.8
		Median		647.2
		Std. Deviation		271.7
		Minimum		442.3
		Maximum		1510.6
		Range		1068.3
		Interquartile Range		406.0
	Winter	Mean		1393.9
		95% Confidence	Lower Bound	1226.4
			Upper Bound	1561.5
		Median		1293.1
		Std. Deviation		423.4
		Minimum		718.9
		Maximum		2114.6
		Range		1395.7
		Interquartile Range		705.9

Indoor air temperature varied between 20.7 and 26.4 °C with the mean value of 23.7 °C during mid-season 2019 questionnaire survey.

During winter questionnaire survey, the average indoor temperature was 19.3 °C. Indoor temperature fell within a range of 17.3 and 22.4 °C.



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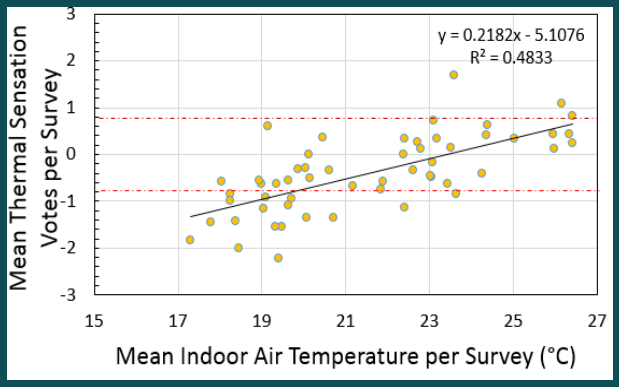

The empirical limits of acceptable thermal environments for 80 % satisfaction (ASHRAE 55).

To find the empirical limits of acceptable thermal environments for 80% satisfaction, the indoor temperature was calculated for the mean thermal sensation votes (TSV) of ±0.85 using the linear regression model.

Participated school children felt comfortable within an indoor temperature range of 19.5 °C to 27 °C. Tn: 23.4 °C
Students demonstrated considerable adaptability to classroom indoor air temperature variations, with one TSV unit equating to about 4.6 °C difference in air temperature.

23

Formaldehyde measurement:

a) over one week in December 2018 (including weekend and unoccupied condition), b) over 8 hours in three normal school days.

The 8-hours average of the formaldehyde concentration:
0.1 ppm to 0.14 ppm.

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Particulate matter (PM) measurement:

Day I:
PM10: 5 to 39 µm/m3 (8-hour mean: 16±6 µm/m3)
PM2.5: 2 to 11 µm/m3 (8-hour mean: 7±2 µm/m3).

8-hour mean urban background levels:
PM2.5: 10.8 µg/m3 and PM10 : 17.7 µg/m3

Day II:
PM10: 1 to 50 µm/m3 (mean: 26±7 µm/m3)
PM2.5: 3 to 12 µm/m3 (mean: 6±1 µm/m3).

8-hour average outdoor PM10 was 16.9 µm/m3.
No PM2.5 was available for this day.

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Conclusion:

- A hybrid ventilation system equipped with a window ventilator and Healthbox 3.0 were installed in February 2019 in one of the two classrooms. The system communicated with smart devices to enable real-time monitoring of the classroom air quality, temperature and humidity.
- Analysis of indoor air quality and thermal comfort shows significant improvements in reducing CO2 concentration in the classroom with ventilation compared to the classroom without a ventilation system.
- Australian students feel comfortable at a neutral temperature of 23.4 °C. This is consistent with previous literature and highlights that children feel comfortable at slightly lower thermal environments compared to adults.
- Use of IOT technology would help to communicate the real time monitoring of IEQ and air quality data and feedback from students.

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Indoor air and environmental quality in social housing dwellings in Australia

Shamila Haddad, Afroditi Synnefa, Riccardo Paolini, and Mattheos Santamouris

40th AIVC - 8th TightVent & 6th venticool Conference

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Energy Poverty in Australia

- There are more than 3 million people (13.2 % of the population) living below the poverty line in Australia
- Low-income families, pensioners, and indigenous Australians have faced increasing difficulty in paying energy bills and ultimately achieving the required indoor environmental conditions.
- Lack of ventilation, inadequate insulation, poor indoor air quality, presence of internal condensation, mould, and damp are associated with illnesses like bronchitis, asthma, influenza, heart deceases, arthritis, migraine, as well as social and mental health problems such as depression and anxiety.

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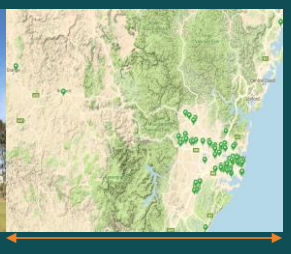
Objectives:

- Monitoring IEQ and indoor air quality in NSW
- Investigating the nexus between building design, comfort and health, and energy in social housing
- Quantifying occupants' comfort and health to improve the quality of life of low income population.





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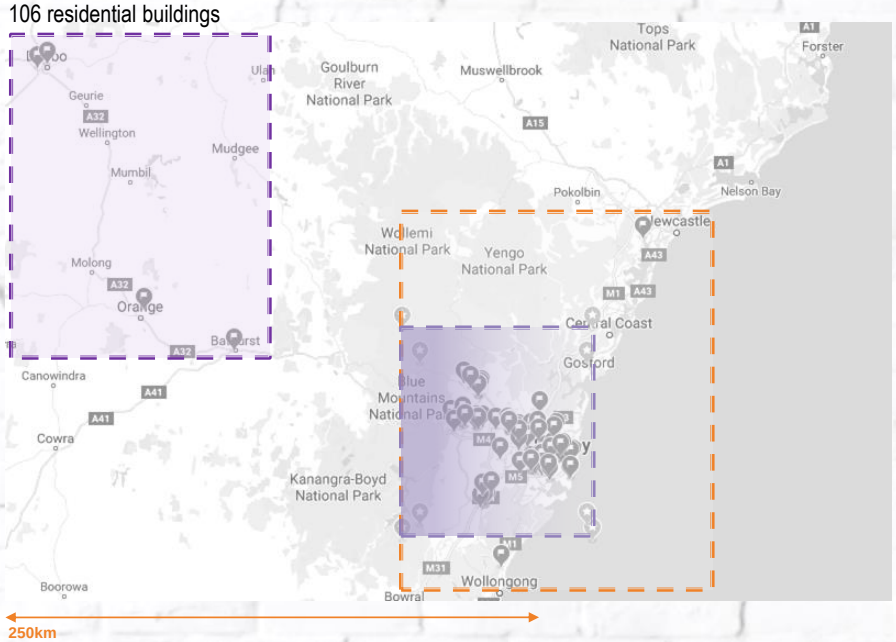
Indoor Environmental Quality (IEQ) monitoring:

106 residential buildings



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Method:

- Measurement of Ta, RH, and CO2 from May 2018 to February 2019 using Air Quality Eggs: 83 Dwellings
- Questionnaire survey with residents: perceptions of the thermal environment, energy bills, quality of the building envelope and indoor thermal and environmental condition (e.g., presence of mould), other features of the building and energy profile (number of people sharing the household, time spent at home), and residents' health conditions and behaviours
- Measurement of indoor and outdoor air temperature every 30 minutes during the long-term monitoring period: 23 Dwellings

Indoor Air Quality Egg recorder





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LOGTAG temperature recorder



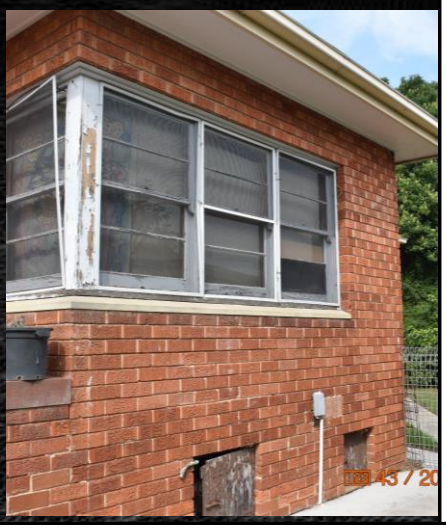


31

Characteristics of the household and dwellings in the



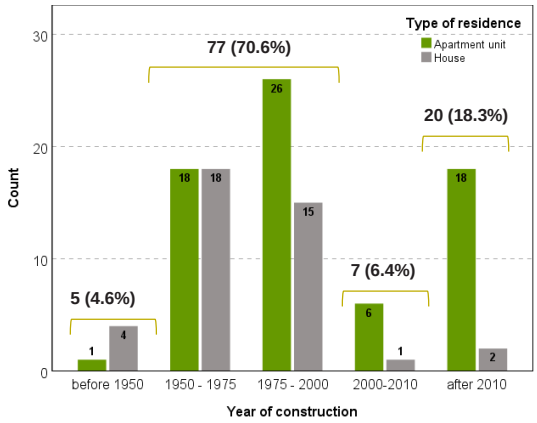




A total of 109 residents participated in the questionnaire survey and 106 households proceeded with the indoor air and environmental quality monitoring campaign.

51.4 %: Public housing
41.3 %: Community housing.
7 %: low-income households with private rental housing

32

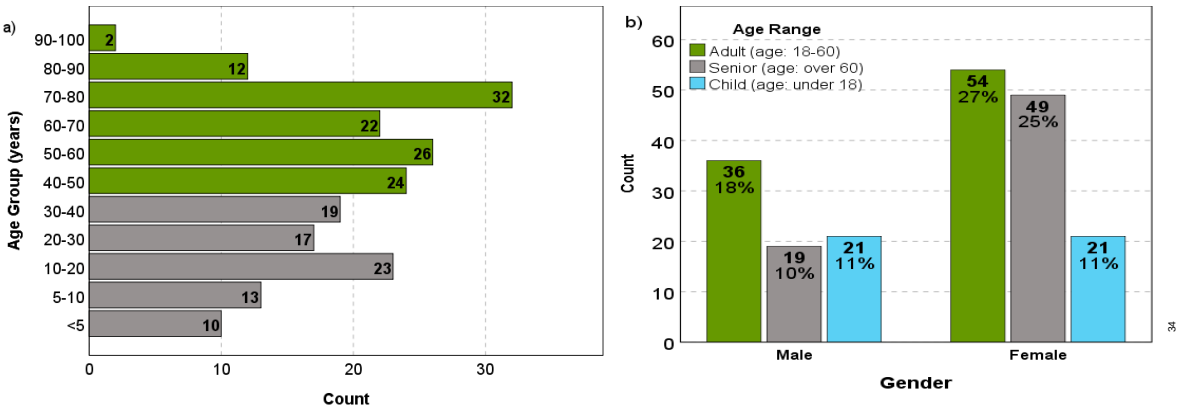


Year of construction of the monitored dwellings

heating and cooling system in the dwellings

Heating and cooling system	%
Percentage of dwellings with a fixed wall mounted A/C [%] (e.g. split system)	3
Percentage of dwellings with portable electric heating systems [%]	69
Percentage of dwellings with other types of heating systems [%] (e.g. gas heaters and fireplace)	7
Percentage of dwellings with no means of heating systems [%]	22
Percentage of dwellings with portable cooling systems [%] (e.g., electric portable and pedestal fans, evaporative cooling, tower fans)	90
Percentage of dwellings with a fixed wall mounted A/C [%] (e.g. split system, ceiling fan)	7
Percentage of dwellings with no means of cooling systems [%]	3

33



The average age of the NSW and greater Sydney population: 38 and 36 years (Australian Bureau of Statistics, 2016), while the average age of participants in this study was 45 years.

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Type of dwelling	Frequency	Percent (%)
Apartment unit or flat	69	63.3
House (detached or semi-detached)	40	36.7

Construction details	
Average floor area of the dwellings [m^2]	69.5
Range of the floor area of the dwellings [m^2]	24-135
Average year of construction [-]	1975-2000
Percentage of insulated dwellings [%]	27%
Percentage of dwellings with double glazing windows [%]	0

Number of residents in each dwelling	
No. of households participated in the survey	109
No. of households participated in both monitoring and survey	106
No. of residents in all dwelling	200
Average persons per household	1.8
Average occupiers' age [years]	45
Median occupiers' age [years]	47
Average area of the residence [m^2]	70
Average family income per fortnight (2018) [$]	~1076
Average income per fortnight per person (2018) [$]	~600
Average education score (1–4) [a]	2.2
Average electricity bill per quarter [$]	271
Average electricity bill per quarter per floor area [$]	3.9
Average electricity bill per quarter per person [$]	150.5

[a]:1= No or low education 2 = Secondary school 3 = University 4 = Diploma

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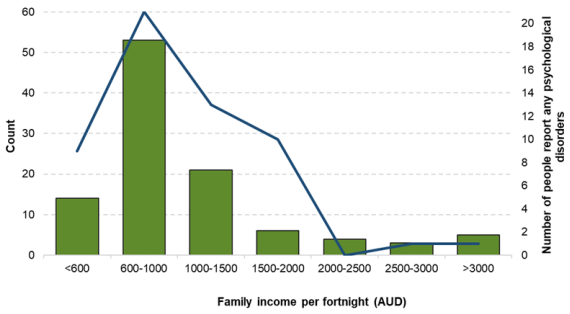
35

			Psychological disorders		Total
			No	Yes	
Age Range	**Adult**	Count	61	29	90
		% of Total	30.5%	14.5%	45.0%
	Child	Count	33	9	42
		% of Total	16.5%	4.5%	21.0%
	Senior	Count	51	17	68
		% of Total	25.5%	8.5%	34.0%
Total		Count	145	55	200
		% of Total	72.5%	27.5%	100.0%

50% and 87% of resident have an income of 600-1000 AUD and below 15000 AUD per household per fortnight



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			Health problem		Total
			No	Yes	
Age Range	**Adult** 18-60	Count	49	41	90
		% of Total	24.5%	20.5%	45.0%
	Child under 18	Count	30	12	42
		% of Total	15.0%	6.0%	21.0%
	Senior Over 60	Count	14	54	68
		% of Total	7.0%	27.0%	34.0%
Total		Count	93	107	200
		% of Total	46.5%	53.5%	100.0%

			Allergies		Total
			No	Yes	
Age Range	**Adult**	Count	64	26	90
		% of Total	32.0%	13.0%	45.0%
	Child	Count	31	11	42
		% of Total	15.5%	5.5%	21.0%
	Senior	Count	41	27	68
		% of Total	20.5%	13.5%	34.0%
Total		Count	136	64	200
		% of Total	68.0%	32.0%	100.0%

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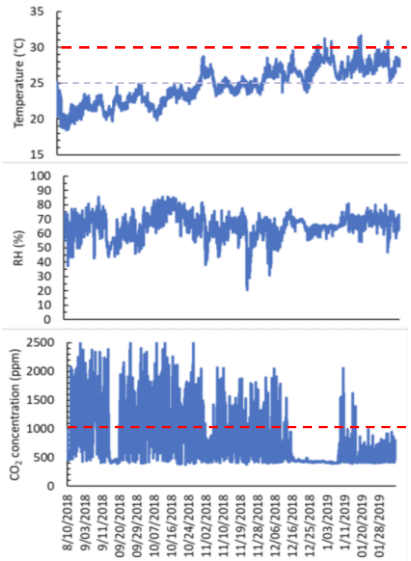
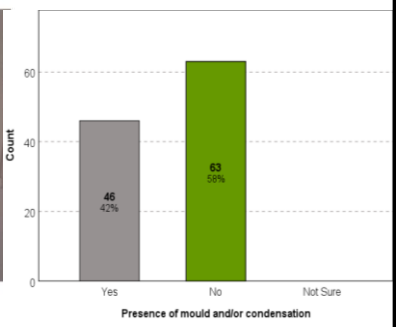
The average relative humidity ranged from 42 % to 68 % during the monitoring period.





Wardrobe *Wall*



Mould and condensation: bedrooms (40 %) and wet areas namely bathroom, laundry, kitchen (38 %), 17 % happened in the living rooms, and 5 % in all rooms.

Indoor mould and dampness:

- Throat and skin irritation, coughing or wheezing, eye irritation
- Localised infection; skin infection, painful swelling etc
- Lung infection, from mild bronchitis to severe pneumonia
- Septicaemic pneumonia causing fever headache breathing difficulties abdominal pain and disorientation

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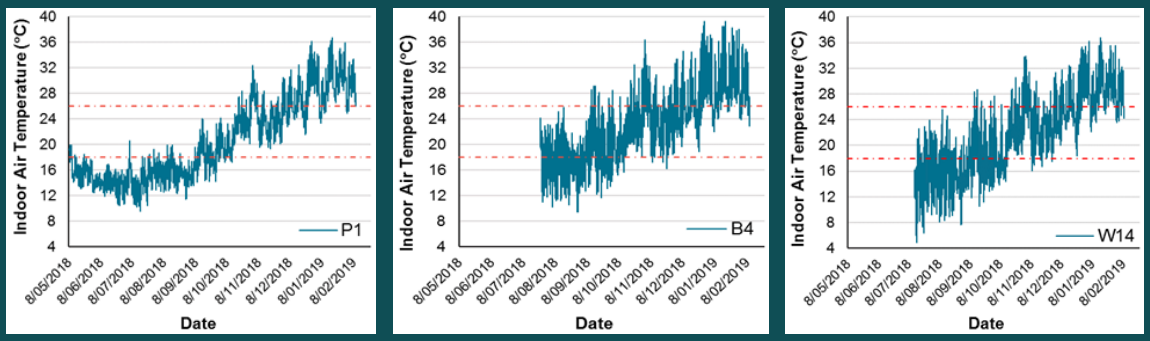
Extreme weather events and indoor air temperature



The minimum indoor air temperature: 4.9 °C to 19.3 °C with an average of 13.5 °C.
The minimum indoor air temperature<10 °C in 20% of dwellings.

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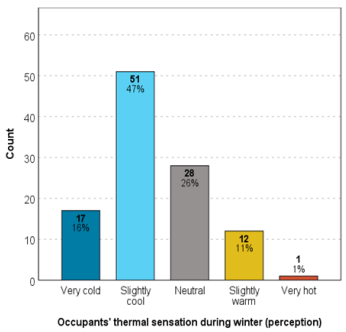
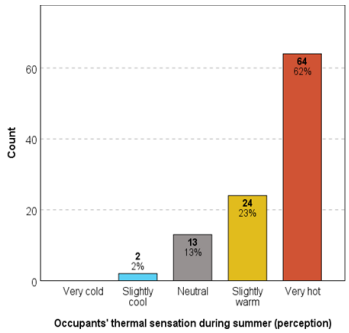


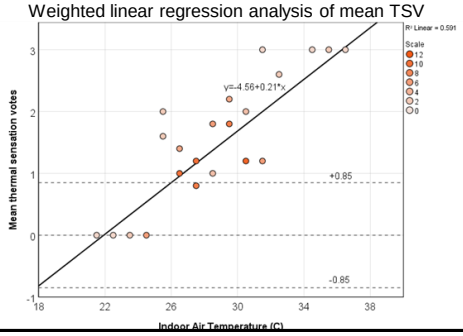


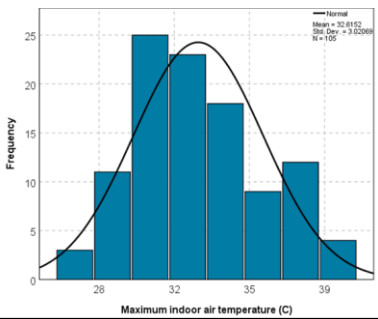
The empirical limits of acceptable thermal environments for 80 % satisfaction (ASHRAE 55).

The dwellers participated in this study have an upper acceptable indoor air temperature of 25.8°C (when TSV=+0.85).

The maximum indoor air temperature recorded during the summer period: 39.8 °C, average maximum temperature: 32.6 ± 3.0 °C.

Weighted linear regression analysis of mean TSV





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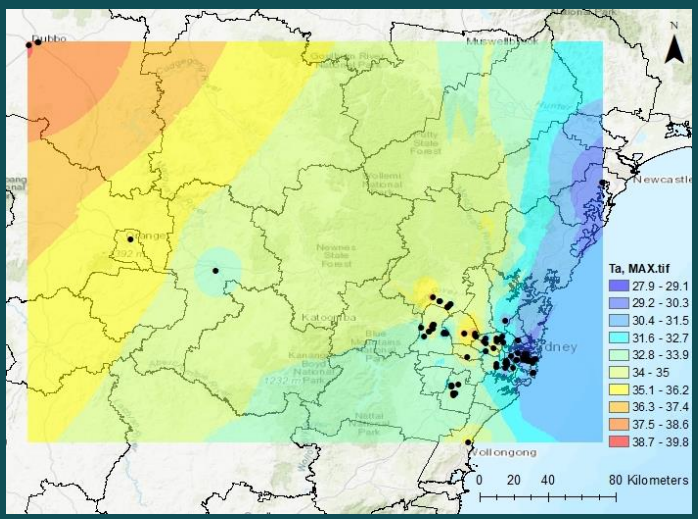
The spatial distribution of the recorded maximum indoor air temperature



Western Sydney frequently presents 7-10 °C hotter than in coastal suburbs (Santamouris et al., 2017).

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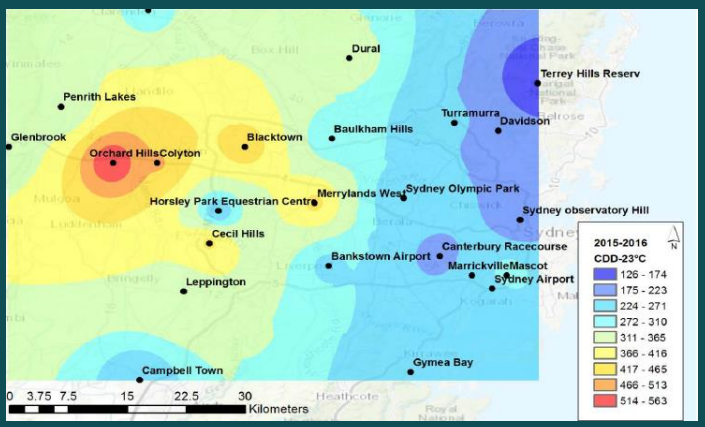
The spatial distribution of the CDD



If things don't change and climate doesn't cool down, certain cities and buildings are at risk of becoming unviable in the next few decades.

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The CO_2 concentration >1000



The CO_2 concentration >2000



The weekly mean concentrations of CO_2 in typical Australian dwelling are 527 ± 121 ppm in Winter/Spring and 544 ±121 ppm in Summer/Autumn (Cheng et al., 2010).

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Conclusion:

- Monitoring of 106 low and very low-income houses during the winter and mid-season of 2018 and summer of 2019 in Greater Sydney has shown that the indoor air temperature is much lower and higher than the minimum and maximum threshold values set for comfort and health purposes.
- In most of the participating residences during winter 2018, long spells of low indoor temperatures are recorded which were much below the internationally accepted conditions.
- The minimum indoor air temperature recorded was about 5 °C during winter 2018 and the maximum indoor air temperature reached 39.8 °C in summer 2019.
- Summer-time indoor air temperature in many of the residences located in Western Sydney largely exceeded the comfort limits.

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Conclusion:

- The maximum indoor air temperatures were higher in western areas compared to those observed in eastern suburbs.
- Many of the investigated dwellings exceeded the recommended threshold of 1000 ppm, particularly during winter and mid-season when there was a limited rate of ventilation.
- Occupants adapted to slightly larger indoor temperature band (with the upper acceptability limit of 25.8 °C), highlighting the importance of the availability of controls to adjust indoor environment. Mean TSV increases 1 point per 4.8 °C increase in the room indoor air temperature.
- Despite adaptability of social housing residents, indoor air temperature during cold and warm seasons exceeded the comfort zone limits and this led to a higher rate of dissatisfaction during cold and warm seasons.
- This highlights the importance of building adaptation techniques to improve the quality of building envelope to reduce the need for active heating and cooling.

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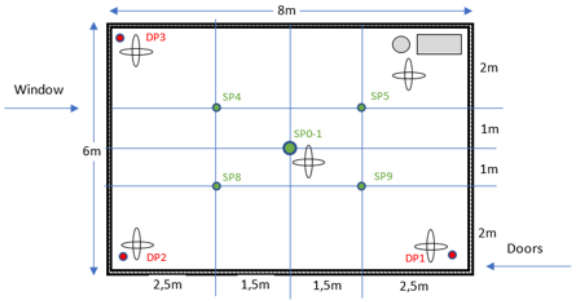
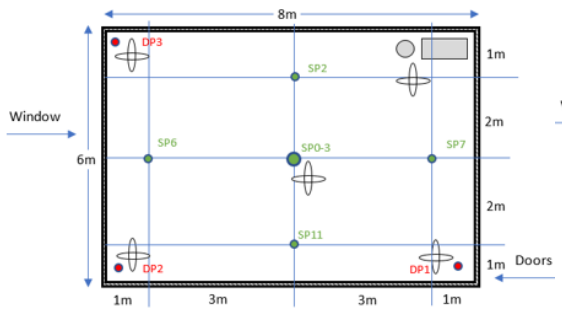
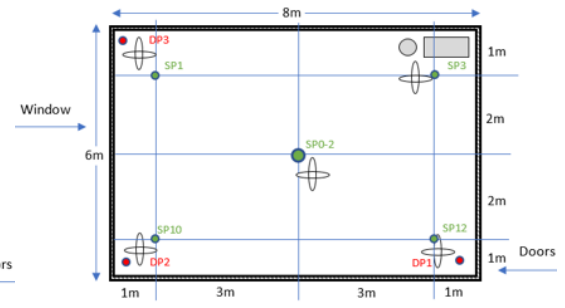
- All the windows and the door were closed.
- The SF6 gas cylinder valve was opened till reaching a pressure of 300kPa ±10% within the gas regulator.
- All the fans were on while dosing phase was active. They were shut down seconds before the decay concentration measurement was started.
- Three dosing flow phases (one for each dosing point) were set up.







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Compounds	Room A5 - No Ventilation						Room A6 with Ventilation					
	13-May			14-May			13-May			14-May		
	1144 HRS	1240 HRS	1422 HRS	0751 HRS*	0845 HRS	1425 HRS	1141 HRS	1240 HRS	1420 HRS	0750 HRS*	0847 HRS	1426 HRS
1-Butanol, 3-methyl-, acetate	-	8.72	3.59	-	-	-	-	-	-	-	-	-
1-Propanol	33.8	12.62	<2	-	-	-	4.68	2.17	-	-	12.35	24.23
2-Pentanol, acetate	-	3.26	<2	-	-	-	-	-	-	-	-	-
5-Hepten-2-one, 6-methyl-	-	-	3.47	-	-	4.26	-	-	<2	-	-	2.74
Acetone	19.07	22.46	17.09	3.94	17.04	9.56	18.34	11.93	9.27	4.04	13.56	17.09
Benzaldehyde	4	3.23	2.91	2.63	3.72	<2	5.2	<2	<2	3.05	6.03	<2
Benzene	<2	<2	<2	<2	<2	<2	<2	<2	-	<2	2.46	-
Benzene, 1,2,3-trimethyl-	-	-	-	<2	-	-	-	-	-	<2	-	-
Benzene, 1,2-dichloro-	-	-	<2	-	-	-	-	-	-	-	-	-
Benzene, 1,3-dichloro-	-	<2	-	-	<2	-	-	-	-	<2	2.58	-
Benzene, 1,4-dichloro-	<2	-	-	<2	-	-	<2	-	-	-	-	-
Benzene, 1-ethyl-3-methyl-	<2	<2	-	<2	2.21	-	<2	-	-	<2	2.19	-
Butane, 2-methyl-	-	-	-	7.1	7.59	-	-	-	-	7.13	7.28	-
Carene	<2	4.72	6.49	-	-	<2	-	-	-	-	-	-
Cyclohexane, methyl-	<2	-	32.88	<2	<2	4.43	<2	-	<2	<2	<2	-
Decanal	2.07	2.3	4.95	-	2.21	5.22	<2	2.26	2.8	-	<2	4.58
Decane	-	-	-	-	<2	-	-	-	-	<2	-	-
D-Limonene	3.51	4.86	6.03	<2	6.88	2.72	4.6	2.11	<2	<2	4.09	<2
Ethanol	5.74	5.2	4.7	-	4.99	<2	3.81	-	<2	-	3.67	4.92
Ethyl Acetate	-	12.78	2.84	-	-	-	-	-	-	-	-	-
Ethylbenzene	<2	-	-	2.79	3.72	-	<2	-	-	2.88	4.85	-
Eucalyptol	-	-	3.64	-	9.03	<2	-	-	-	-	-	-
Heptane	<2	-	-	<2	<2	-	<2	-	-	<2	2.92	-
Isobutyl acetate	-	5.72	<2	-	-	-	-	-	-	-	-	-
Isoprene	4.49	7.41	6.36	-	5.25	2.73	4.55	4.54	2.15	-	5.22	2.84
Isopropyl Alcohol	90.54	36.67	4.96	-	2.21	-	29.18	12.9	9.6	-	32.32	75.53
Mesitylene	2.52	<2	<2	2.06	5.07	-	<2	-	-	3.37	5.56	-
n-Hexane	<2	<2	-	<2	2.04	-	<2	-	-	2.12	2.47	-
Nonanal	2.92	4.57	6.06	<2	6.04	5.77	3.42	3.51	2.26	2.27	2.4	5.29
Nonane	<2	-	-	<2	<2	-	<2	-	-	-	<2	-
Octanal	-	-	-	-	-	2.02	-	-	-	-	-	-
o-Xylene	<2	<2	-	<2	<2	-	<2	-	-	<2	<2	-
Pentane, 2-methyl-	<2	-	-	<2	<2	-	-	-	-	<2	<2	-
Phenol	-	4.28	-	-	-	2.2	-	-	-	-	-	-
p-Xylene	<2	<2	<2	4.71	3.66	-	<2	<2	<2	4.45	4.28	-
R(-)3,7-Dimethyl-1,6-octadiene	-	<2	<2	-	<2	-	<2	<2	-	-	<2	-
Tetrachloroethylene	-	-	4.23	<2	<2	<2	-	-	<2	<2	-	-

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RADIANT HEATING AND COOLING SYSTEMS COMBINED WITH DISPLACEMENT VENTILATION IN SCHOOLS; STRATEGIES TO IMPROVE IAQ

Michel Tardif ing.
Sébastien Brideau Ph.D



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2

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2

Presentation Content

- Study building and Measurement procedure
- Observations on classroom,ventilation system and climatic conditions
- Results
- Discussion
- Conclusion

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Study building and Measurement procedure



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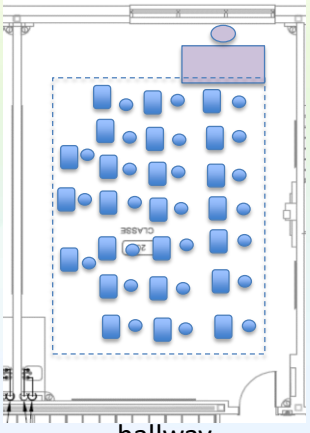
Study building and Measurement procedure





Classroom layout
24 students

South west



hallway

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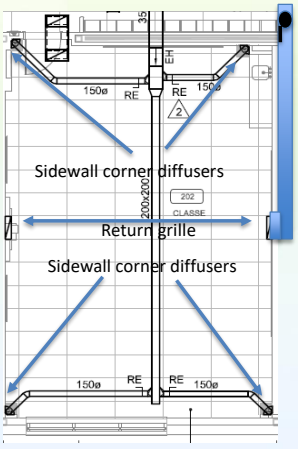
Study building and Measurement procedure



Air distribution in classroom



Centrifugal inline fan

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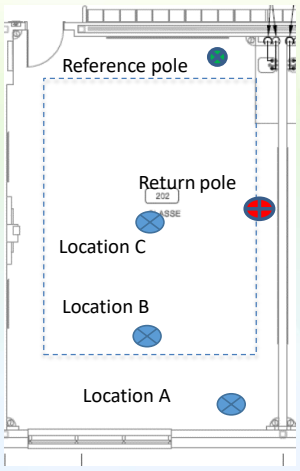
Study building and Measurement procedure





Location	Start at	Stop at	Door state	Exhaust fan
A	08h00	08h30	open	On
A	08h30	08h55	close	On
break	08h56	09h09	Not monitored	On
A	09h10	09h55	open	On
A	09h56	10h15	close	On
Change of location	10h16	10h19	Not monitored	On
B	10h20	10h45	open	On
B	10h46	11h15	close	On
Lunch time	11h16	12h31	Not monitored	On
C	12h32	12h59	open	On
C	13h00	13h30	close	On
C	13h31	13h44	close	Off
C	13h45	14h15	open	Off

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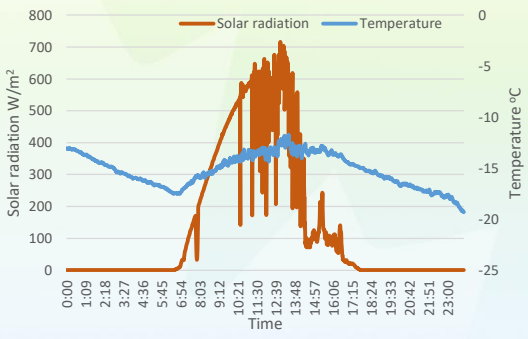
Observations on classroom,ventilation system and climatic conditions

Monitoring date	February 26, 2019
Classroom	202
Orientation	South West
Floor area (m2)	68.7
Fenestration area (m2)	7.12
Ceiling height (m)	2,77
Number of students	24 +1 teacher
Student age	12
Monitoring period	08h00-14h15
Number & type diffuseurs	4 Corner displacement diffusers
Air flow supplied to the classroom	213 l/s (8.5l/s.occ)
Air flow exhaust fan	187 l/s



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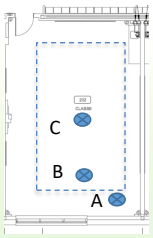
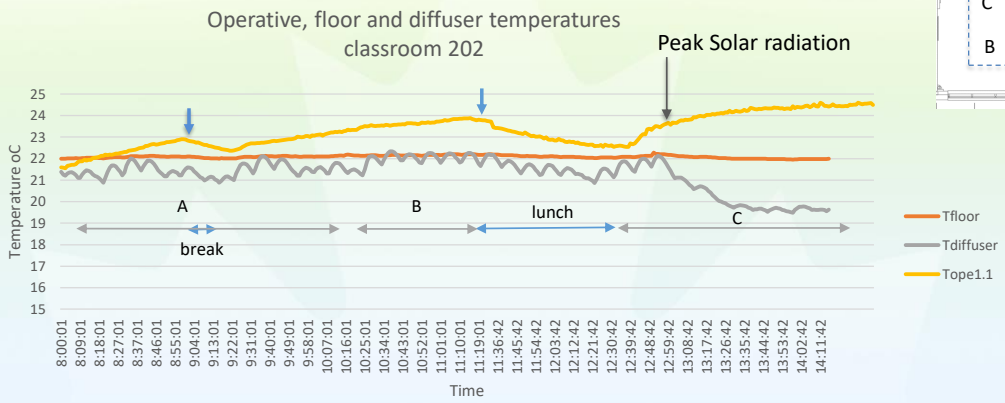
Results





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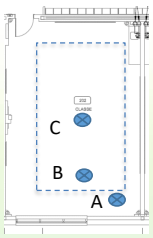
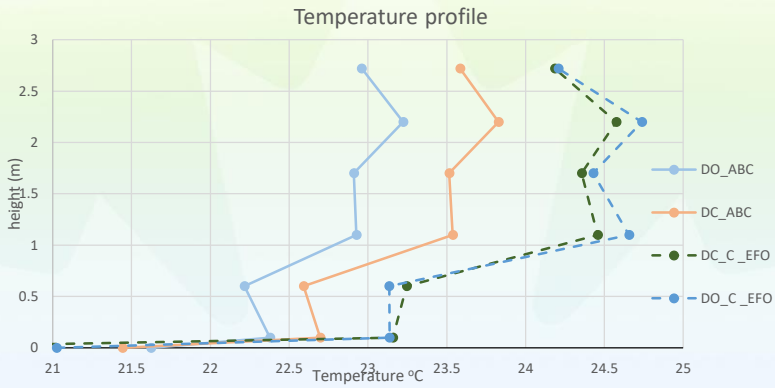
9

Results





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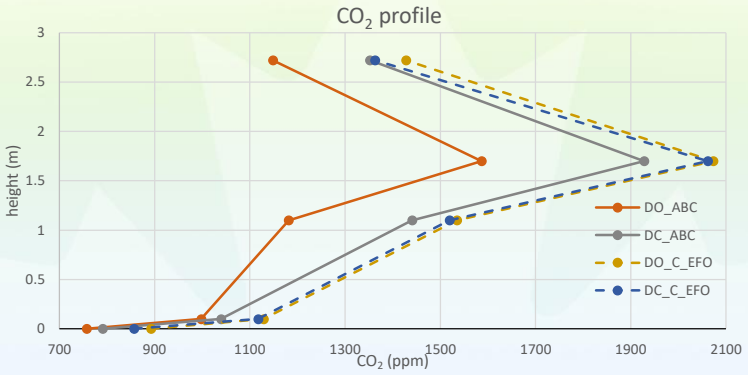
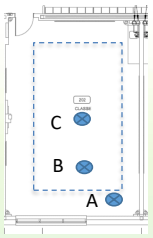
10

Results





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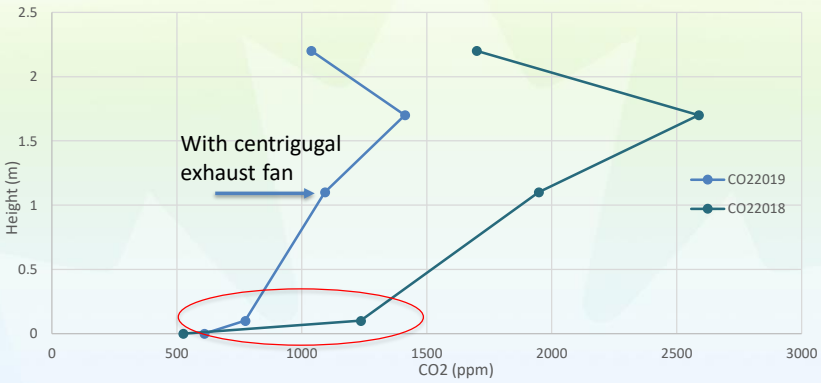
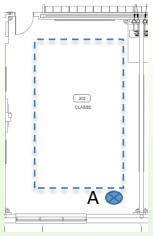
11

Results





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12

Conclusion

- Floor heating and displacement ventilation are well suited to provide thermal comfort, good air quality and significant energy savings. However, the specific design of Marie-Soleil Tougas School was found to be more challenging for maintaining a good indoor environmental quality. Simple solutions such as the classroom door position and the addition of a local mechanical exhaust fan were tested and the monitoring results showed the positive impact of those strategies

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Thank you

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University of Nottingham
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The evaluation of real-time indoor environment parameters measured in 297 Chilean dwellings

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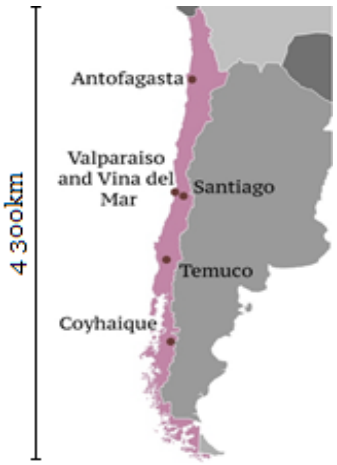
1

University of Nottingham
UK | CHINA | MALAYSIA

Chile

- Located in South America
- Population of 18m
- No longer considered *developing*
- 4,300km long
- 177km wide on average
- Ambient air temperature varies by up to 6C laterally and 15C longitudinally



2

Santiago

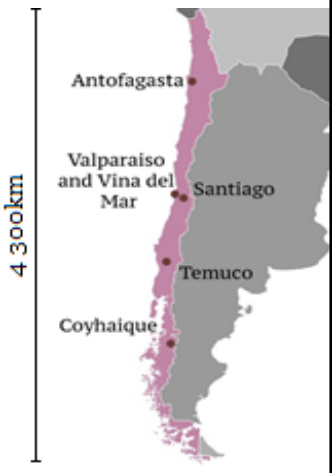


3

Red Nacional de Monitoreo de Viviendas (ReNaM)

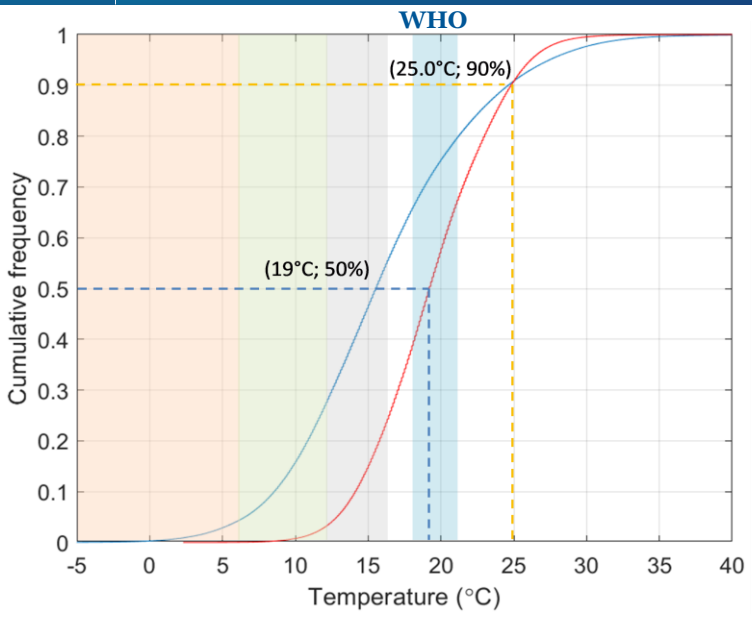
- Netatmo weather stations in 299 houses (150 in Santiago) by MINVU
- Netatmo measures (~$150)
  - Dry bulb air temperature
  - Relative humidity
  - CO2
  - Sound pressure level
- Located in living room & some in bedroom
- Sample every 30 minutes and forwarded via wifi
- Started in 2016 and ongoing
- >100 million data points available





4

Results: Indoor thermal conditions



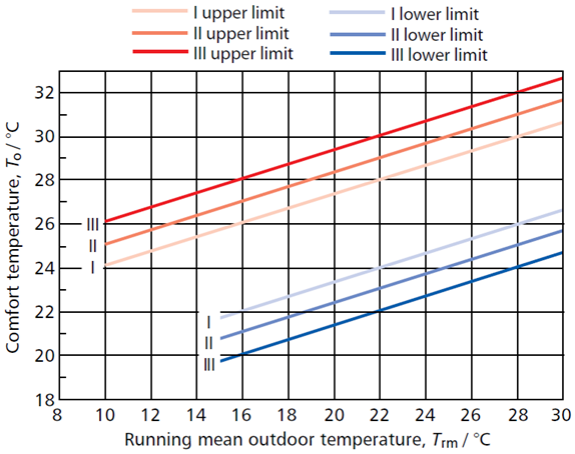
Outdoor Air Temperature

Indoor Air Temperature

5

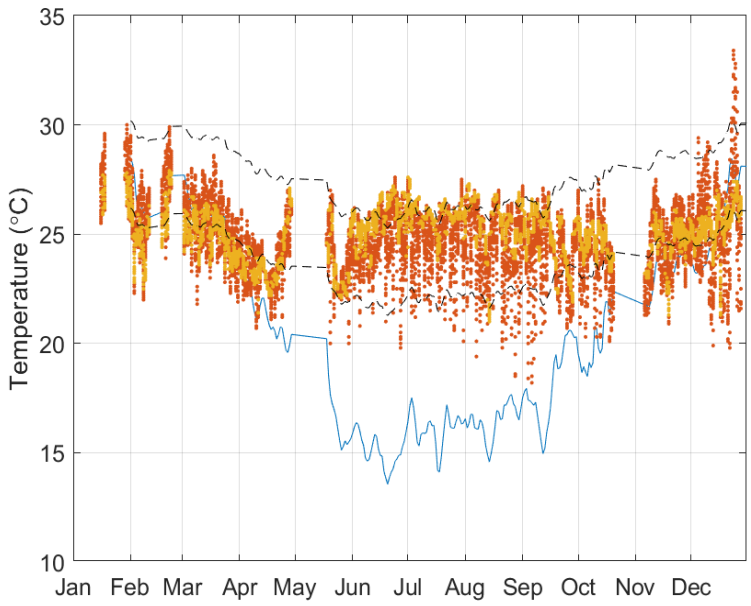
Results: EN 15251 comfort

- An adaptive model used
- Perez-Fargallo *et al.* (2018) applied EN15251 to 14 low income dwellings in the south of Chile
- We also applied EN15251 to assess comfort
- Relationships between socio-economic status and comfort
  - Many households in fuel poverty (>10% of income spent on fuel)
  - 61% in the colder south of Chile



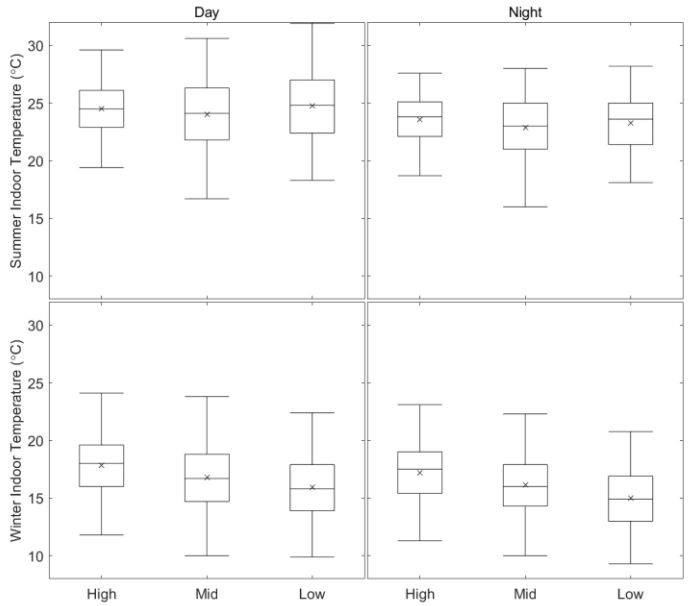
6

Results: EN 15251 comfort



Black: comfort boundaries
Blue: running mean
Orange: night
Red: day

Results: Indoor thermal conditions by season and demographics



High: Top decile of population.
Family monthly income >$2177
Mid: 8-9 deciles.
Family income $825-$2177
Low: 1-7 deciles.
Family income <$825

Summary

- Indoor air temperatures (IATs) are cold when compared to EN 15251, even in the north of Chile
- IATs are above thresholds found to negatively affect health of vulnerable groups 78% of the time (and safe?)
- Daily variation in IAT is modest
- Seasonal variation in IAT is large
- Winter temperatures indicate limited heating
- Low socio-economic status (SES) homes are coldest
- There is no difference in temperatures by SES in summer
- Comfort is not a function of dwelling type, construction materials, or year of construction
- All research needs a *research question*!

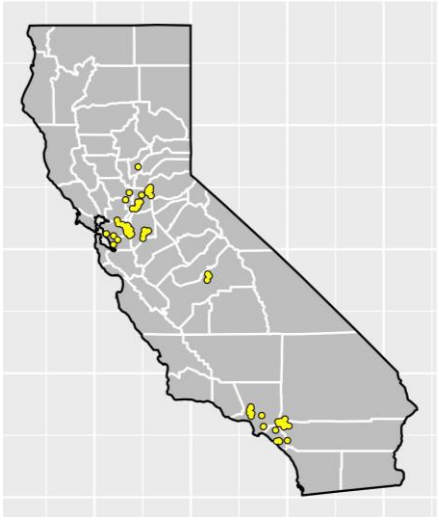
Ventilation and Measured IAQ in new US Homes

Iain Walker
Lawrence Berkeley National Lab
iswalker@lbl.gov

1

Healthy Efficient New Gas Homes (HENGH)

- 70 California homes with mechanical ventilation
  - Whole house ventilation [ON]
  - Windows/door closed
- Indoor air quality, occupant activities and ventilation use monitored for one week in each home
- Compare to previous California New Home Study (CNHS) from 10 years ago without mechanical ventilation
- AIVC Contributed Report: CR18
- ***Are mech vent systems operating as intended?***
- ***What is IAQ in these mech vented homes?***



2

IAQ Monitoring: Integrated + real-time (every minute)

PM2.5





CO_2 T, RH



NO_2

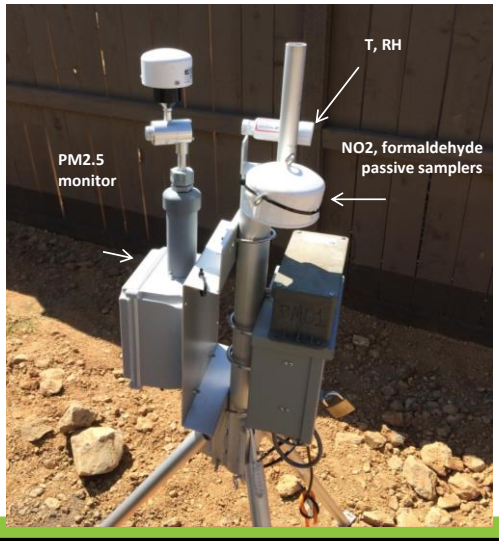


Formaldehyde





Concurrent Outdoor Monitoring



3

Diagnostic Testing

Envelope and Duct Leakage



Exhaust Fan Airflow



Range Hood Airflow



4

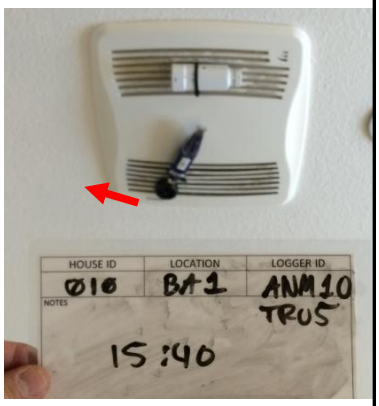
Activity Monitoring



Cooking (cooktop, oven)



Cooker hood use



Exhaust fan use

5

Activity Monitoring

External door use (patio, garage)





Clothes dryer





Heating/Cooling

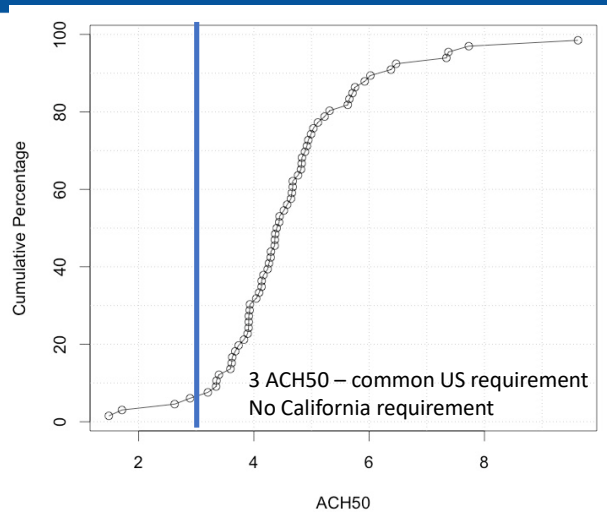


6

Envelope & Duct Leakage

Median Envelope: 4.5 ACH50

Median duct leakage: 50 L/s



7

Whole-House Mechanical Ventilation

64 exhaust systems

6 supply systems

In all but 2 homes, the measured airflow of the exhaust fan exceeded the minimum requirements

On average 50% higher than minimum requirement

8

Supply Ventilation Very Hard to Verify





Make air inlets more accessible?
On-Board diagnostics?
Also true for HRV/ERVs



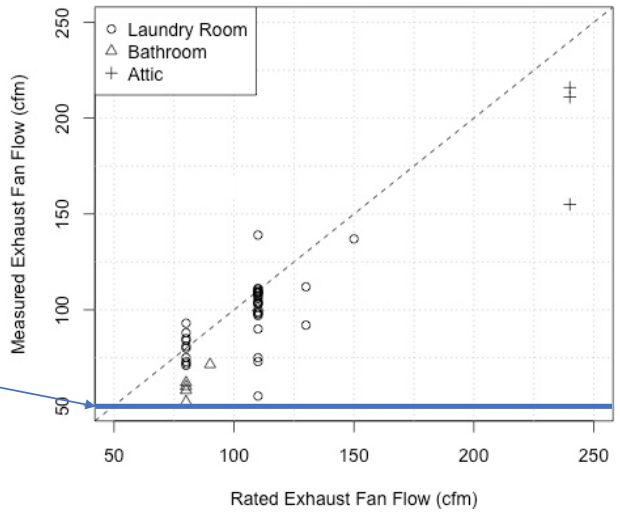




9

Bathroom/Laundry Exhausts

Rated air flows rarely achieved…..
…but meet minimum standard



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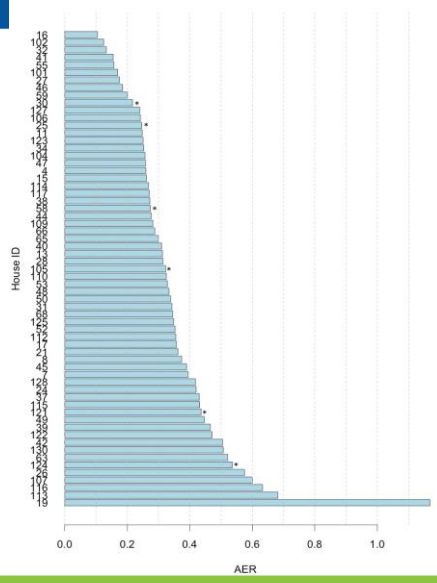
Air Change Rates: Infiltration + Fans



Mechanical Ventilation Requirements lead to substantially higher air change rates

HENGH: 0. 35 ACH

CNHS: 0.24 ACH

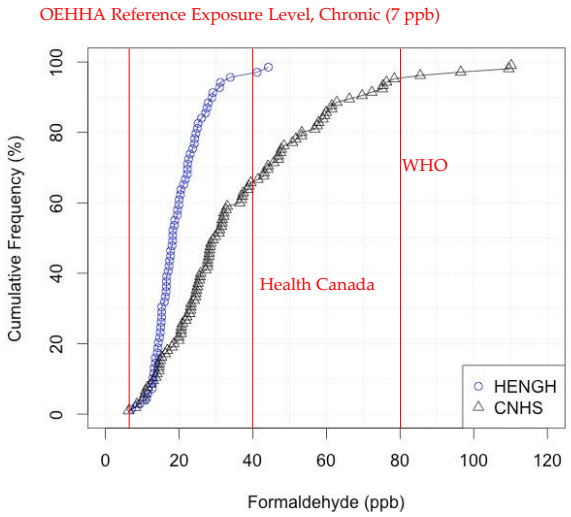
11

Contaminant Results

Median Time-Integrated Indoor Concentration	HENGH	CNHS
Formaldehyde	18 ppb	30 ppb
$PM_{2.5}$	5 µg/m^3	10 µg/m^3
NO_2	4.5 ppb	3.2 ppb

12

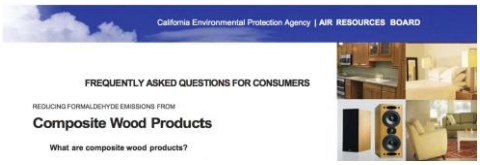
Formaldehyde



Better Ventilation

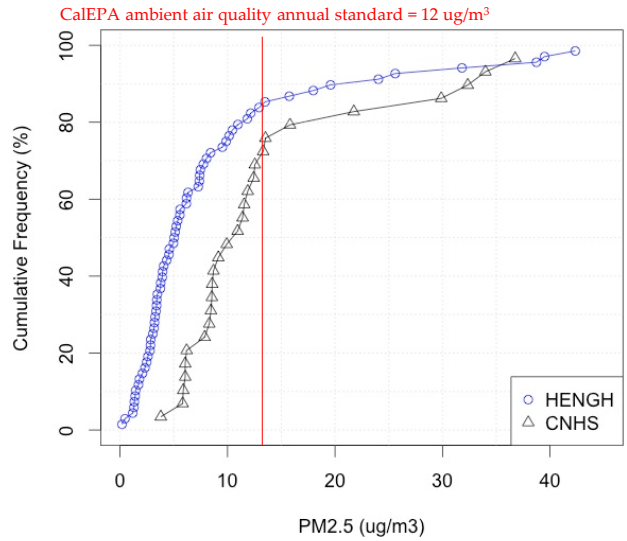
+

Lower Emissions



13

PM2.5

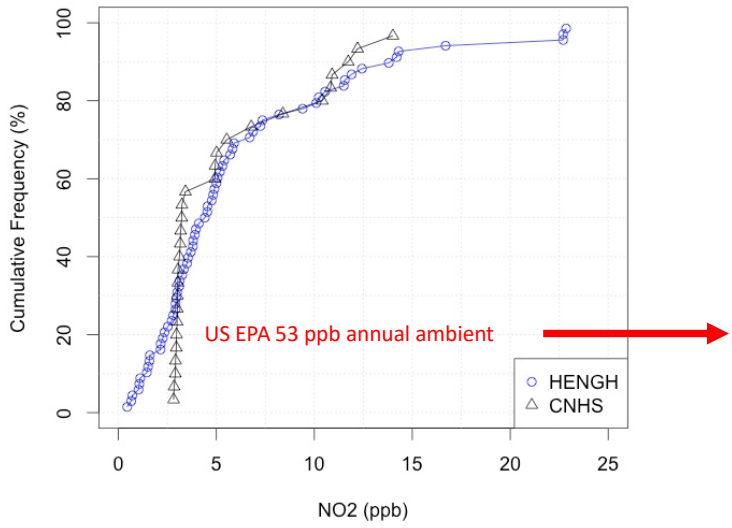


HENGH homes:

- MERV 8-11 (or better) filters on central heating/cooling system
- Cooker hood use?
- All had gas cooking – almost none in CNHS

14

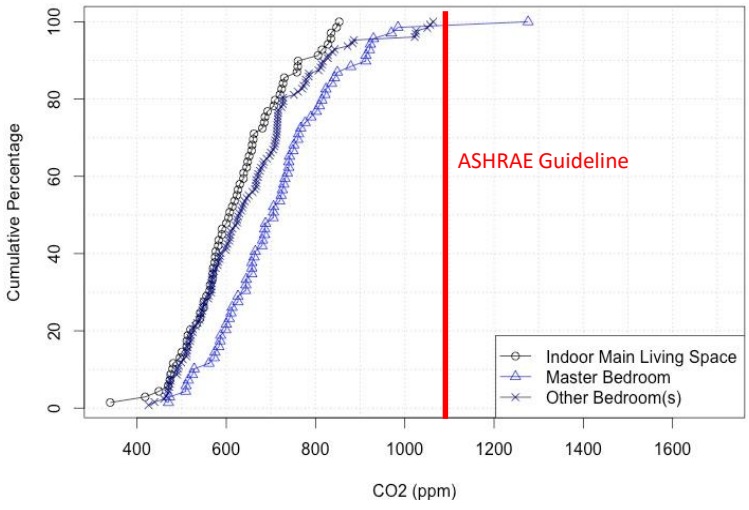
NO_2



All HENGH homes had gas cooking – almost none in CNHS

15

CO_2



Generally low due to low occupancy: 90 m^2/person

16

Label & Control Problem

Only **1** in **4** homes with whole-house ventilation system running as found

17

Labels & Controls

Whole-House Ventilation Control	Controller Labelled?	% On As-Found
On/Off Switch	No (N=42)	5%
	Yes (N=12)	58%
Programmable Controller	No (N=10)	50%
Thermostat	No (N=2)	0%
Breaker Panel	No (N=1)	100%
No Controller	No (N=3)	100%







18

Labels not always clear

CONTINUOUS DUTY



To maintain minimum levels of outside air ventilation required by the State of California, this fan should be on at all times when the building is occupied, unless there is outdoor air contamination.



19

19

Labeling Guidance

ASHRAE Guideline 24:

Manual switches associated with a whole-building ventilation system should have a clear label such as,

*"**This controls the ventilation system of the home. Leave on except for severe outdoor contamination.**"*

In addition, guidance on operations and maintenance procedures should be provided to occupants.

Paul Raymer: *Label electric circuit as "**TV and Ventilation**"*

EEBA 2019

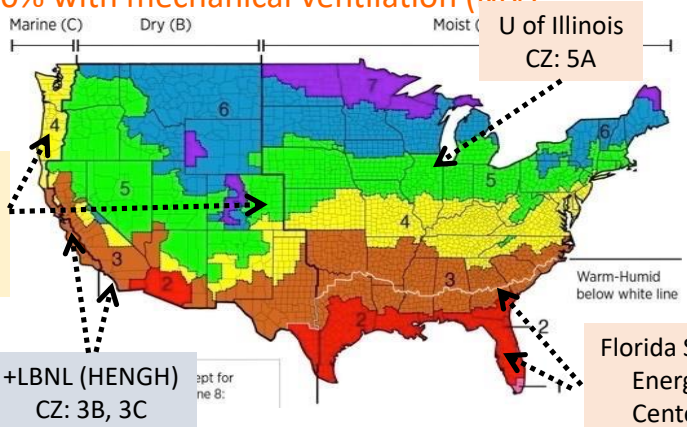
20

Conclusions

1. New systems meet ventilation requirements
2. IAQ is acceptable in homes meeting California (ASHRAE 62.2) requirements *when systems are operating*
3. IAQ improved c/w non-mechanically ventilated homes
4. Better labeling would have a big impact
5. Encourage the use of commissionable systems
   - Supply/HRV/ERV systems need on-board diagnostics?

Next Steps: Building America New Home IAQ Study

- 25-30 homes per climate zone (CZ):
  ~50% with mechanical ventilation (MV)



U of Illinois
CZ: 5A

Pacific NW
National
Lab
CZ: 4C, 5B

+LBNL (HENGH)
CZ: 3B, 3C
70 homes w/MV

Florida Solar
Energy
Center
CZ: 2A, 3A

- Characterize home, mechanical equipment
- Monitor ventilation, IAQ, activities for 1 week
- Repeat with/out MV operating in 6-8 homes per CZ*

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Building AMERICA U.S. Department of Energy

PG&E

SoCalGas A Sempra Energy utility

gti

KU LEUVEN

Overview of model based control strategies for ventilation systems

Hilde Breesch
Bart Merema, Maarten Sourbron

1

Ventilation control in nZEB: challenges

- nZEB buildings
  - slower reactions towards disturbances
  - High impact of internal heat gains
- Variable occupancy pattern
- All-air systems: heating <> ventilation demand

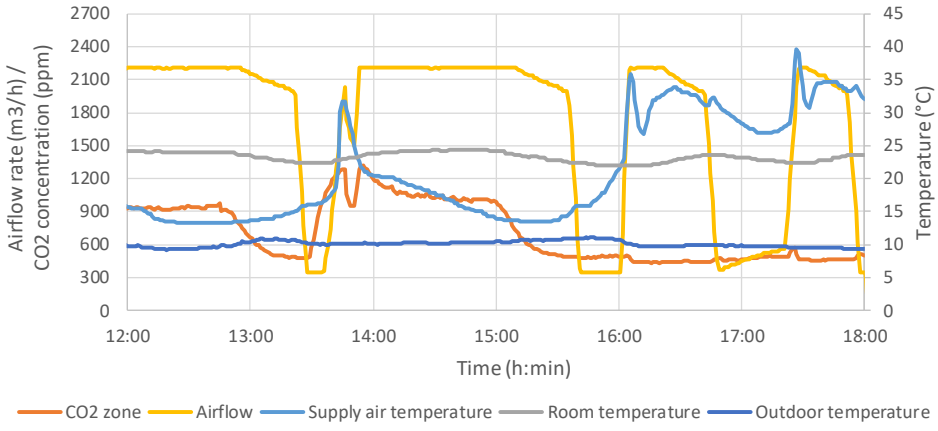


Challenge to control IEQ in nZEB

4

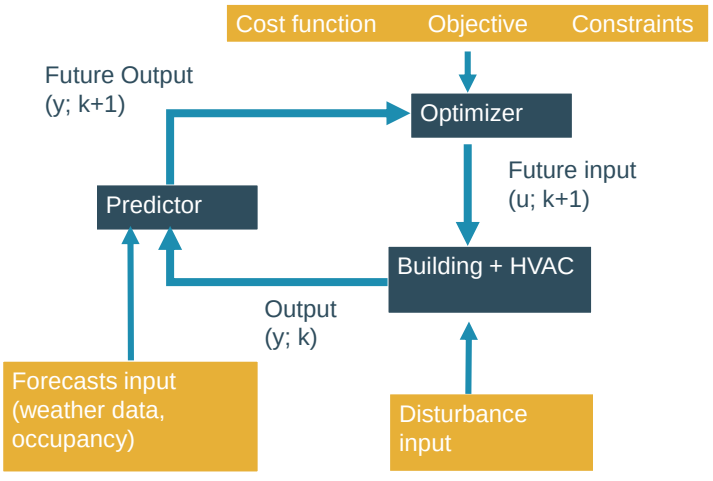
Ventilation control in nZEB: challenges

- Example: Test lecture rooms
  - Lecture > 50 persons (13:30 - 15:00h)



5

Model predictive control (MPC)



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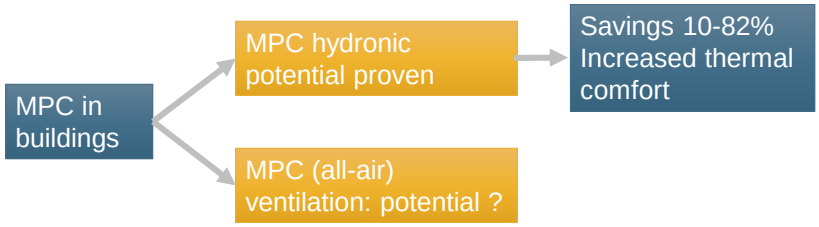
Model predictive control (MPC)



- MPC for (all-air) ventilation
  - Dual optimization: Energy use and CO_2-concentration
  - Interaction between ventilation system (fast dynamics) and building (slow dynamics)

7

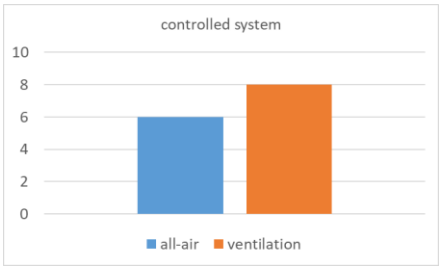
MPC ventilation: state-of-the-art

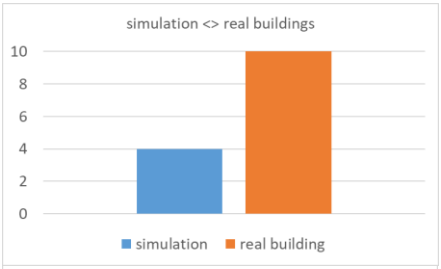
Study	Control Airflow	Type model identification	Energy efficiency	Implementation	MPC
(Bengea et al. 2014)	T+CO_2	RC model (grey box)	20% HVAC system	Office building	Non-linear
(Liang et al. 2015)	T	ARMAX (black box)	27,8% HVAC system	Office Building	Linear
(Yuan and Perez 2006)	T	linearized differential equation (grey box)	-	Office Building	Linear
(Parisio et al. 2014)	T+CO_2	grey box for Temp and ARX for CO_2 (black box)	-	1-zone experimental test	Linear
(Walker et al. 2017)	T+CO_2	linearized differential equation (grey box)	23.5-30% HVAC system	Office building (simulations)	Linear
(Afram et al. 2017)	T	ANN (black box)	6-73% operating cost	Residential building	Non-linear
(Niu and Neill 2016)	T	Non-linear regression (black box)	22,1% HVAC system	Data-driven simulations	Non- Linear
(Zacekova et al. 2015)	T	MPC relevant identification (black box)	-	Data-driven simulations	Linear and non-linear
(Erfani, Rajabi-ghahnaviyeh, and Boroushaki 2018)	T	NARX network (black box)	55,1% electrical 43,7% gas	3-zone experimental test	Non-linear
(West, Ward, and Wall 2014)	T	RC Model (grey box)	19-32% for the HVAC system	2 Office buildings	Linear
MPC also for TABS system					
(Sturzenegger et al. 2016)	T	Bilinear RC model (grey box)	17% HVAC, lighting and equipment	Office building	Bilinear
(Picard et al. 2016)	T	RC and Modelica model (grey and white box)	-	Office building (simulations)	Linear
(Jorissen 2018)	T+CO_2	Modelica model (white box)	82% electrical	Office building	Non-linear
(Hilliard, Swan, and Qin 2017)	T	Random forest regression model (black box)	10-29% electrical 63% thermal	Academic building	Non-linear

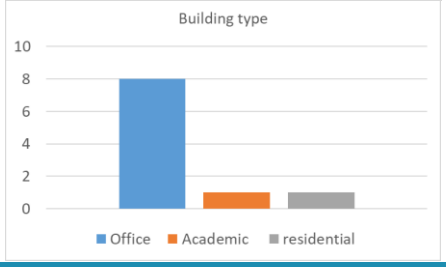
8

MPC ventilation: state-of-the-art

- Application

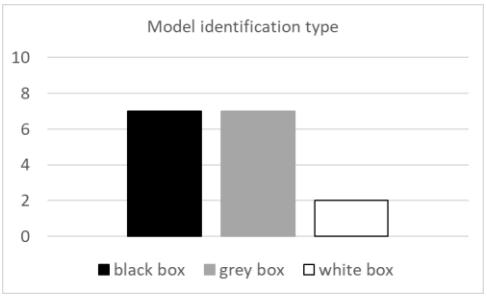






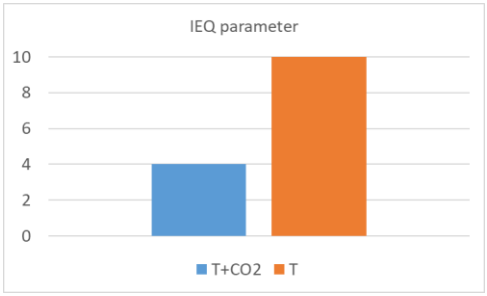
MPC ventilation: state-of-the-art

- Model identification type
  - Black box: ARX, ARMAX, ANN, non-linear regression
  - Grey box: RC model, linearized differential equation
  - White box: Modelica model



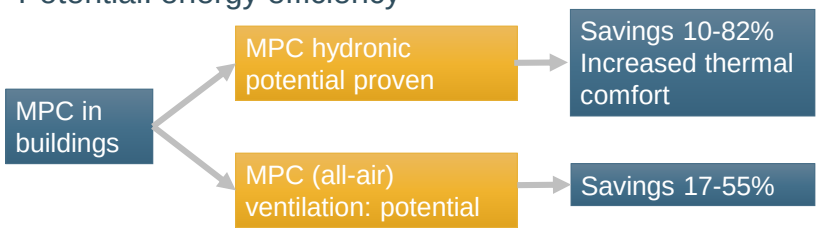
MPC ventilation: state-of-the-art

- IEQ parameter
  - Supply air temperature
  - Airflow rate



MPC ventilation: state-of-the-art

- Potential: energy efficiency



- Challenges
  - How to transfer developed MPC method to other buildings?
  - High expertise knowledge required for implementation
  - A lot of data + fine-tuning needed for model identification

KU LEUVEN

Predictive control for all-air HVAC systems in nZEB office and educational buildings

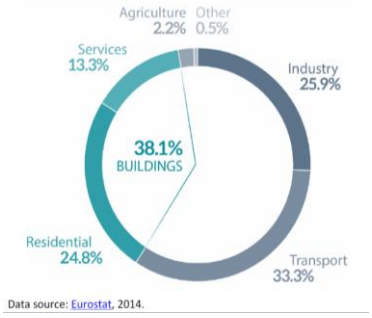
Bart Merema
Promotors: prof. Hilde Breesch
prof. Dirk Saelens

Faculty of Engineering Technology

1

Objective

- Improve the energy efficiency of the HVAC system
  - Guarantee IEQ
- MPC can be a solution
  - Includes the current situation (measurement)
  - Future demand (predictions)

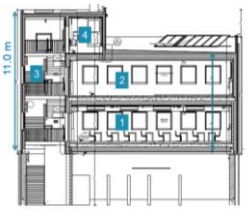


2

Case study

- Educational building with 2 lecture rooms
  - Lecture room 140 m^2 with maximum of 80 students
- Demand controlled ventilation system (CO_2 + T)
  - AHU is in use 07:30-17:30 during weekdays
  - 400-2200 m^3/h per lecture room

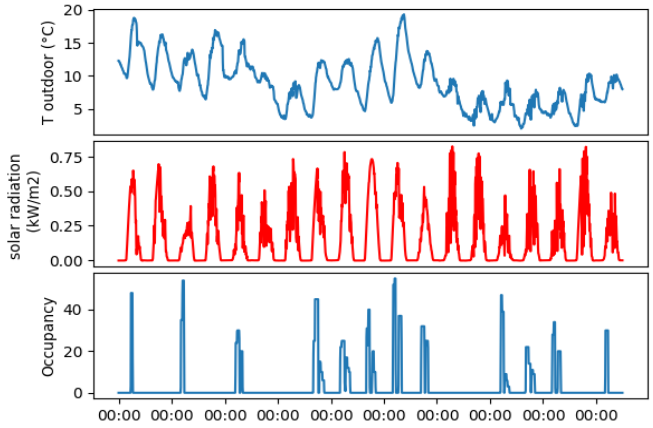




Construction part	U-Value (W/m²K)
Wall	0,15
Roof	0,14
Floor	0,15
Glazing (glazing)	0,60
Glazing (frame)	0,90

3

Case study

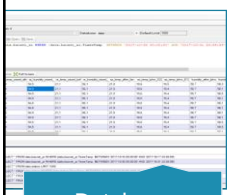


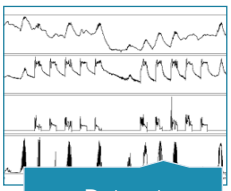
Measurement data (April, 2016)

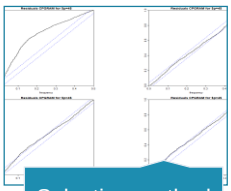
4

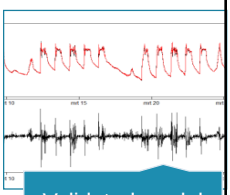
ARX models

- ARX model > $y(t) = a_1 y(t-1) - \cdots - a_{na} y(t-n_a) + b_1 u(t-1-n_k) + \cdots + b_{nb} u(t-n_b-n_k) + e(t)$
- Identified ARX models for temperature and CO_2 (Merema, Breesch and Saelens, 2019)


Database


Dataset


Selection method


Validated model

5

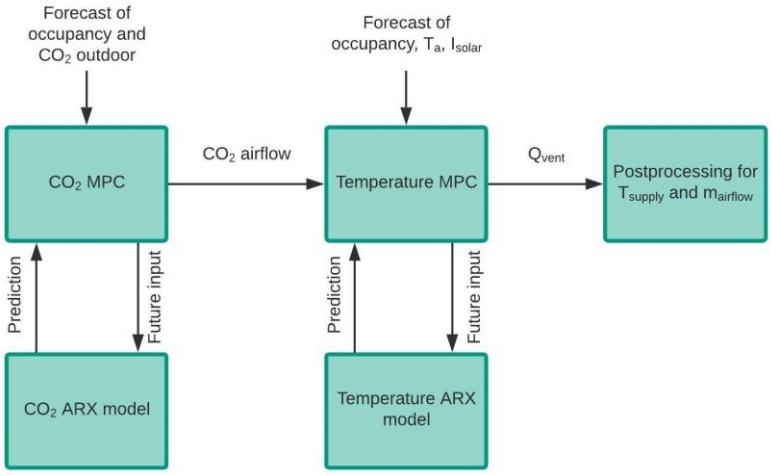
MPC control algorithm

- The ventilation energy here is the (heating) energy supplied by the ventilation system:

$$Q_{vent} = m_{air} * \rho_{air} * c_{air} * (T_{sup} - T_{room}) \quad (1)$$

- Problem: Product of two optimization variables
  - $m_{airflow}$ and T_{supply}

Linear MPC approach



MPC cost function

Solve the control problem every 15 minutes (horizon 10 steps)

- **CO_2 MPC:** $\boldsymbol{Min}\ \sum_{k=0}^{Hp}(zCO_2)^2 + (Airflow)^2$

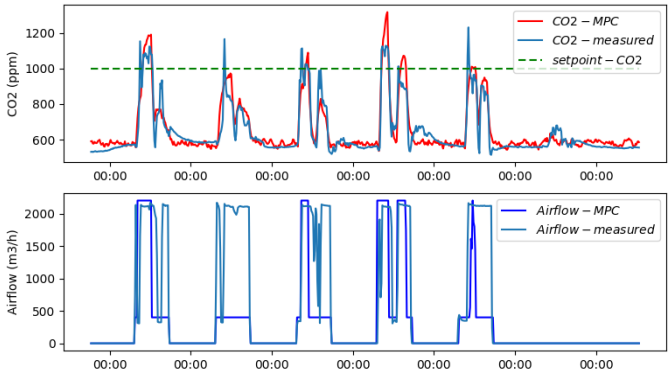
- $CO_2\ room\ \leq 1000\ ppm + zCO_2$
- $Airflow\ CO_2 \geq 0\ m^3/h\ \ (7{:}30 - 17{:}30h\ \ Airflow\ \geq 400\ m^3/h)$
- $Airflow\ CO_2 \leq 2200\ m^3/h$
- $zCO_2\ \geq 0$

- **Temperature MPC:** $\boldsymbol{Min}\ \sum_{k=0}^{Hp}(z)^2 + (Q_{vent})^2$

- $T_{room} \geq 22°C - z\ \ (17{:}30 - 7{:}30\ T_{room} \geq 16°C - z)$
- $T_{room} \leq 26\ °C + z$
- $Q_{vent} = 0.34 * m_{air}(T_{supply} - T_{room})$
- $-6\ kW \geq Q_{vent} \leq 12\ kW$
- $z \geq 0$

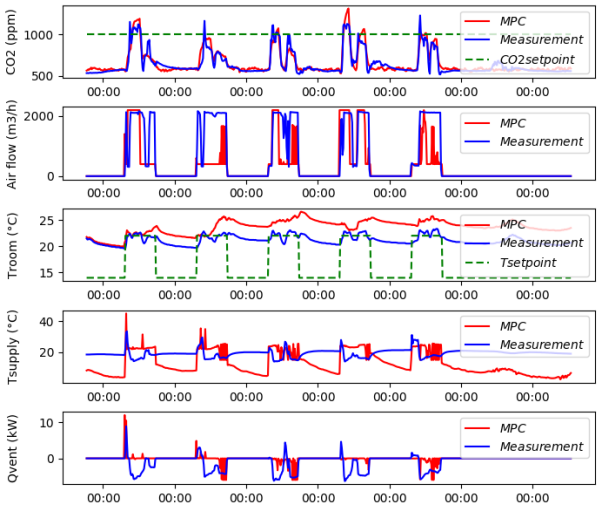
MPC CO2

- ARX CO_2 model is linear > Airflow CO_2 is obtained and used as input for step 2



9

MPC Ventilation



- Thermal discomfort
  - MPC: 10 Kh
  - Real: 92 Kh
- CO_2
  - MPC: 1562 ppmh
  - Real: 1915 ppmh

10

MPC ARX - Results

- Summarized results for evaluation period of 3 weeks

	Measurements	MPC ARX
Thermal discomfort (T_{room} < heating setpoint)	92 Kh	10 Kh
Thermal discomfort [T_{room}> 26°C]	-	1 Kh
CO_2 discomfort [> 1000 ppm]	1915 ppmh	1562 ppmh
Theoretical savings		
Airflow	-	47%
$Q_{ventilation\text{-}heating}$	-	56%

Conclusions

- MPC-ARX can be used for all-air systems to reduce energy use while guarantee the IEQ
- Reductions in energy use:
  - 47% less airflow
  - 56% reduction for $Q_{ventilation}$
- Future research
  - Robustness, sensitivity of MPC (e.g. timestep, thermal capacity, occupancy)
  - Implementation MPC in case study building

Model based design of intelligent ventilation concepts

Koen Maertens

AIVC Conference, Ghent, 15/10/2019

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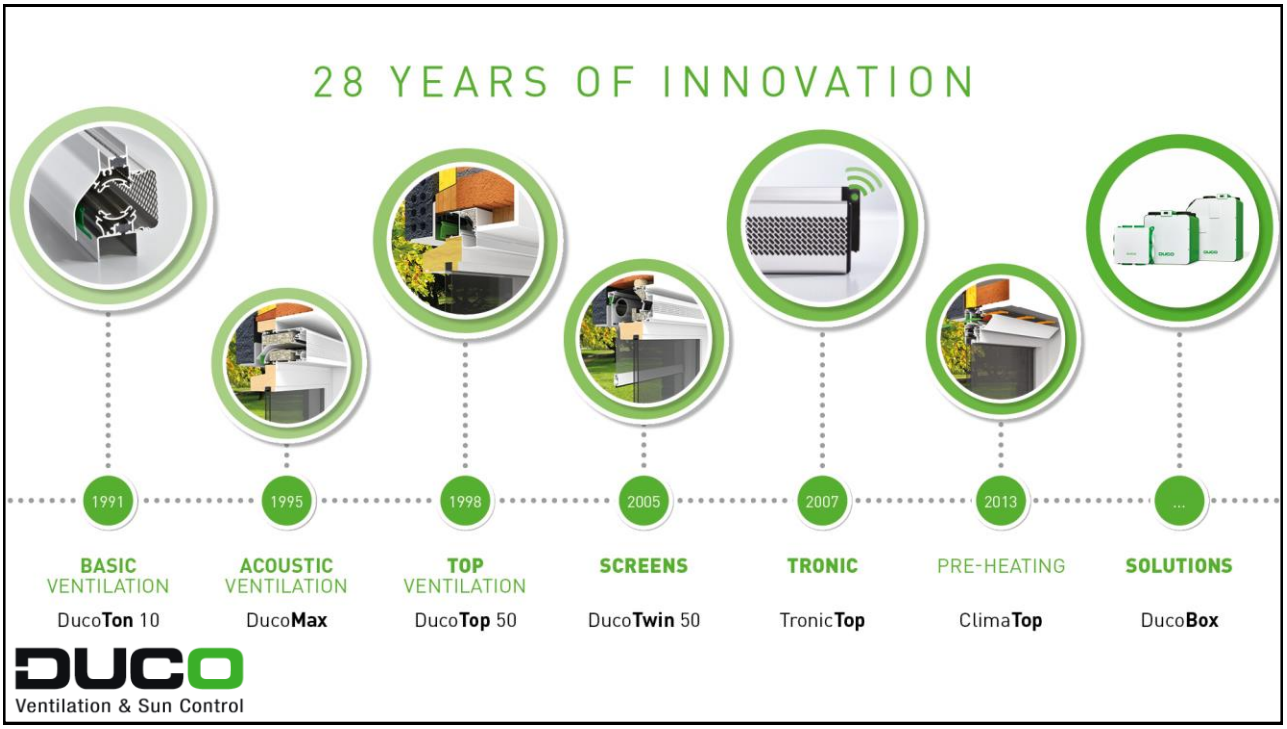
Ventilation & Sun Control




28 YEARS OF INNOVATION
1991
1995
1998
2005
2007
2013
...
BASIC VENTILATION
DucoTon 10
ACOUSTIC VENTILATION
DucoMax
TOP VENTILATION
DucoTop 50
SCREENS
DucoTwin 50
TRONIC
TronicTop
PRE-HEATING
ClimaTop
SOLUTIONS
DucoBox
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3


DUCO
VENTILATION
AUTO
DUCO
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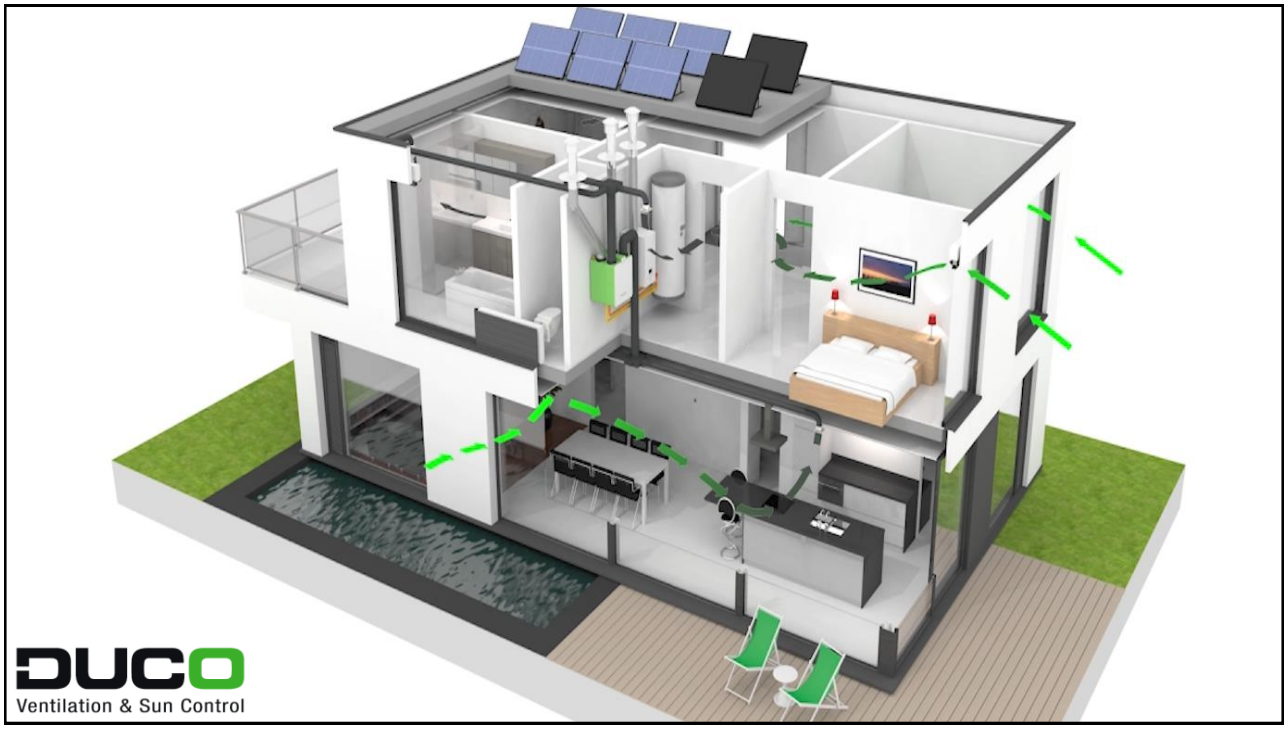
5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6


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7

How to design smart, modular ventilation concepts that

- Fullfill IAQ promises in all dwelling topologies
- Take into account varying climate conditions
- Cope with varying behaviour of residents
- Fullfill formal, local regulations

AND

- Work together in a reliable and robust way
- Are easy and robust to install
- Are servicable during total product life cycle

Modelbased Product Development

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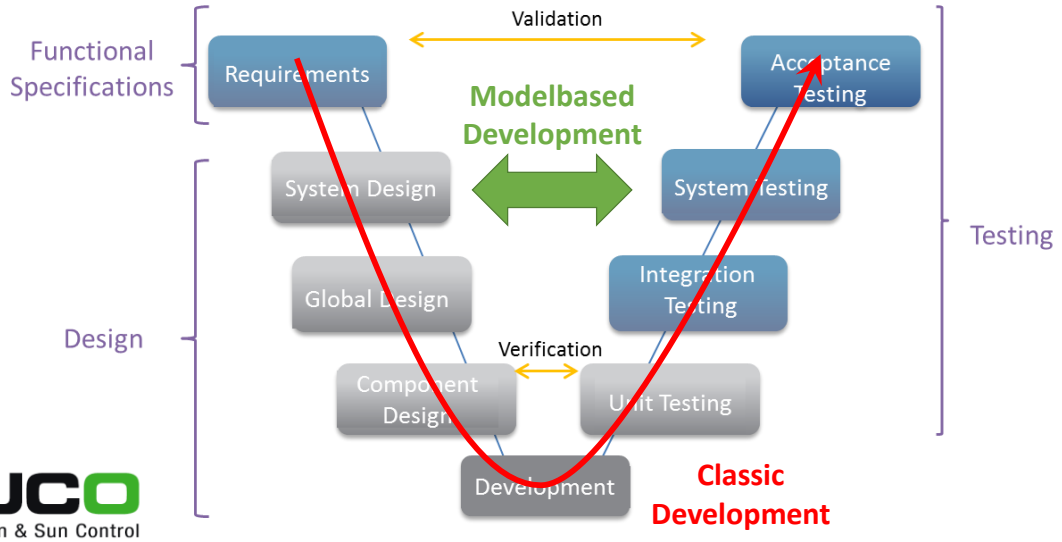
Modelbased Product Development Process



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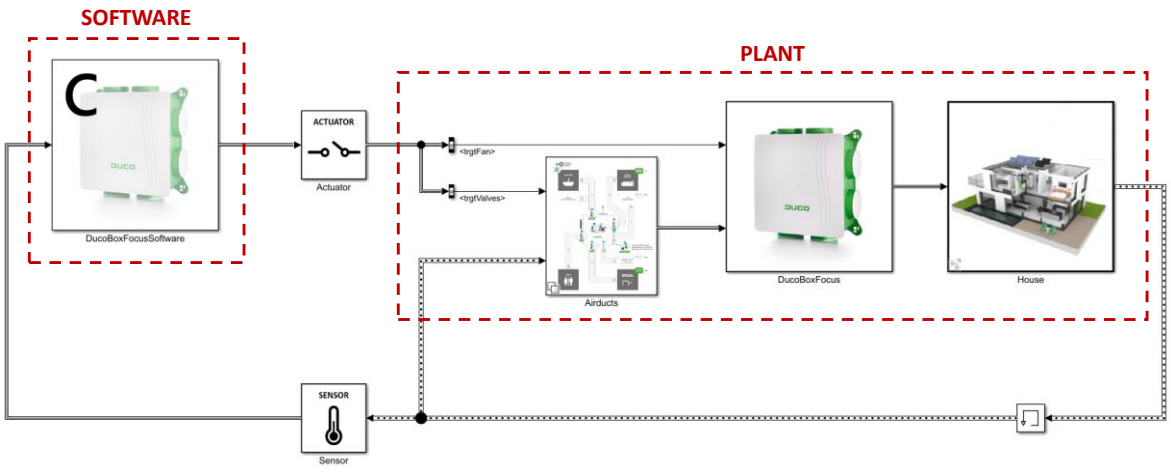

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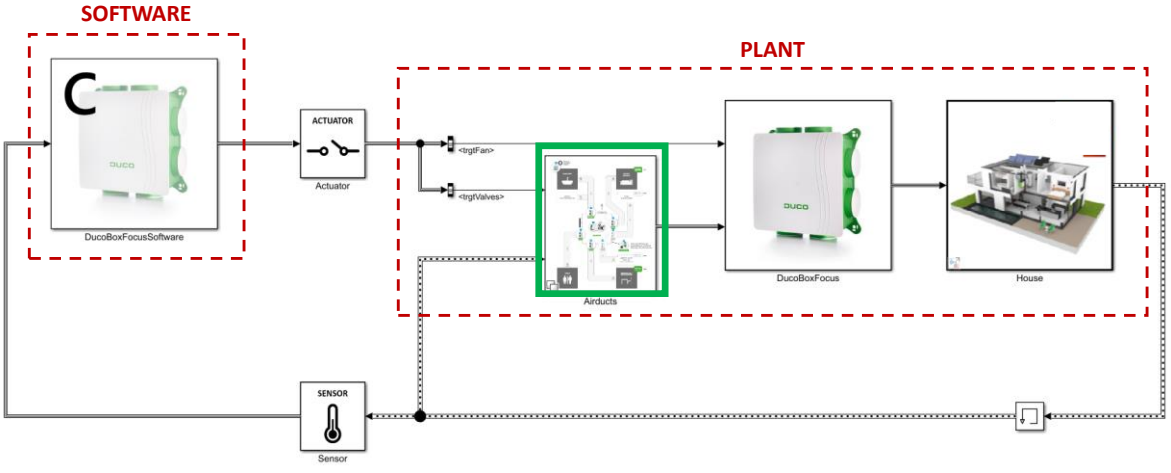
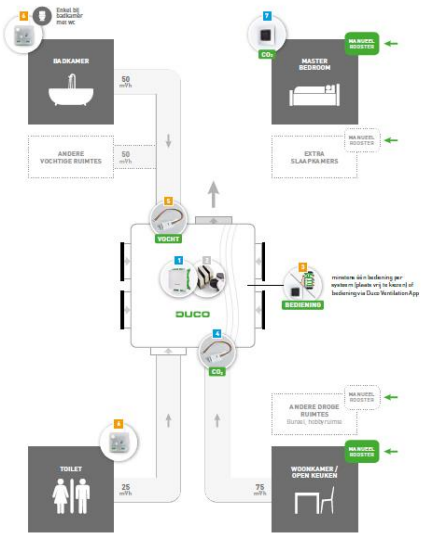
12



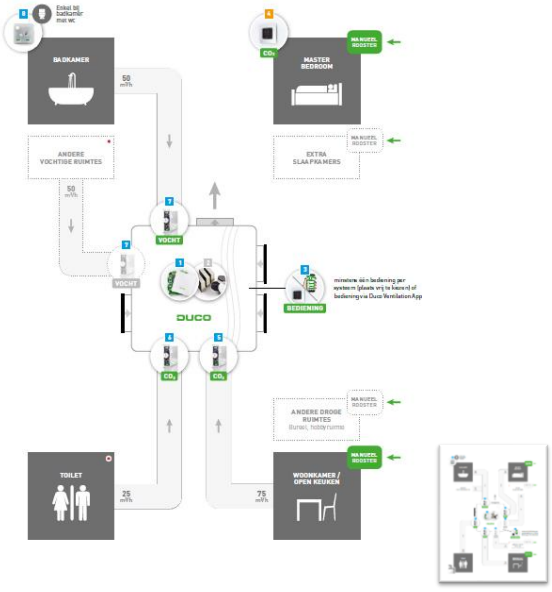
Ventilation & Sun Control

13

Duco **Reno** System



Duco **Comfort Plus** System



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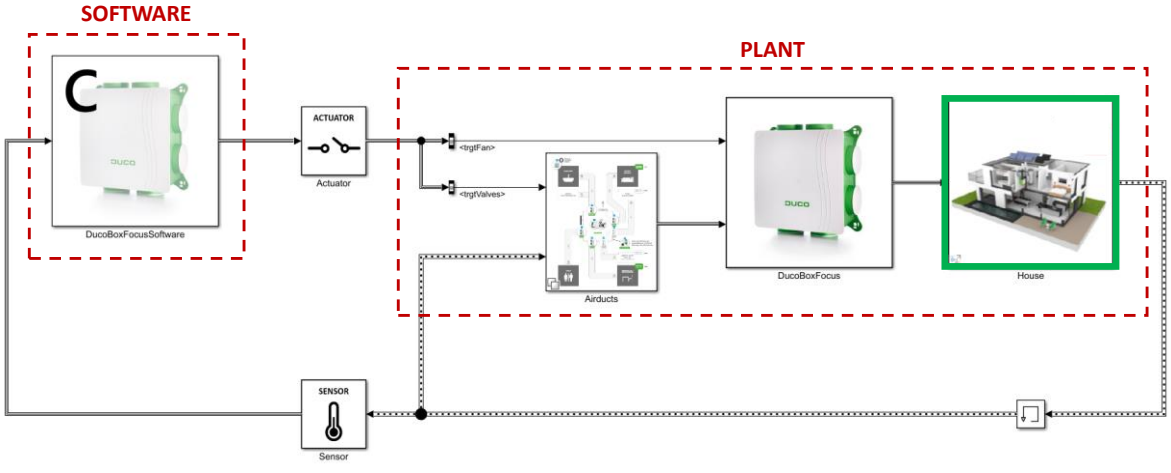

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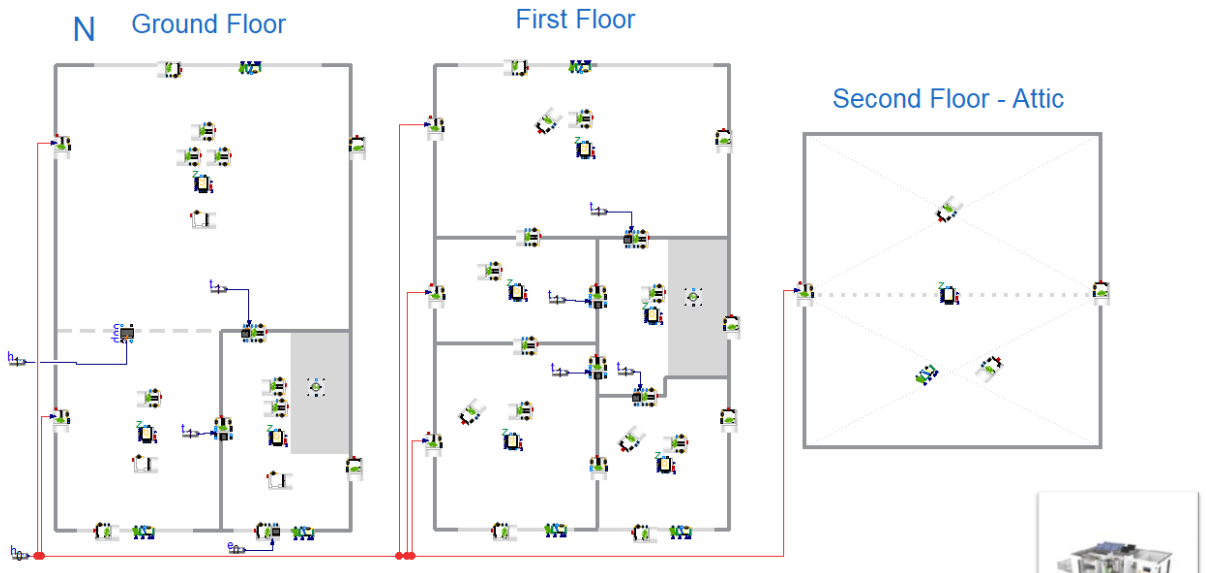
15



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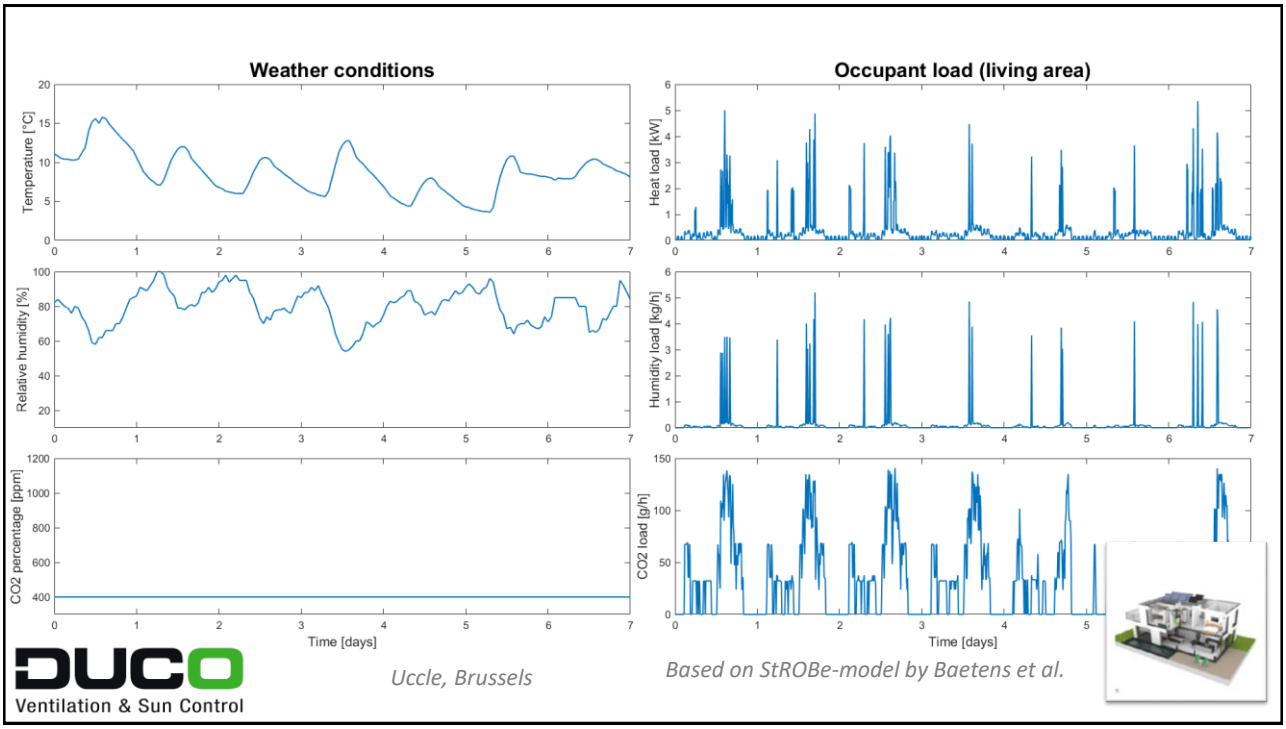

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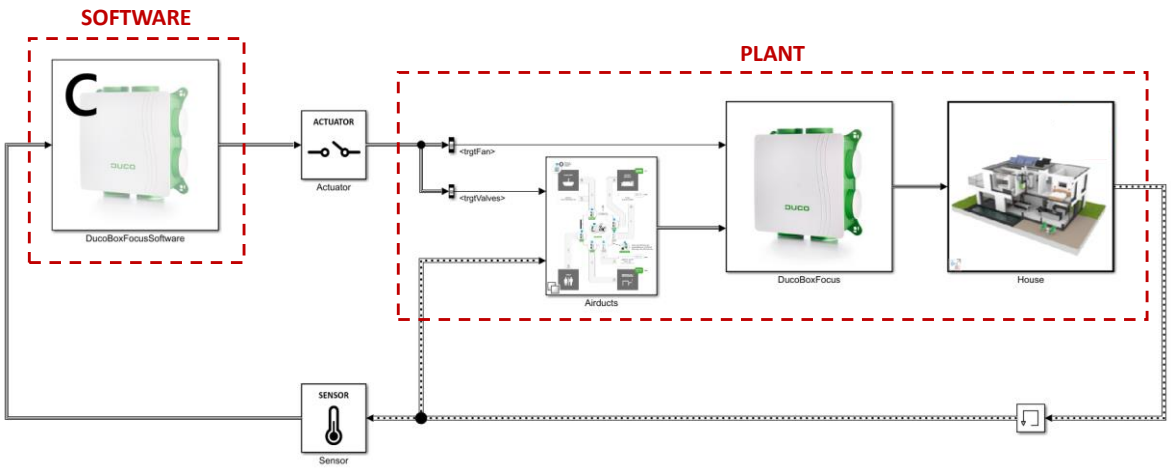
Uccle, Brussels

Based on StROBe-model by Baetens et al.

17



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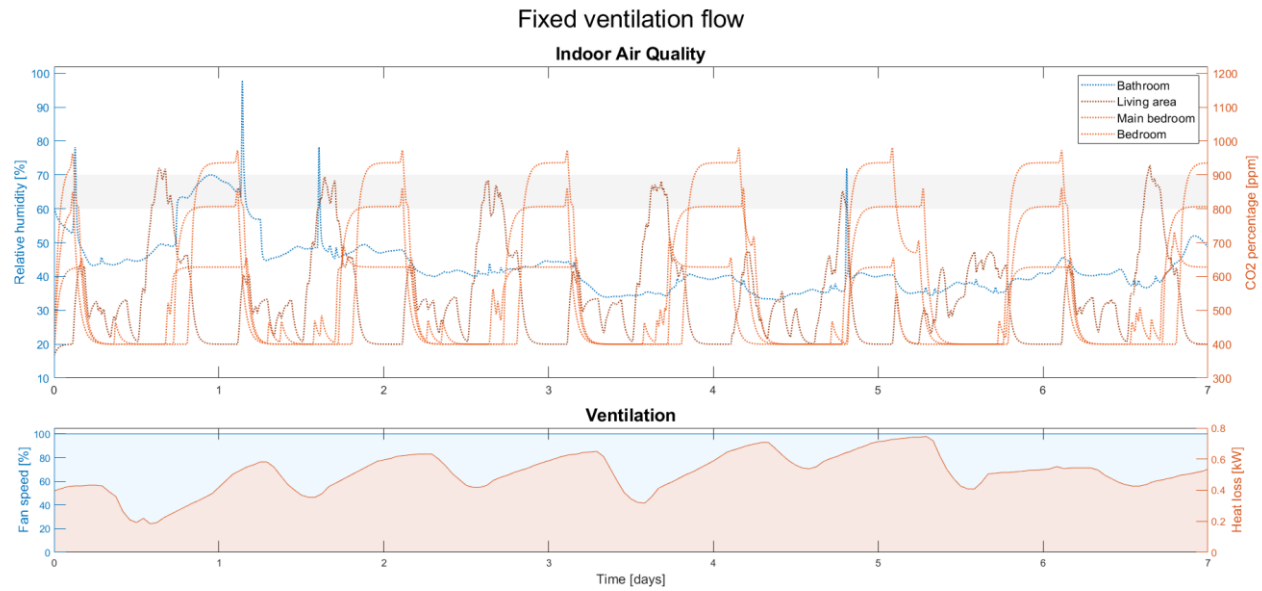
18



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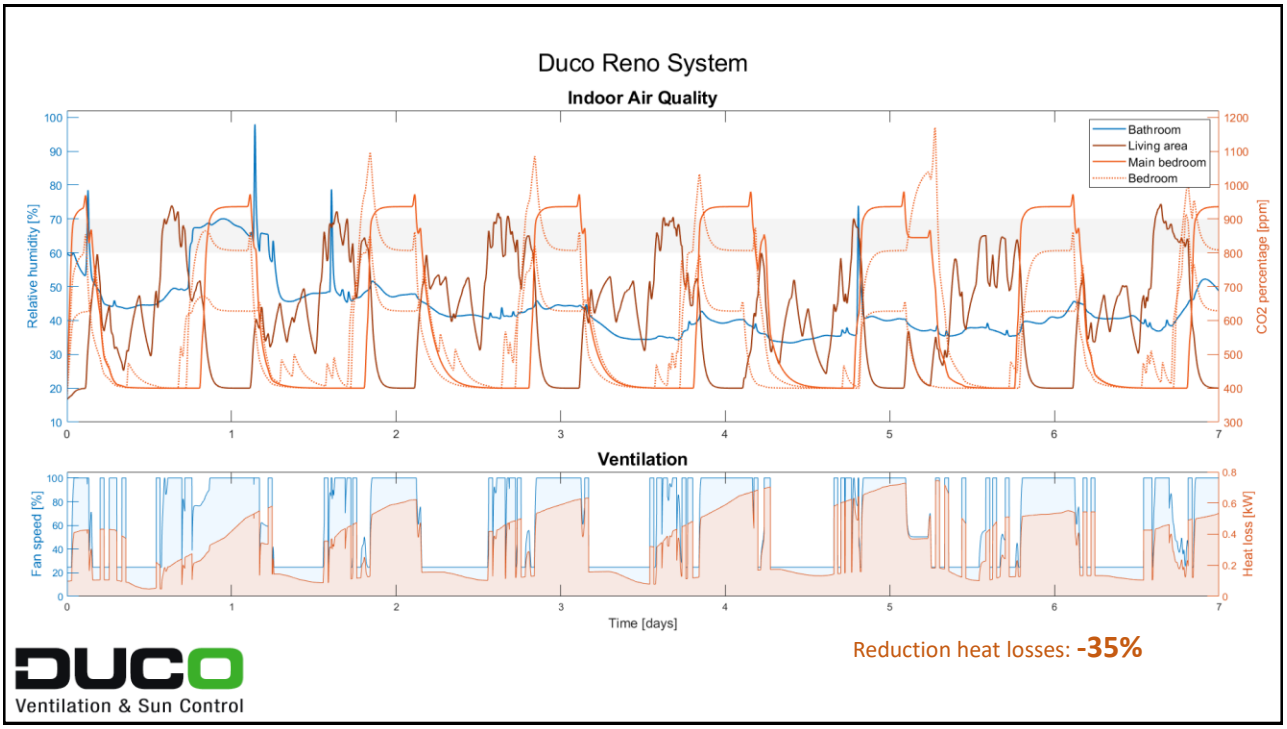
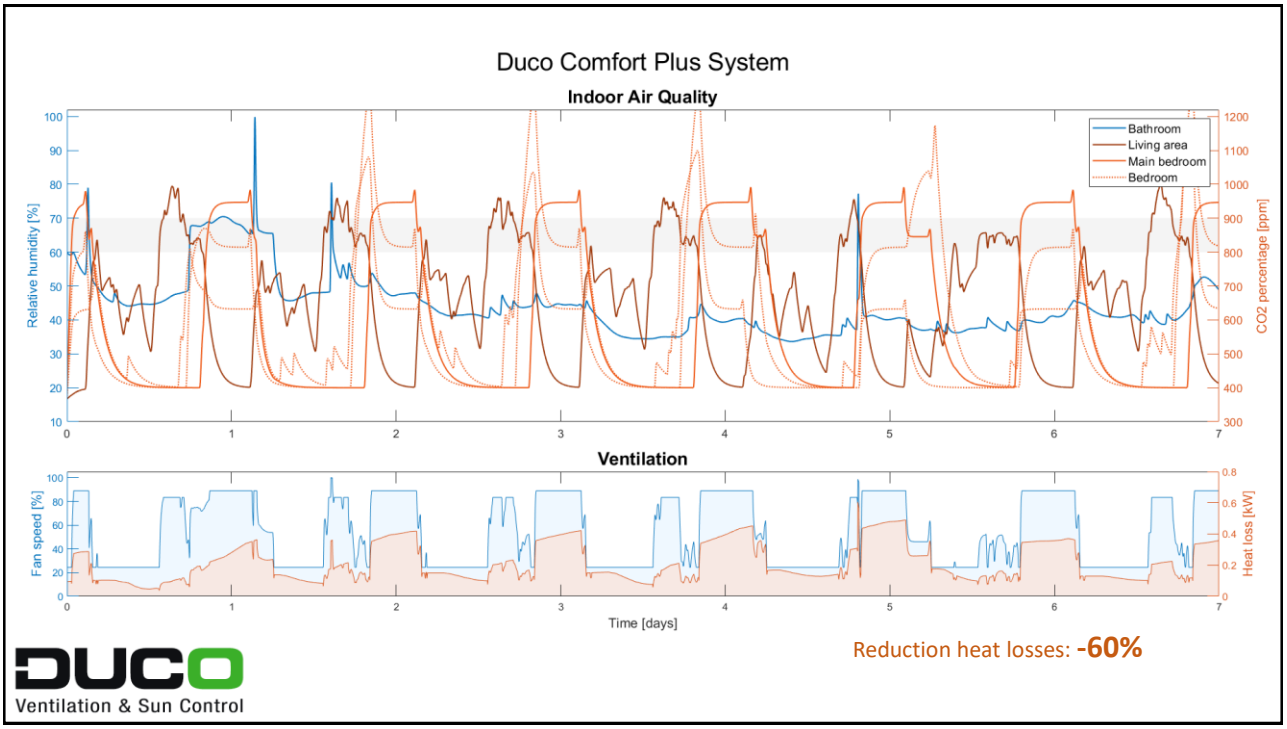
19



Ventilation & Sun Control

Reduction heat losses: **-35%**

20



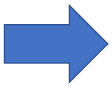
Ventilation & Sun Control

Reduction heat losses: **-60%**

21

Conclusions and outlook

- Dynamic simulations are required to evaluate and to optimize smart ventilation systems
- Modelbased development process is crucial to realize
  - Early functional check on system behaviour, without implementation effort
  - Reliable systems in variety of dwelling and system topologies
  - Smart solutions, coping with varying environment and residents
- Experiments are still required, mostly to validate the assumptions and interactions with users and dwellings



Modelbased approach is key enabler for evaluating smart HVAC applications !

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Ventilation & Sun Control

VRIJE UNIVERSITEIT BRUSSEL

VCVTB

https://github.com/belbert/VCVTB



Ventilation Controls Virtual Test Bed with Synthetic User Model

An Open Source Toolbox for Research & Development
of Robust Mixed-Mode IAQ and User Comfort Systems

Mixed-mode ventilation as an extension to demand-controlled approaches

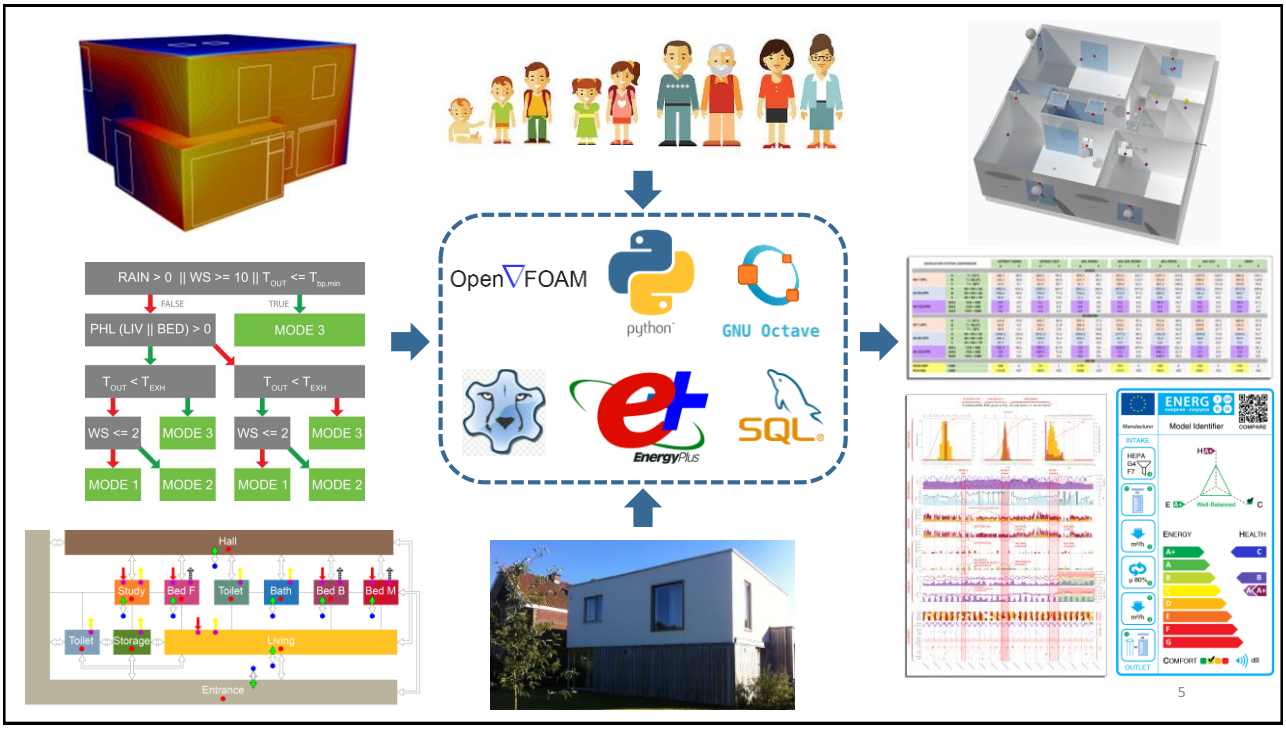


Informed and people-centric ventilation as opposed to fully automated



Simple in theory, but switching between modes is challenging





5

5

VCVTB

Case Study

Airflow Network

Outside Pressure Conditions

User Model

Control Logic

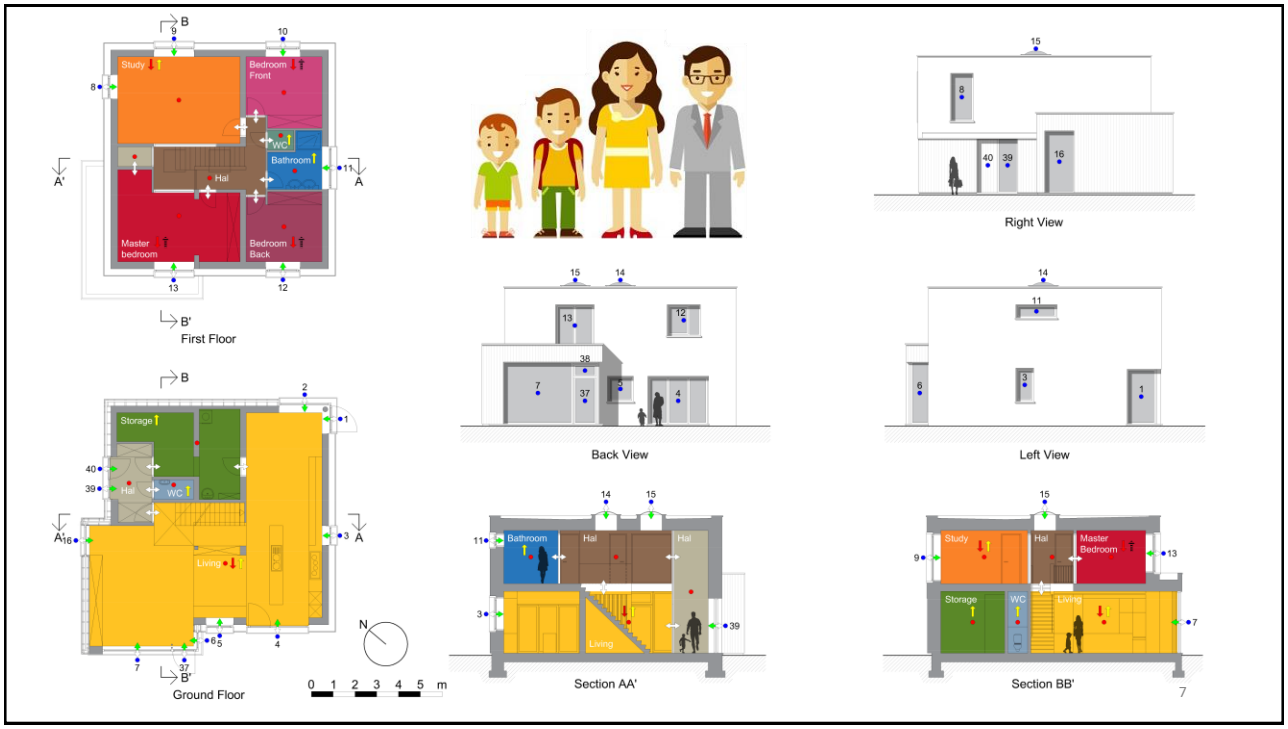
Report Sheets

3D Airflow Model

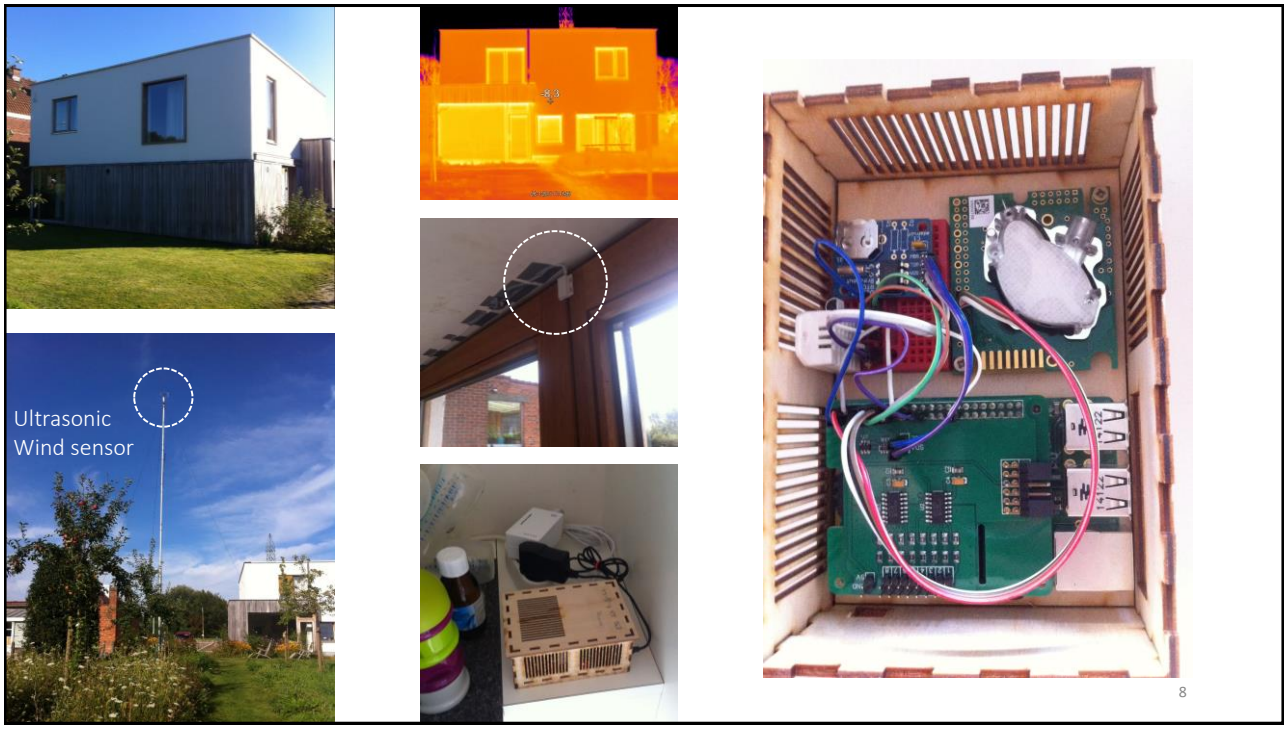
Comparative Table

6

6


Study
Bedroom Front
WC
Bathroom
Hal
Master bedroom
Bedroom Back
First Floor
Storage
Hal
WC
Living
Ground Floor
0 1 2 3 4 5 m
Right View
Back View
Left View
Bathroom
Hal
Hal
Living
Section AA'
Study
Hal
Master Bedroom
Storage
WC
Living
Section BB'
7

7


Ultrasonic
Wind sensor
8

8

VCVTB

Case Study

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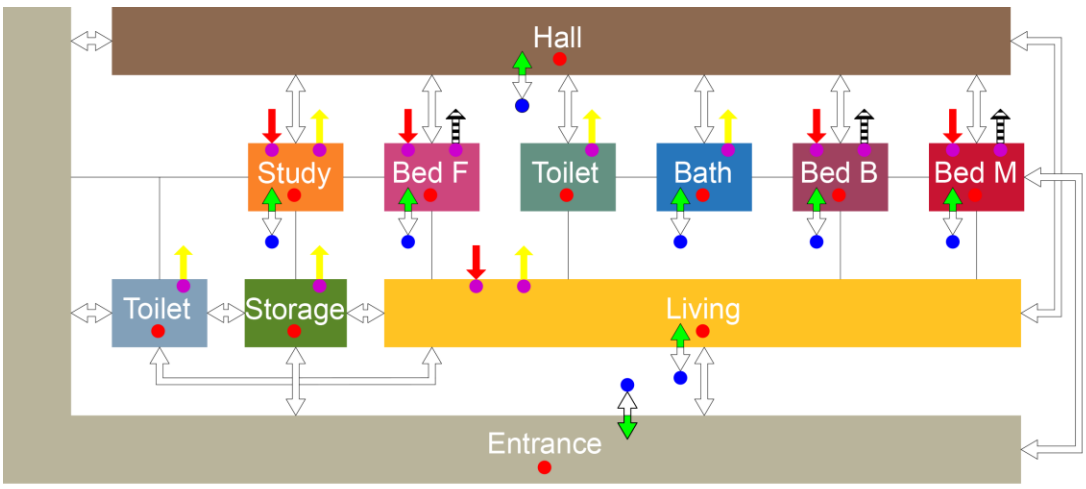
Comparative Table

Label



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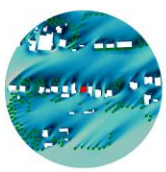
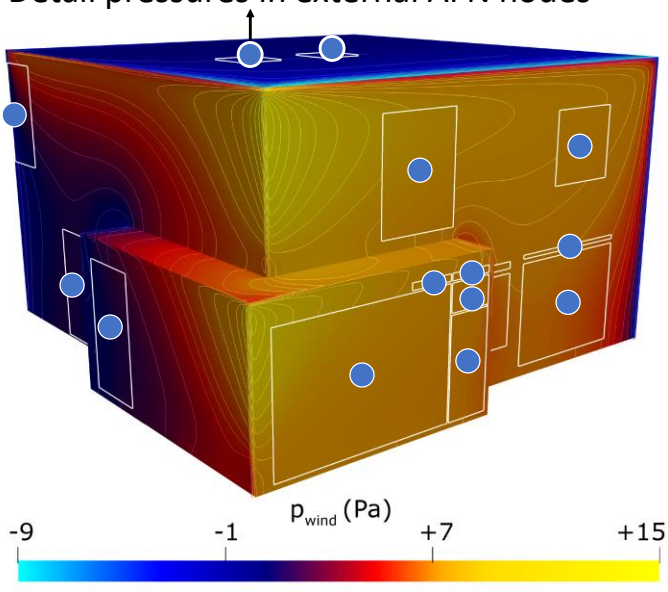
Label





Wind direction interval (30°)
- Building Shape
- Terrain
- Obstacles

Detail pressures in external AFN nodes



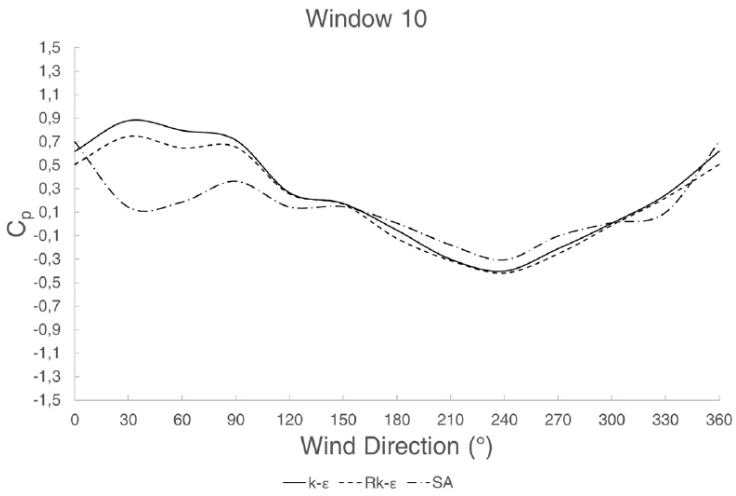
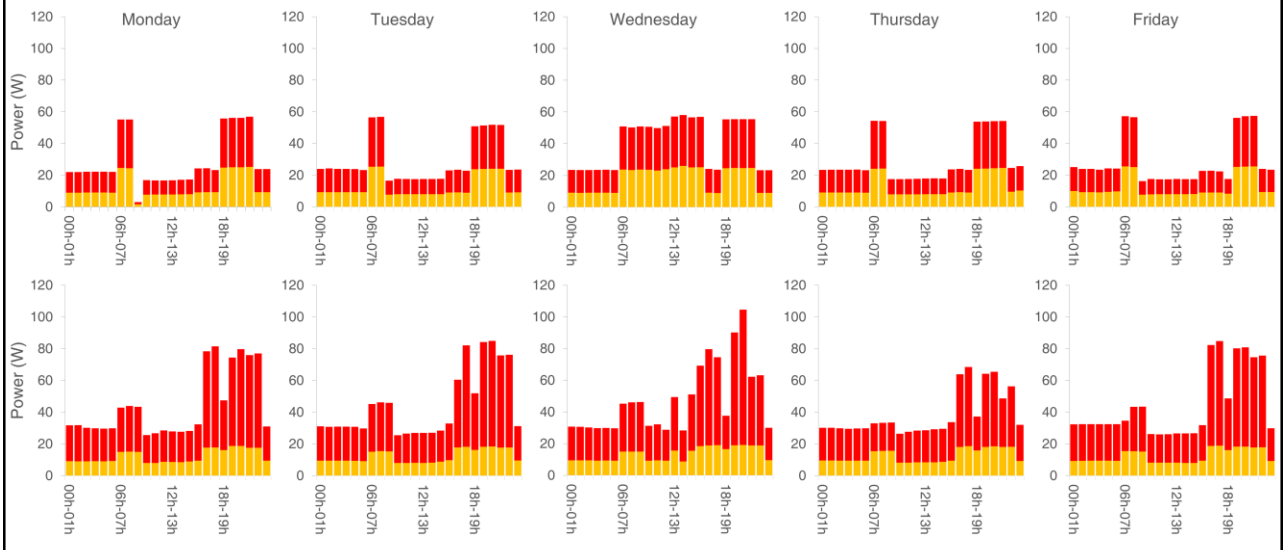


Figure 4.19: C_p's on Window 10 as predicted by k-ϵ, realizable k-ϵ and SA. Window 10 is located under the roof edge of the front façade, Figure 3.1. The C_p's deviate strongly between the k-ϵ models and SA when the window is on the windward side (0-90°). The same behaviour is observed for other windows in the vicinity of eaves. The same findings are reported by Yi et al. (2017).

13

13



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14

VCVTB

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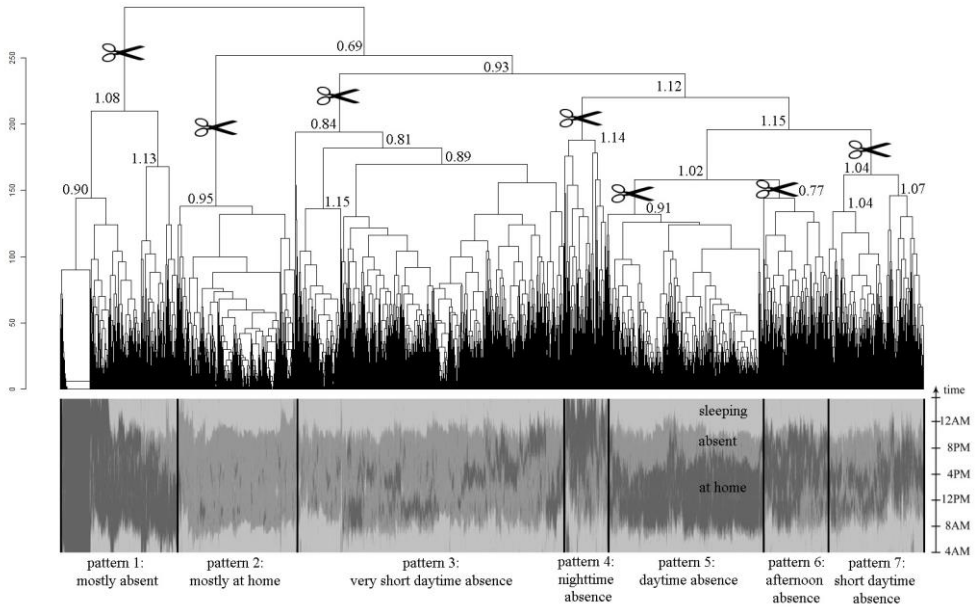
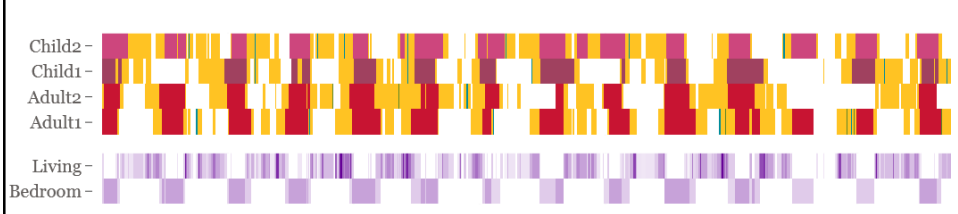
3D Airflow Model

Comparative Table

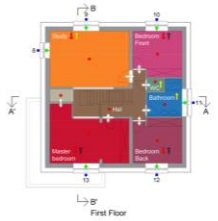
Label

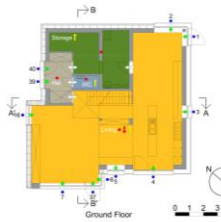


Aerts, D. (2015). *Occupancy and Activity Modelling for Building Energy Demand Simulations, Comparative Feedback and Residential Electricity Demand Characterisation*. Phd, Vrije Universiteit Brussel.









Female
16y
57 kg

Male
34y
76kg



≠



Watching TV

Working

Persily, A. K. and de Jonge, L. (2017). Carbon dioxide generation rates for building occupants. *Indoor Air*, 27(5):868–879.

17

17

Pallin, S., Johansson, P., and Hagentoft, C. E. (2011). Stochastic Modeling of Moisture Supply in Dwellings based on Moisture Production and Moisture Buffering Capacity. *Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association*, pages 14–16.

VARYING ACTIVITIES

HEAT

MOISTURE



VARYING METABOLISM

HEAT

MOISTURE

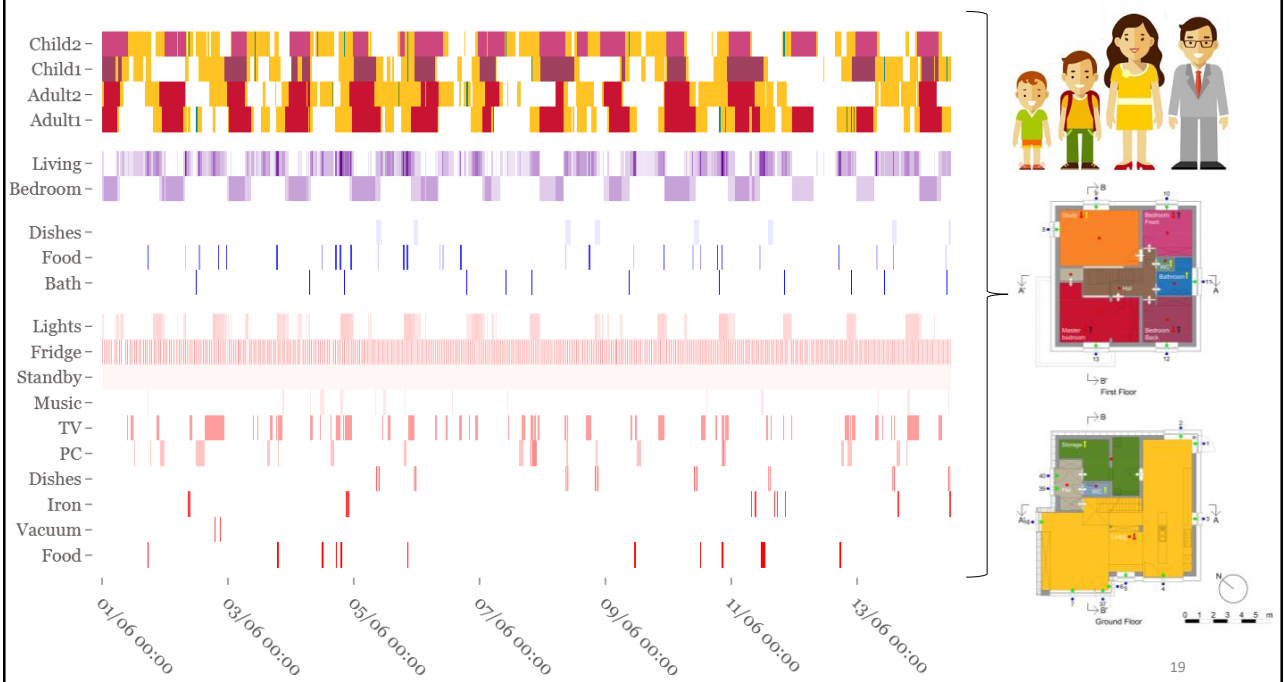
CO2

VARYING OCCUPANCY



18

18



19

VCVTB

Case Study

Airflow Network

Outside Pressure Conditions

User Model

Control Logic

Report Sheets

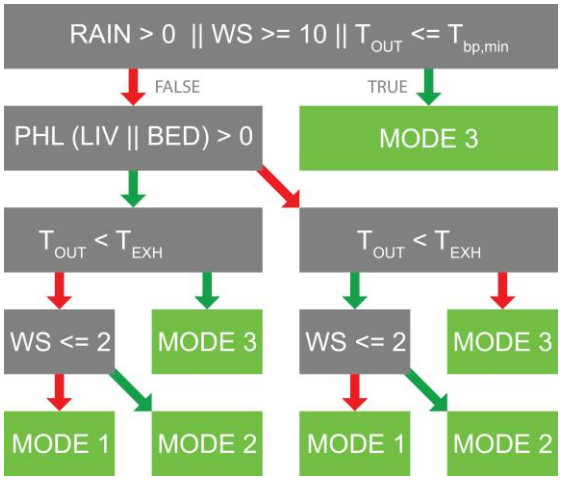
3D Airflow Model

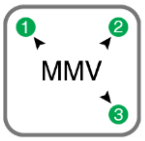
Comparative Table

Label

20

20





1. Natural inlets and outlets: trickle vents, windows, other openings
2. Natural inlets, mechanical exhaust
3. Balanced mechanical supply and exhaust with heat recovery and filters

VCVTB

Case Study

Airflow Network

Outside Pressure Conditions

User Model

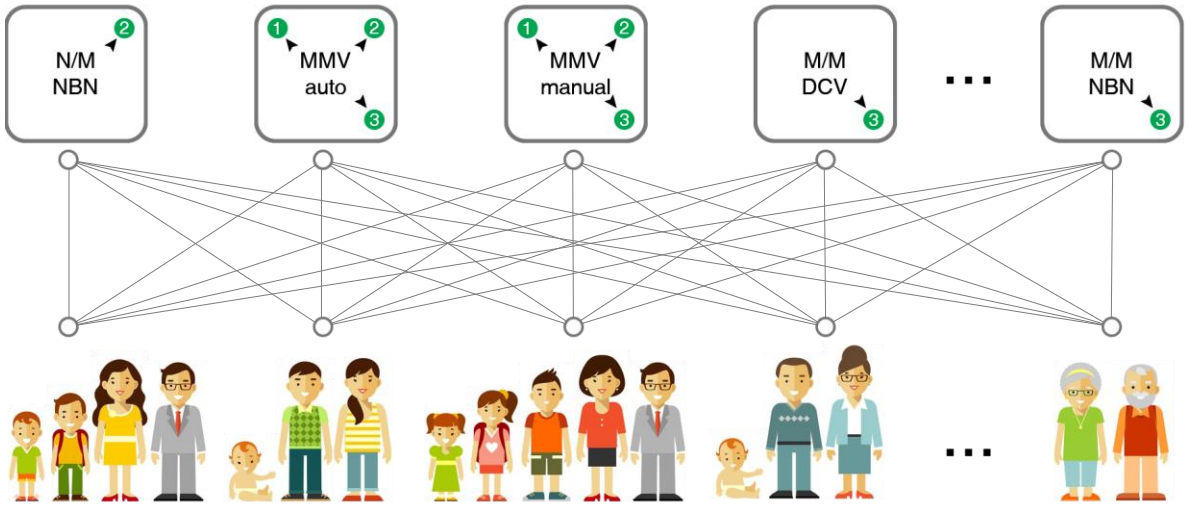
Control Logic

Interactive Report Sheets

3D Model of Airflows

Comparative Table

Ventilation Systems
(5 types)



Virtual Test Panel
(140 Households = 7 types x 20 families)

VENTILATION SYSTEM COMPARISON

Ventilation Systems →

			n / M NBN		MMV* manual		MMV* auto		M / M DCV		M / M NBN	
			μ	2σ	μ	2σ	μ	2σ	μ	2σ	μ	2σ
Yearly Unmet Hours Living Room												
Class A*	T < 25.5 °C	UH_{pp}	525	260	176	222	191	242	685	284	812	372
Class B*	T < 26 °C	UH_{pp}	422	248	12	36	15	54	485	224	679	334
Class C*	T < 27 °C	UH_{pp}	211	204	0	1	0	1	167	130	423	280
Class A	30 % < RH < 50 %	UH_{pp}	1959	426	1274	320	1244	300	985	316	1045	240
Class B	25 % < RH < 60 %	UH_{pp}	397	98	104	48	100	40	49	38	84	30
Class C	20 % < RH < 70 %	UH_{pp}	31	12	0	0	0	0	0	0	0	0
IDA1	$CO_2 < CO_{2env} + 400$ ppm	UH_{pp}	0	0	7	16	8	18	0	0	0	1
IDA2	$CO_2 < CO_{2env} + 600$ ppm	UH_{pp}	0	0	0	0	0	0	0	0	0	0
IDA3	$CO_2 < CO_{2env} + 1000$ ppm	UH_{pp}	0	0	0	0	0	0	0	0	0	0
Heating Period												
Average auxiliary energy use of fans		kWh	54	0	73	4	73	4	74	4	173	0
Average energy demand for heating		kWh	9140	646	4476	482	4488	498	4353	570	5381	562
Average Ventilation Flow Rate	Min	m3/h	145	0	0	0	0	0	37	2	210	0
	Mean	m3/h			58	10	58	10	58	10		
	Max	m3/h			210	18	213	16	207	22		
Summer and mid-season												
Average auxiliary energy use of fans		kWh	56	0	60	14	64	14	327	70	179	0
Average energy demand for heating		kWh	793	214	164	86	160	84	87	44	192	78
Average Ventilation Flow Rate	Min	m3/h	145	0	0	0	0	0	37	4	210	0
	Mean	m3/h			55	12	56	12	167	32		
	Max	m3/h			425	4	425	4	427	2		

Key Performance Indicators NBN EN 15251

			n / M NBN μ	n / M NBN 2σ	MMV* manual μ	MMV* manual 2σ	MMV* auto μ	MMV* auto 2σ	M / M DCV μ	M / M DCV 2σ	M / M NBN μ	M / M NBN 2σ
			Yearly Unmet Hours Living Room									
Class A*	T < 25.5 °C											
Class B*	T < 26 °C	UH_{pp}										
Class C*	T < 27 °C											
Class A	30 % < RH < 50 %											
Class B	25 % < RH < 60 %	UH_{pp}										
Class C	20 % < RH < 70 %											
IDA1	$CO_2 < CO_{2env} + 400$ ppm											
IDA2	$CO_2 < CO_{2env} + 600$ ppm	UH_{pp}										
IDA3	$CO_2 < CO_{2env} + 1000$ ppm											

← Operative temperature

← Relative Humidity

← CO_2 (IAQ Tracer)

Thresholds

Adaptive Comfort limits for MMV

VENTILATION SYSTEM COMPARISON

Energy Performance

			n / M NBN μ	n / M NBN 2σ	MMV* manual μ	MMV* manual 2σ	MMV* auto μ	MMV* auto 2σ	M / M DCV μ	M / M DCV 2σ	M / M NBN μ	M / M NBN 2σ
			Heating Period									
Average auxiliary energy use of fans		kWh									173	0
Average energy demand for heating		kWh									5381	562
Average Ventilation Flow Rate	Min	m3/h										
	Mean	m3/h									210	0
	Max	m3/h										
			Summer and mid-season									
Average auxiliary energy use of fans		kWh	56	0	60	14	64	14	327	70	179	0
Average energy demand for heating		kWh	793	214	164	86	160	84	87	44	192	78
Average Ventilation Flow Rate	Min	m3/h			0	0	0	0	37	4		
	Mean	m3/h	145	0	55	12	56	12	167	32	210	0
	Max	m3/h			425	4	425	4	427	2		

← Auxiliary Energy Fans + Heating Demand

← Indication of Operation

Yearly Unmet Hours

VENTILATION SYSTEM COMPARISON			n / M* NBN		MMV* manual		MMV* auto		M / M* DCV		M / M DCV		M / M* NBN	
			SA + IW		SA		SA		SA + IW		SA		SA + IW	
			μ	2σ	μ	2σ	μ	2σ	μ	2σ	μ	2σ	μ	2σ
			Yearly Unmet Hours Living Room											
Class A*	T < 25.5 °C		68	152	160	230	197	206	134	142	695	332	243	384
Class B*	T < 26 °C	UH_{pp}	7	46	10	34	11	36	10	18	488	256	42	132
Class C*	T < 27 °C		1	4	0	0	0	0	0	1	168	150	2	16
Class A	30 % < RH < 50 %		1953	924	1269	354	1264	290	1485	448	963	286	1229	212
Class B	25 % < RH < 60 %	UH_{pp}	413	168	106	48	103	42	254	250	48	36	176	52
Class C	20 % < RH < 70 %		35	20	0	0	0	0	45	74	0	0	0	0
IDA1	$CO_2 < CO_{2env} + 400$ ppm		0	0	5	12	4	10	0	0	0	0	0	0
IDA2	$CO_2 < CO_{2env} + 600$ ppm	UH_{pp}	0	0	0	0	0	0	0	0	0	0	0	0
IDA3	$CO_2 < CO_{2env} + 1000$ ppm		0	0	0	0	0	0	0	0	0	0	0	0
			Yearly Unmet Hours Master Bedroom											
Class A*	T < 25.5 °C		161	86	18	22	16	18	43	68	123	52	103	74
Class B*	T < 26 °C	UH_{pp}	57	36	2	4	1	4	12	28	58	30	30	36
Class C*	T < 27 °C		57	36	2	4	1	4	12	28	4	8	30	36
Class A	30 % < RH < 50 %		1268	646	875	172	821	132	943	300	517	94	689	22
Class B	25 % < RH < 60 %	UH_{pp}	196	126	74	24	63	18	107	86	21	8	12	26
Class C	20 % < RH < 70 %		12	14	2	4	0	0	6	14	0	0	0	0
IDA1	$CO_2 < CO_{2env} + 400$ ppm		890	434	76	24	70	26	8	8	8	8	1746	200
IDA2	$CO_2 < CO_{2env} + 600$ ppm	UH_{pp}	338	244	13	10	3	4	0	0	0	0	0	0
IDA3	$CO_2 < CO_{2env} + 1000$ ppm		10	12	3	6	0	0	0	0	0	0	0	0

Energy Demand for Heating , Auxiliary Fan Electricity and Average Airflow Rates

VENTILATION SYSTEM COMPARISON			n / M* NBN		MMV* manual		MMV* auto		M / M* DCV		M / M DCV		M / M* NBN	
			SA + IW		SA		SA		SA + IW		SA		SA + IW	
			μ	2σ	μ	2σ	μ	2σ	μ	2σ	μ	2σ	μ	2σ
			Yearly											
Average auxiliary energy use of fans		kWh/a	110	42	134	18	139	18	276	92	403	80	350	12
Average energy demand for heating		kWh/a	9629	2520	4509	682	4457	610	5615	2574	4273	910	5535	822
Average M	Min	m3/h			0	0	0	0	35	6	36	2		
Ventilation Flow	Mean	m3/h	145	0	57	12	57	10	92	20	114	22	210	0
Rate	Max	m3/h			425	4	425	2	427	2	428	2		
			Heating Period											
Average auxiliary energy use of fans		kWh	54	0	73	4	73	4	74	12	74	8	172	12
Average energy demand for heating		kWh	8806	666	4364	591	4326	534	4801	1704	4193	876	5297	752
Average M	Min	m3/h			0	0	0	0	37	4	37	2		
Ventilation Flow	Mean	m3/h	145	0	59	10	58	8	60	10	60	12	210	0
Rate	Max	m3/h			213	22	209	26	209	26	210	32		
			Summer and mid-season											
Average auxiliary energy use of fans		kWh	56	0	60	16	66	16	203	92	329	76	178	0
Average energy demand for heating		kWh	823	288	145	94	131	76	814	1124	80	46	239	152
Average M	Min	m3/h			0	0	0	0	35	4	37	2		
Ventilation Flow	Mean	m3/h	145	0	55	14	56	12	123	34	168	36	210	0
Rate	Max	m3/h			425	4	425	4	427	2	428	2		

Conclusions

Uninformed (intuitive) window opening by occupants can be detrimental to the performance of a ventilation strategy.

If we are able to nudge users toward effective window use mixed-mode ventilation proves to be competitive.

Need to investigate appropriate turbulence models for case specific simulations of airflow, but the general conclusions are robust

There is a need to take steps to improve simulation software to allow the development of robust and future proof ventilation within a smart context

VRIJE UNIVERSITEIT BRUSSEL

VCVTB

https://github.com/belbert/VCVTB



B. Belmans, D. Aerts, S. Verbeke, A. Audenaert and F. Descamps.
Set-up and evaluation of a virtual test bed for simulating and comparing single- and mixed-mode ventilation strategies.
Building and Environment, 151 (March): 91-111, 2019

Bert.Belmans@vub.be

KU LEUVEN

Topical session 10: Model based control and concepts for ventilation systems

Hilde Breesch, Maarten Sourbron

1

Discussion with the audience

- Subject = use of (simulation) models in ventilation control and concepts
- Questions
  - What are opportunities, challenges, benefits and difficulties of model based (predictive) control for ventilation and all-air systems?
  - How can simulation models improve development of new ventilation concepts and products?

2

About you (1)

- What is **your role** related to ventilation?
  - Designer
  - Manufacturer/dealer
  - Researcher
  - User
  - Other

About you (2)

- Do you have already experience with **model predictive control (MPC)** of ventilation?
  - Yes, al lot
  - Yes, a little bit
  - No, but I plan to
  - No and I have no plans

About you (3)

- Do you have already experience with **model based design** of ventilation?
  - Yes, al lot
  - Yes, a little bit
  - No, but I plan to
  - No and I have no plans

About Model Predictive Control

- Do you think that MPC has **potential** in control of ventilation?
  - Yes, a lot
  - Yes, a little bit
  - No

About Model Predictive Control

- What is in your experience the most important **barrier** for implementation of MPC in ventilation control?
  - Cost
  - Potential not clear
  - Lack of knowledge of designer
  - Lack of experience of installer
  - Difficult to convince building owner/user
  - Other

About product development

- Do you expect that the use of (simulation) models will **increase** in product development?
  - Yes, a lot
  - Yes, somewhat,
  - No, will remain the same
  - No, will decrease
  - I do not know

About model based design

- For which purpose do you have already experience with simulation tools/modelling?
  - Dimensioning of ventilation
  - Calculation of energy use
  - Not yet
- In your experience, which tools are useful for model based design?

Summary

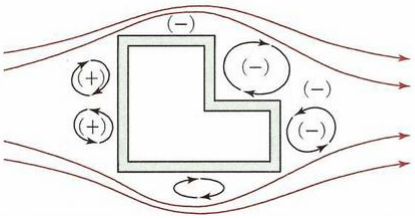
- Answers to questions
  - What are opportunities, challenges, benefits and difficulties of model based (predictive) control for ventilation and all-air systems?
  - How can sumulation models improve development of new ventilation concepts and products?

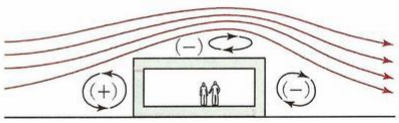
Influence of the external pressure tap position on the airtightness test result

Jiří Novák

Faculty of Civil Engineering
Czech Technical University in Prague

Motivation - questions





Author. Heekwan L.

- does the position of an external Δp tap influence a test result?
- variability of the results?
- influence of the wind speed ?
- possible improvements?



Measured building

- a single-family house
- 10.2 x 8.6 m, height (roof ridge) 8 m
- V = 326 m^3, n_{50} = 0.7 h^{-1}



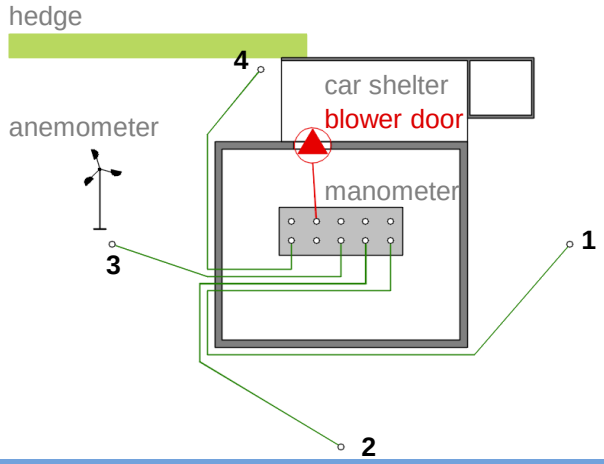
Measured building and its surroundings

- plot in slope
- close to neighbouring buildings
- small trees, hedges



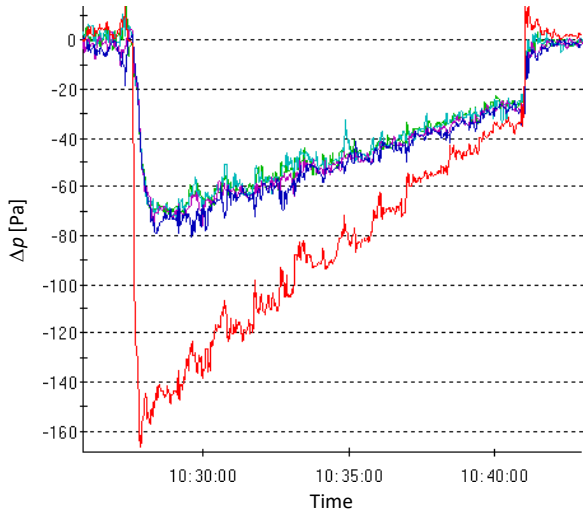
Experimental set-up

- 1 ÷ 4 external pressure taps
- equipped with T-pieces (protection against wind impact)



Recorded data and evaluation

- 1 test → 5 results (q_{50} [m³/h])



Δp_1 — Δp_{fan} → $q_{50,1}$

Δp_2 — Δp_{fan} → $q_{50,2}$

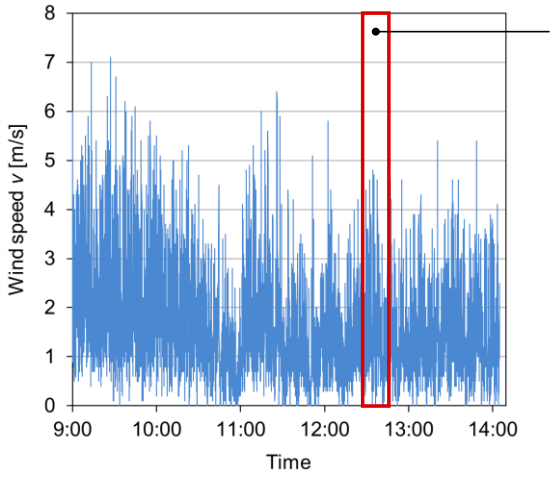
Δp_3 — Δp_{fan} → $q_{50,3}$

Δp_4 — Δp_{fan} → $q_{50,4}$

$\Delta p_{avg(1÷4)}$ — Δp_{fan} → $q_{50,ALL}$

Recorded data and evaluation

- wind speed (v [m/s])
- sampling frequency 1/s



for each test:
- avg. wind speed
- wind speed standard deviation (indicator of wind speed fluctuation)

Method

9 tests

- different dates – different climatic conditions
- different technicians with different equipment

⬇

5 results of each test

- obtained under repeatability conditions

⬇

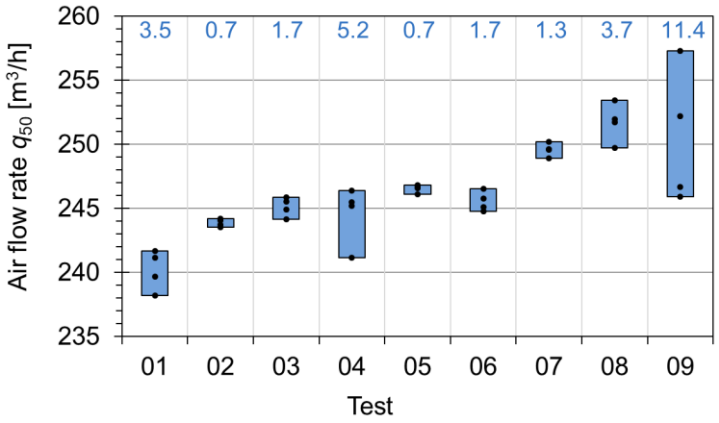
Analysis

- variability of the results of the same test
- order of the results – common patterns
- influence of the wind speed
- influence of the wind speed fluctuation

Results

Variability of the results

- results obtained with 4 ext. Δp taps
- indicator of variability: range $R = q_{50,max} - q_{50,min}$



Results

Use of repeatability limits (ISO 5725-6)

- 4 test results
- obtained by means of a standardised test method (EN ISO 9972, 1 external pressure tap)
- under repeatability conditions
- with a repeatability standard deviation $s_r = 1.96$

⬇

- with a 95 % probability:

$R \leq 7.05$ m³/h

$R = q_{50,max} - q_{50,min} \leq CR_{0.95}(4) = f(4) \cdot s_r = 3.6 \cdot 1.96 = 7.05$

Results

Use of repeatability limits (ISO 5725-6)

- 4 test results
- obtained by means of a standardised test method
- under repeatability conditions
- with a repeatability standard deviation $s_r = 1.96$

- obtained in a stand-alone repeatability experiment

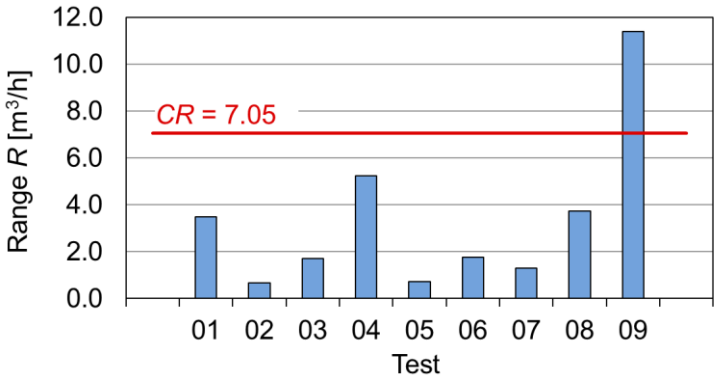




Results

Variability of the results X repeatability

- the range of the results is lower than the range expected in case of 4 tests repeated with the same ext. Δp tap position



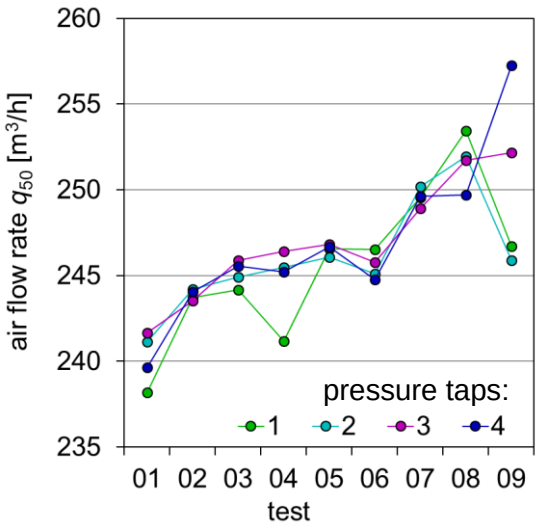
Results

Order of the 4 results obtained with 4 ext. Δp taps

- no systematic order

⬇

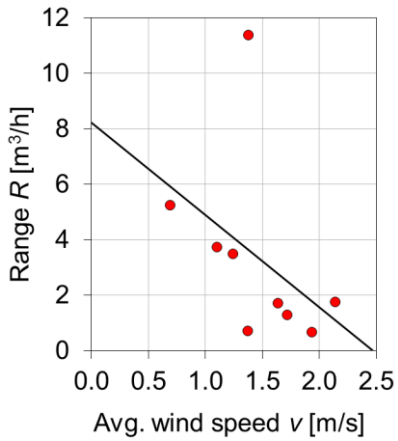
- changing wind direction?



Results

Influence of the wind speed

- variability of the results obtained wit 4 different ext. Δp tap positions decreases with the wind speed



correlation coeff. $r = 0.435$
→ not correlated – probability 20%

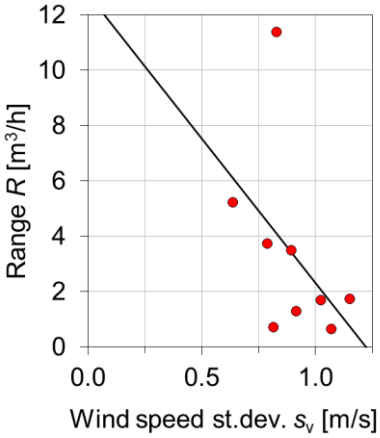
X

- very similar avg.wind speeds ($0.7 \le v \le 2.1$)
- more test results in more variable wind conditions needed

Results

Influence of the wind fluctuation

- variability of the results obtained wit 4 different ext. Δp tap positions decreases with the wind fluctuation



correlation coeff. $r = 0.460$
→ not correlated – probability 23%

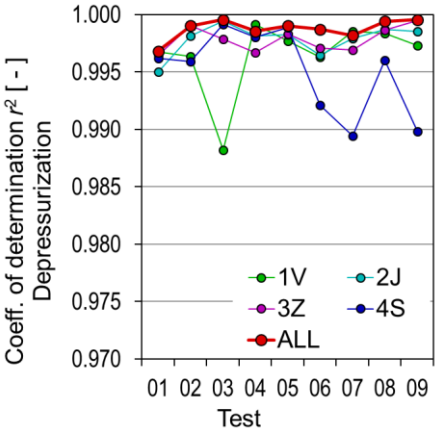
X

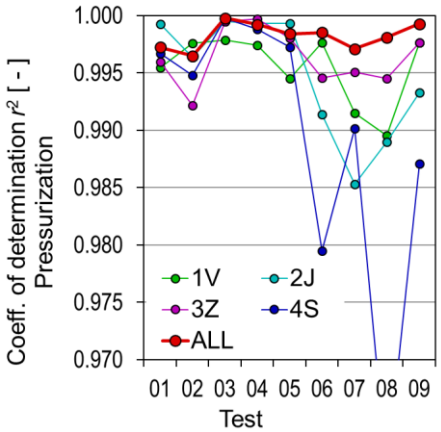
- very similar wind conditions ($0.64 \leq s_v \leq 1.15$)
- more test results in more variable wind conditions needed

Results

Coefficient of determination

- stronger wind, more fluctuating wind → smaller r^2
- r^2 - indirect indicator of measurement accuracy





Conclusions

Influence of the ext. Δp position on the test result

- the external Δp tap position had no significant influence on the variability of test results
- the uncertainty due to the external Δp tap position was in the same order as the uncertainties from other sources

X

- measurements carried out under relatively low wind speed
- technical measures taken in order to reduce the wind impact on the external Δp taps
  (T-pieces, distance from facades, longer records of Δp)

Conclusions

Practical outcomes

- testing with 1 external Δp tap - no particular, favourable position of the tap was found which would systematically reduce the wind impact
- averaging of 4 pressures – proved to be a good strategy for reducing the wind impact
  (higher r^2 values systematically obtained)

Conclusions

Correlation with wind

- correlation with wind found in this study - questionable (very similar wind conditions during the tests)
- more extensive study needed (diverse wind conditions)
- the study will continue...



Thank you for your attention

Questions?

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Airtightness of Buildings

Considerations regarding place and nature of pressure taps

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BBRI – Belgian Building Research Institute

1

Pressure taps

Eight months ago I was asked a question…





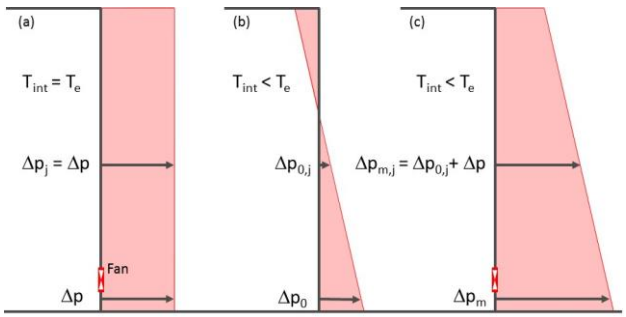
3

Basic principle of measurement

The principle of the buildings airtightness measurement method (ISO 9972)

is to make the link between
the airflow rate generated by the fan
and the induced pressure difference

Additivity of pressure differences



Airflow rate generated by the fan
induces a pressure difference that is added
to the natural pressure difference
(or zero-flow pressure difference)

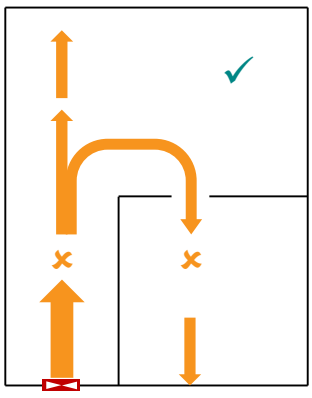
What do we want to measure?

We want to measure
the pressure difference generated by the fan

Therefore we need

- A right measurement place inside the building
- A stable pressure reference
- A correct measurement method

Pressure tap inside the building



Any place may be convenient

But where air velocity
is not negligible

- Difficult to measure
  total pressure p_t

Better to measure static
pressure at quiet place

- Dynamic pressure $p_d \cong 0$
- So $p_t = p_s$

Pressure reference outside the building

In free field

Outside pressure =
atmospheric pressure (static) +
wind pressure (dynamic)

Since wind is always fluctuating

Better to take static pressure as a reference

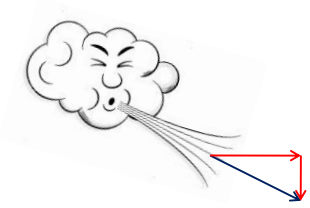
- More stable reference
- Static pressure tap

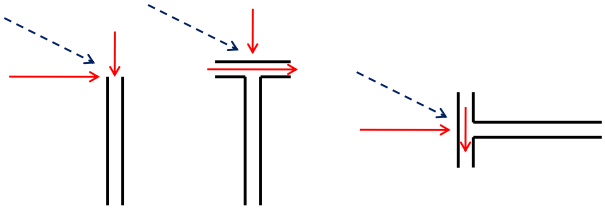
Static pressure tap



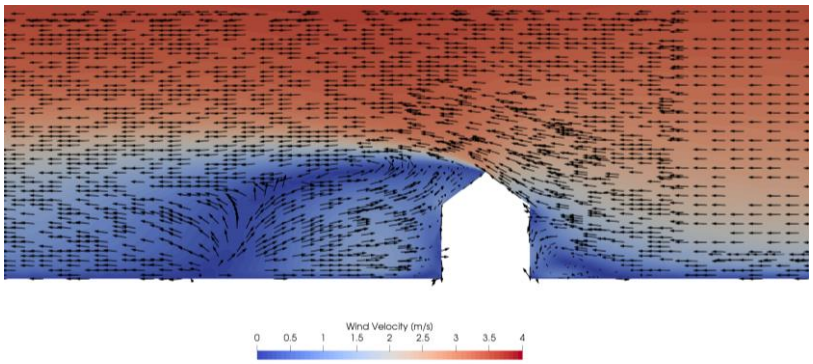








Pressure close to obstacles or building



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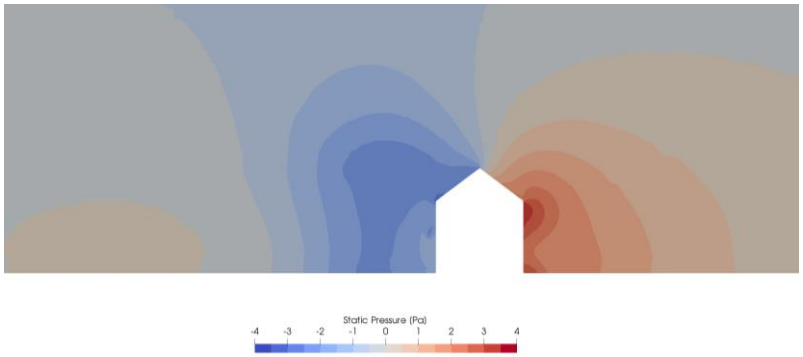
Pressure close to obstacles or building



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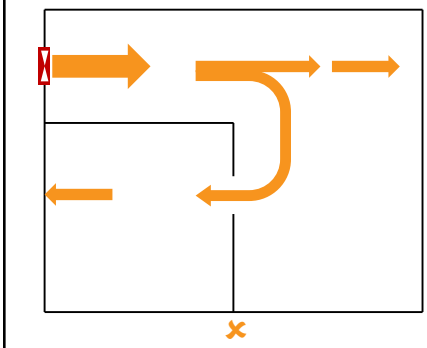
Pressure close to obstacles or building





✓

Better to avoid static pressure generated by the wind

Exterior pressure tap

- some distance away from the building
- not close to other buildings or obstacles

Change in the equilibrium internal pressure

Equilibrium internal pressure is affected by

- Wind speed and direction
- Outside temperature
- Inside temperature

It cannot be isolated from the pressure difference generated by the fan

Possible changes are estimated by zero-flow pressure measurements

Experimental results

Repeatability tests

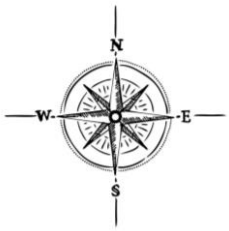
- 6 repetitions x 7 pressure taps
- Wind – About 4 Beaufort





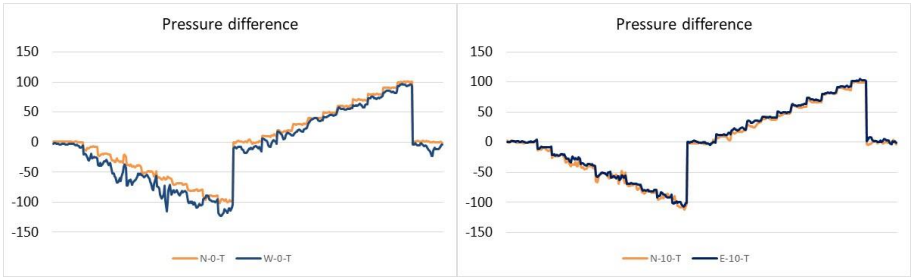
Experimental results





N-10-B
N-10-S
N-10-T
10 m
N-0-T
W-7-T
W-0-T
E-10-T
7 m
10 m

Example of measured pressure differences



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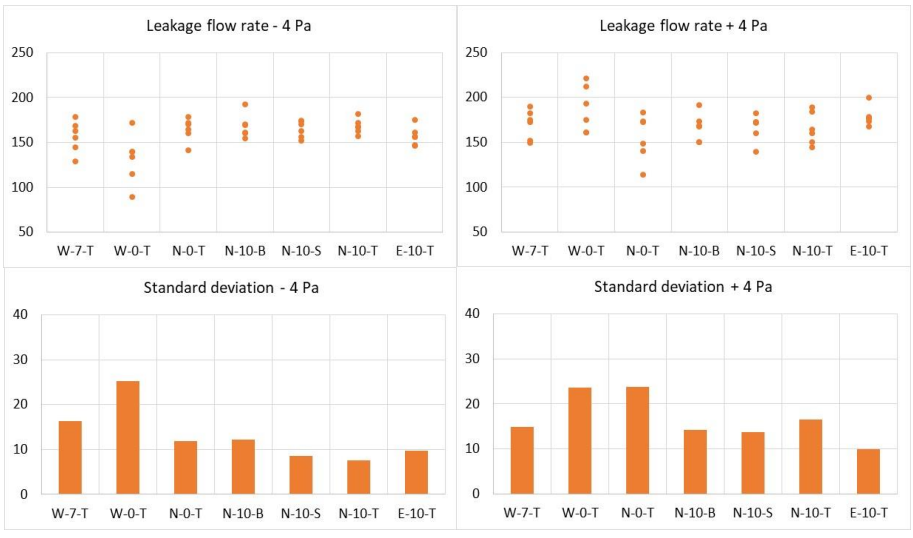

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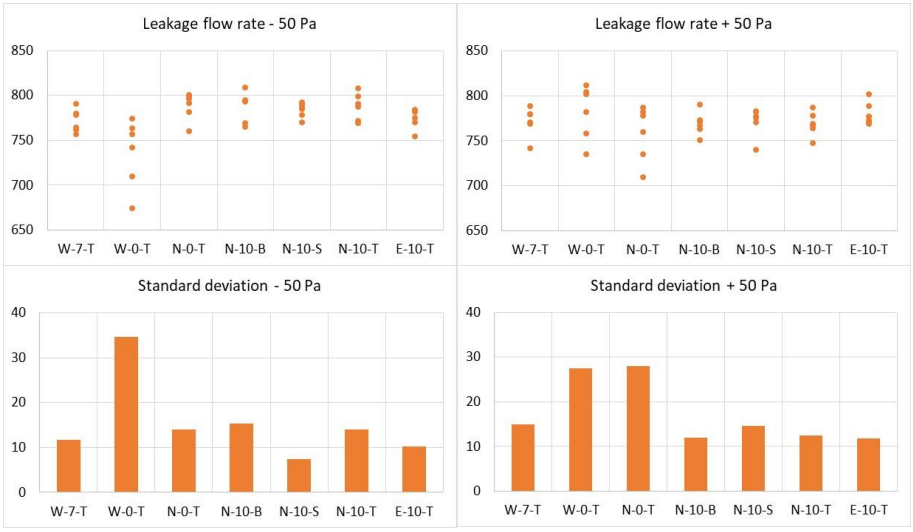

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Recommendations

Ensure that interior and exterior pressure taps are not placed within the draught caused by the air moving equipment

Ensure that the interior pressure tap is not placed in a zone of possible draught

- e.g. corridor or door opening

Especially in windy conditions, ensure to place the exterior pressure tap some distance away from the building, but not close to other buildings or obstacles

Ensure the exterior pressure tap is designed to measure static pressure only

19

Quantification of uncertainty in Zero-Flow pressure approximation

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Entreprises Jacques Delens

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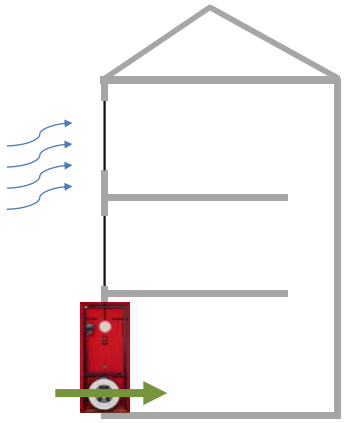
AirPath$_{50}$ Project supported by
innoviris.brussels
empowering research

1

Wind pressure and stack effect: bias in Δp



Fan
➔ Δp_{fan}

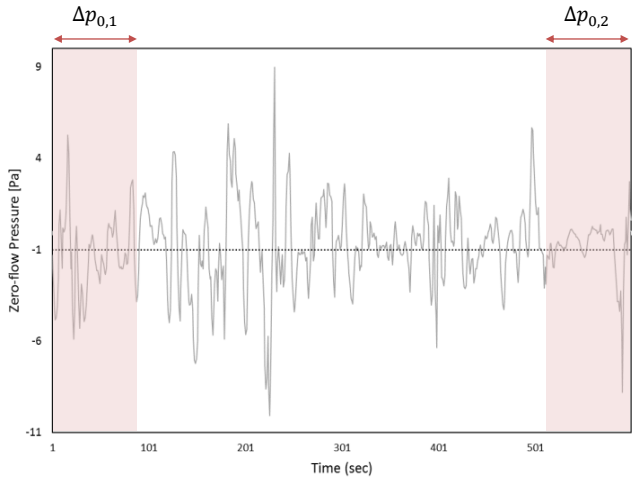
Wind Pressure
Stack effect
➔ Δp_0

$$\Delta p_m = \Delta p_{fan} + \Delta p_0$$

Biases due to wind pressure and stack effect are handled by the measurement of Δp_0

2

Approximation for zero-flow pressure



Hypothesis:
Δp_0 constant
$\Delta p_0 = \frac{\Delta p_{0,1} + \Delta p_{0,2}}{2}$

3

Uncertainty in zero-flow pressure

Δp_0 measurement $u(\Delta p_{0,m})$ (precision error)
Δp_0 approximation $u(\Delta p_{0,a})$ (modelization error)

$$\boldsymbol{u(\Delta p_0) = \sqrt{\frac{u(\Delta p_{0,m1})^2 + u(\Delta p_{0,m2})^2}{4} + u(\Delta p_{0,a})^2}}$$

1. **Why do we have to compute this modelization error ?**
2. **How do we quantify it ?**
3. **What is its impact on fan pressurization measurement ?**

4

Why do we have to compute this uncertainty?

The commonly used method (OLS) assumes
- Constant uncertainty along y-axis ($\ln(q_i) = y_i$)
- Negligible uncertainty along x-axis ($\ln(\Delta p_i) = x_i$)

Questioned by many authors (Sherman and Palmiter, Delmotte, Okuyama and Onishi, etc.)

Alternative methods suggested in literature ➔ Weighted methods

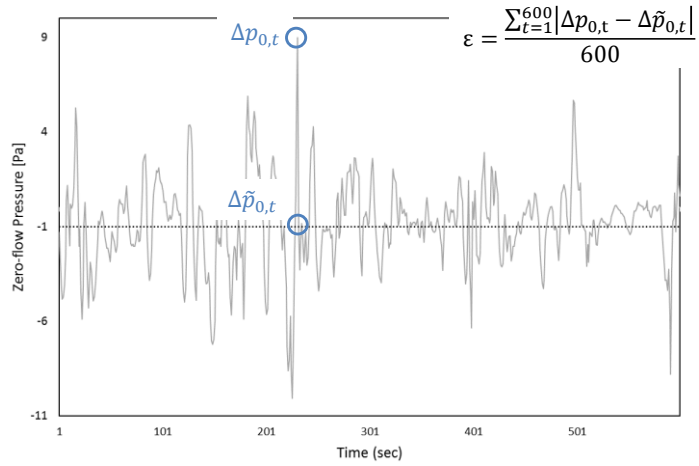
x_i becomes $v_i = \frac{x_i}{u(x_i)} = \mathrm{f}\left(u(\Delta p_m)\,;u(\Delta p_0)\right)$

y_i becomes $w_i = \frac{y_i}{u(y_i)}$



How do we quantify $u(\Delta p_{0,a})$

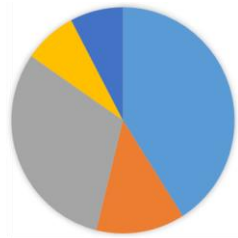
- Zero-flow pressure test (14 minutes)
- Compute ε (uncertainty indicator) for each test

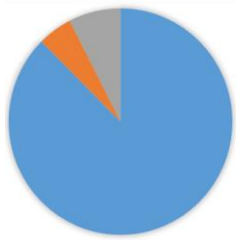




40 zero-flow pressure tests on 30 different units







Limitations:
- no high-rise buildings
- $>$ 80% of Volume $<$ 500 m³

7

Multiple regression analysis

Tested variables

$\Delta p_{0,a}$	Zero-flow pressure approximation
Δ	Difference between pre and post zero-flow pressure measurements
σ	Standard deviation of the zero-flow pressure measurement
w	Wind speed (from a close meteorological station)
V	Volume of the unit
s	Floor level of the tested unit
ΔT	Difference between inside and outside temperature

All variables

Variables	Period 30	
Intercept	-1.2 e-00	**
$\Delta P_{0,a}$	2.9 e-01	**
Δ	-3.1 e-01	N.S.
σ	1.1 e-00	***
w	7.4 e-02	***
V	1.3 e-04	**
s	8.6 e-02	N.S.
ΔT	8.9 e-04	N.S.
Multiple R^2	0.77	

w removed

Variables	Period 30	
Intercept	3.8 e-02	N.S.
$\Delta p_{0,a}$	2.7 e-01	*
σ	1.1 e-00	***
V	8.6 e-05	N.S.
s	4.3 e-02	N.S
Multiple R^2	0.64	

V, s and $\Delta p_{0,a}$ removed

Variables	Period 30	
Intercept	1.1 e-01	N.S.
σ	9.8 e-01	***
Multiple R^2	0.55	

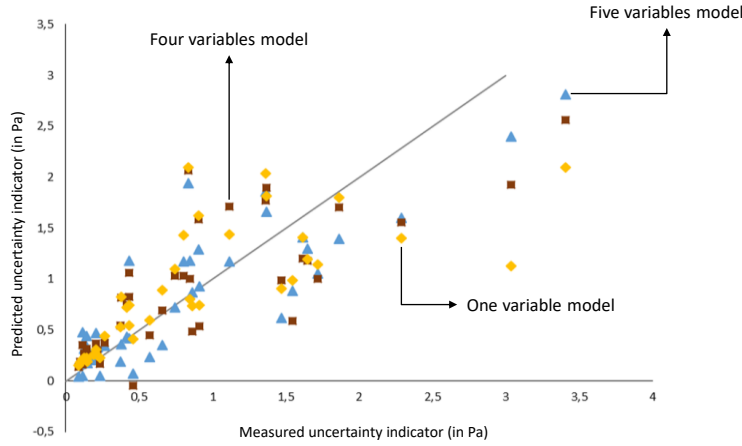
$$\varepsilon = 0.11 + 0.98 * \sigma(\Delta p_{0,m})$$

$$\varepsilon = 0.04 + 0.27 * \Delta p_{0,a} + 1.1 * \sigma + 8.6\, e^{-5} * V + 0.04 * s$$

$$\varepsilon = -1.2 + 0.30 * \Delta p_{0,a} + 0.85 * \sigma + 0.07 * w + 1.3\, e^{-4} * V + 0.12 * s$$

8

Predicted vs. Measured uncertainty indicator



9

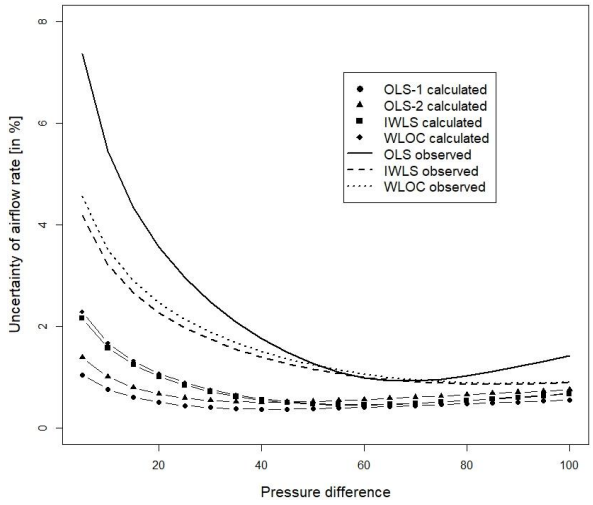
What is the impact of changing regression?

- Journal paper under submission
- 30 fan pressurization tests on the same apartment
- For each test ➔ n, C, $Q_{5\rightarrow100}$, $u(n)$, $u(C)$, $u(Q_{5\rightarrow100})$

Observed uncertainty:	vs	Calculated uncertainty:
$\sigma(Q_{5\rightarrow100})$		$\mu\left(u(Q_{5\rightarrow100})\right)$

10

Results from comparison between methods



Observed uncertainty with OLS > with IWLS/WLOC

Δ between observed and calculated uncertainty with OLS > with IWLS/WLOC

Even for the best case, Δ between observed and calculated uncertainty is still important

11

Discussion

- Requirements on $\sigma(\Delta p_0)$?

  Since $u(\Delta p_0)$ highly depends on $\sigma(\Delta p_0)$, shouldn't we have a requirement on this variable in addition to Δp_0 value?

- OLS or weighted methods?

  - Should we continue using OLS (and accept higher uncertainty). Therefore focusing on documenting uncertainty with repeatability test?
  - Should we use alternative methods. Therefore focusing on documenting significant source of errors in fan pressurization test.

12

Thank you

❑ Related publications

Prignon M., A. Dawans, and G. van Moeseke (2019). ***A method to quantify uncertainties in airtightness measurements: Zero-flow and envelope pressure.*** *Energy and Buildings, vol. 188.*

Prignon M., A. Dawans, and G. van Moeseke (2019). ***Quantification of uncertainty in zero-flow pressure approximation.*** *40th AIVC - 8th TightVent & 6th venticool Conference. Ghent, Belgium.*

Prignon M., C. Delmotte, A. Dawans, S. Altomonte and G. van Moeseke. ***Changing the regression method to reduce and better estimate uncertainty in airtightness measurement using fan pressurization test.*** *Under submission process.*

❑ Contact

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Designing a model-scale experiment to evaluate the impact of steady wind on building air leakage measurements

A. Mélois, A. D. Tran, M. El Mankibi, F. R. Carrié, B. Moujalled and G. Guyot

1

Context: wind impact in the literature… some examples

1984, A. K. Persily and Grot
"wind (direction and speed) … significantly interfere with the test pressure differences…..

1986, Dickinson and Feustel
the error due to wind was estimated from 24% to 74% with wind velocity from 2.24 m.s-1 to 4.47 m.s-1 in depressurization tests.

1990, Modera and Wilson
wind is one the 3 main sources of uncertainty for the ELA determination…
- a perfectly steady wind would induce biases on pressure differences measurement;
- the wind turbulences would induce time variations both on pressure difference and airflow rate.

1994, Sherman and Palmiter
errors due to precision included the weather effects (wind and temperature difference) for pressure measurement, especially for low pressure, where the variation of the wind speed may induce fluctuation of the reading

2012, Carrié and Wouters
5 sources of differences… wind and stack effect, reference pressure, data collection protocol and analysis method.

2013, I.S. Walker, M.H. Sherman, J. Joh, W.R. Chan
Study based on analysis of more than 6,000 test performed in different wind conditions. One conclusion: Using single-point methods with fixed value for n reduce the error on the ELA4 for wind speed above 6 m/s

2016, Carrié and Leprince
numerical evaluation of the impact of the wind. ..overall uncertainty at 50 Pa, for a one-point tests method, is 6% and 12% for wind speeds below 6 m.s-1 and 10 m.s-1, respectively. The uncertainty reaches 33% at 4 Pa

2

Objectives

- **Evaluate the reliability of building air leakage measurements results regarding steady wind impact**
  - model-scale experiments
  - controlled laboratory conditions



3

Experimental design

- Fixed parameters:
  - Initial inside and outside temperatures
  - Total leakage area
- Variable parameters:
  - (steady) wind speed (from 0 to 12 $m.s^{-1}$)
  - Leakage areas distribution
  - External pressure tap location

4

Similarity conditions: presentation of the model

- **A simplified single-zone building model:**
  - No internal wall or partition
  - 2 circular leaks
    - 1 opening of the windward façade
    - 1 opening of the leeward façade

- **6 key equations:**
  - pressure difference at leakage sites Δp_i (2 equations);
  - airflow through leakage sites q_i (2 equations);
  - continuity equation;
  - energy conservation equation.

5

Similarity conditions: dimensionless numbers and scale ratios

$\Pi_1 = \frac{\rho_{ref} . {U_{ref}}^2}{p_{ref}}$	$\Pi_2 = \frac{p_{ref} . {A_{ref}}^2}{\rho_{ref} . {q_{ref}}^2}$
$\Pi_3 = \frac{\sqrt{A_{ref}}}{L_{ref}}$	$\Pi_4 = \frac{V_{ref} . U_{ref}}{L_{ref} . q_{ref}}$

$$\Pi_{i,real} = \Pi_{1,model}$$

$$\bar{X} = \frac{X_{ref\ model}}{X_{ref\ real}}$$

$\bar{U} = \bar{p}$	$\bar{p} . \bar{A}^2 = \bar{q}^2$
$\bar{A}^{0,5} = \bar{L}$	$\bar{V} . \bar{U} = \bar{L} . \bar{q}$

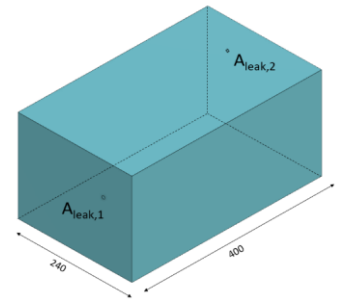
6

Similarity conditions: sizes of the model

Real house → **Reduced model**



	Real house	Model (1/25th)
l [m]	6	0.24
L [m]	10	0.40
h [m]	5	0.20
$Q_{4Pa\text{-}surf}$ [$m^3.h^{-1}.m^2$]	0,6	0.6
Atbat [m^2]	220	0.35
Volume [m^3]	300	0.02
ELA [m^2]	0.014	$2.3*10^{-5}$
Diameter 1 leak [m]	0.095	0.004
S [m^2]	30	0.05



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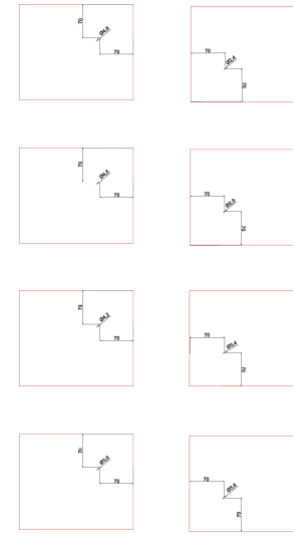
Similarity conditions: sizes of the model

% total leak area (W / L)	*10% 90%*	*20% 80%*	*30% 70%*	*40% 60%*	*50% 50%*	*60% 40%*	*70% 30%*	*80% 20%*	*90% 10%*
Windward Leak diameter[mm]	1,7	2,4	2,9	3,4	3,8	4,2	4,5	4,8	5,1
Leeward leak diameter [mm]	5,1	4,8	4,5	4,2	3,8	3,4	2,9	2,4	1,7



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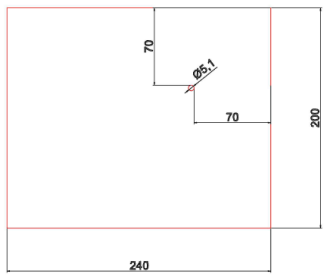

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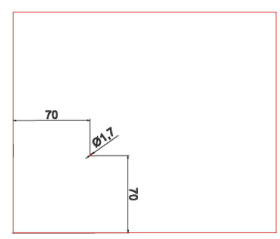


8

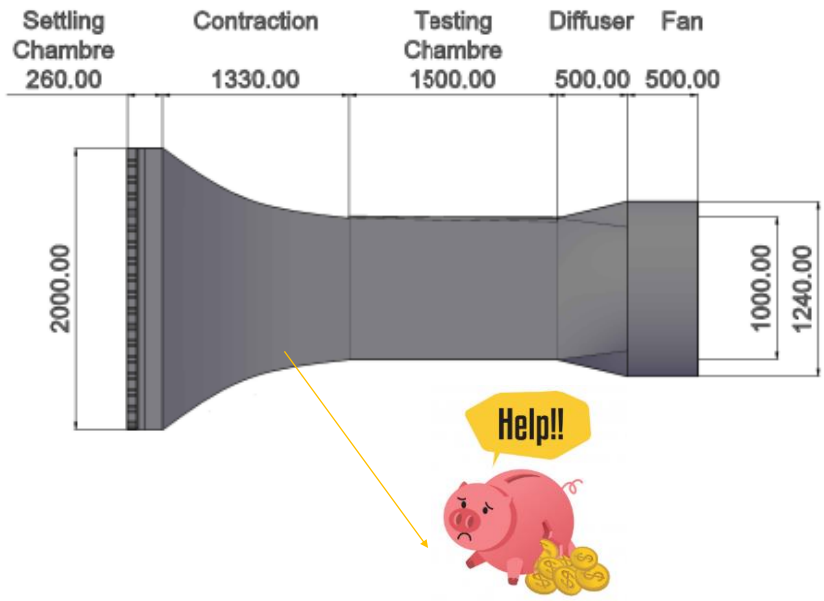
Similarity conditions: airflows to be measured

- **Estimate the airflow providing by the fan pressurization device for :**
  - Pressure stations from **10 Pa to 70 Pa**
  - Wind speed from **0 to 12 m.s^{-1}**
  - **9 configurations**

Configuration	1	2	3	4	5	6	7	8	9
	10% 90%	20% 80%	30% 70%	40% 60%	50% 50%	60% 40%	70% 30%	80% 20%	90% 10%
q_{pres}MIN [l/s]	0,09	0,09	0,09	0,09	0,08	0,07	0,06	0,05	**0,03**
q_{pres}MAX [l/s]	**0,31**	0,29	0,27	0,26	0,25	0,25	0,25	0,25	0,25

9

Similarity conditions: sizes of the tunnel



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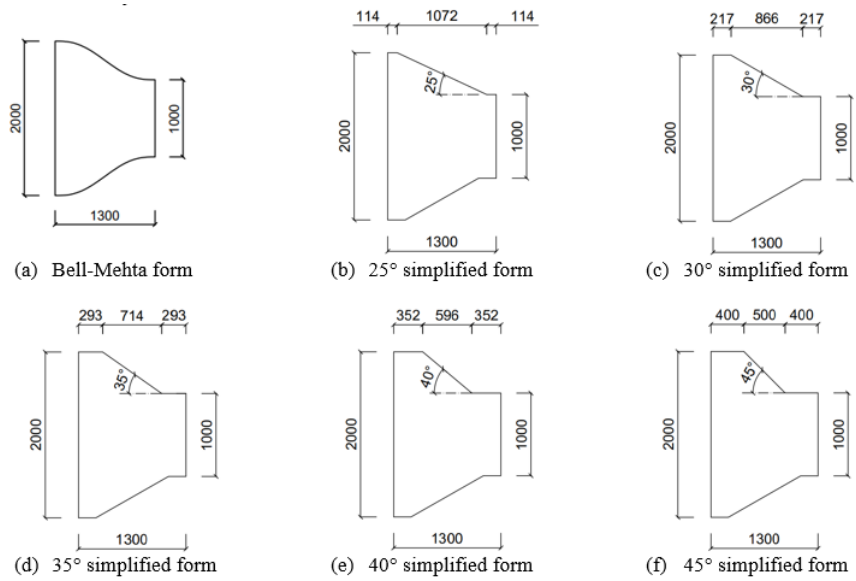
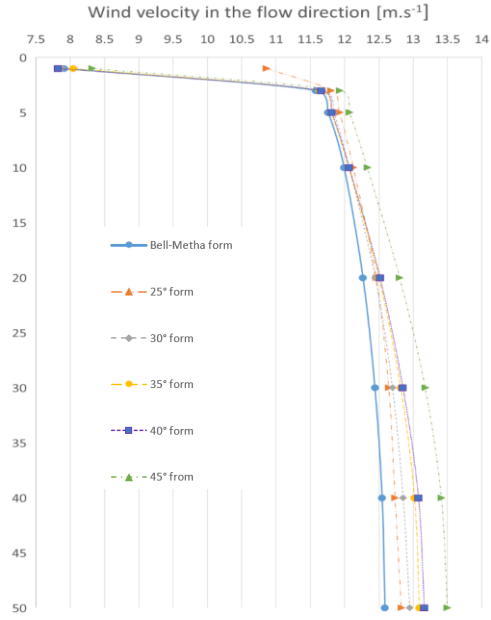
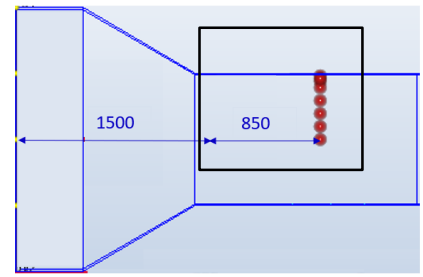
Similarity conditions: sizes of the tunnel

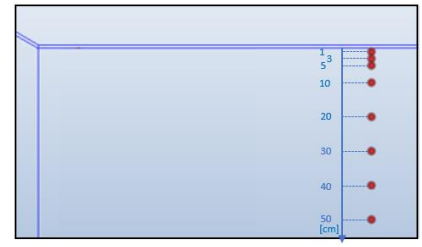


11

Similarity conditions: sizes of the tunnel







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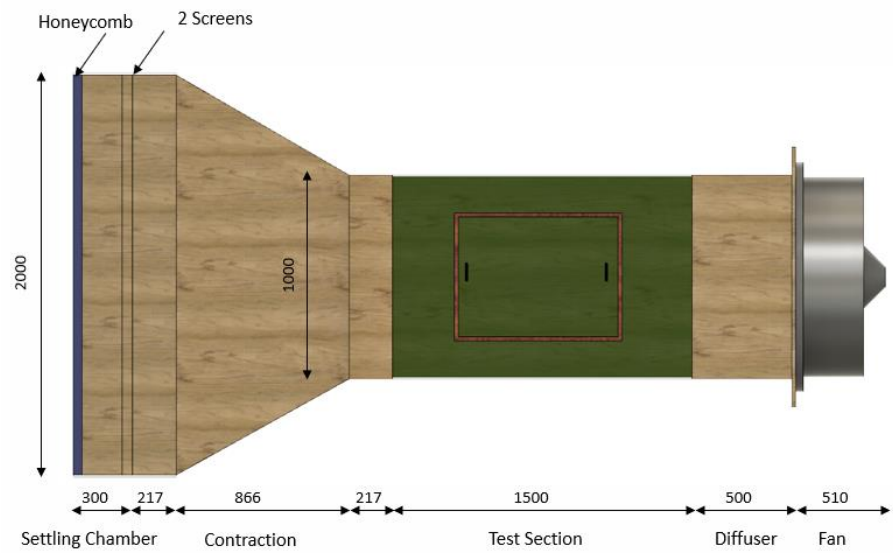
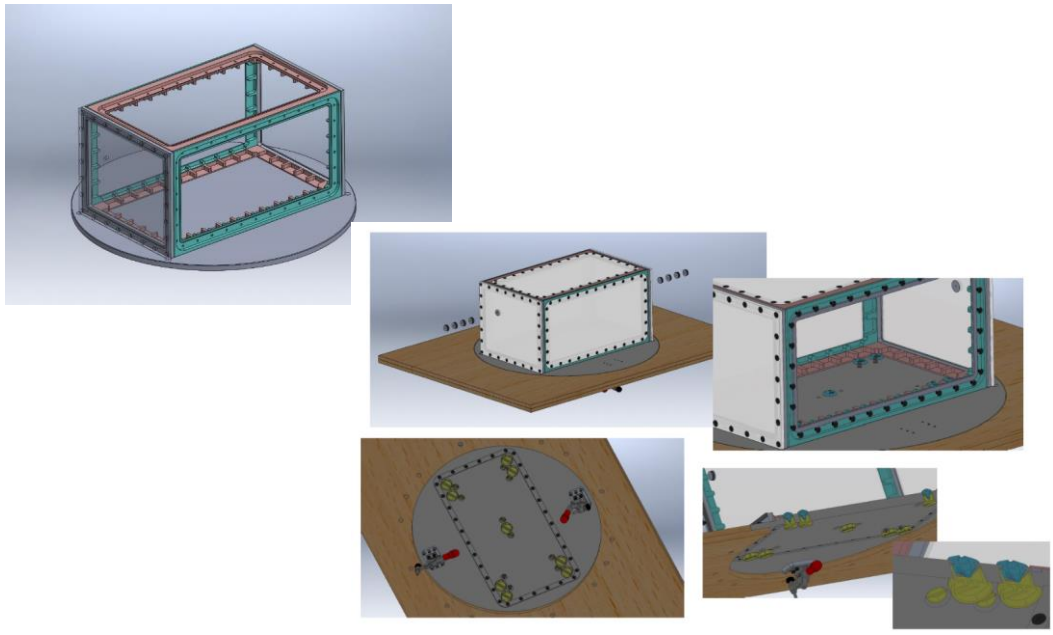
Similarity conditions: sizes of the tunnel



13

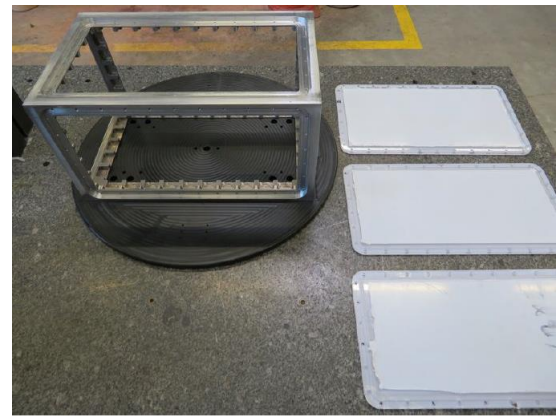
Manufacturing of the model



14

Manufacturing of the model





15

Installation of the fan pressurization device



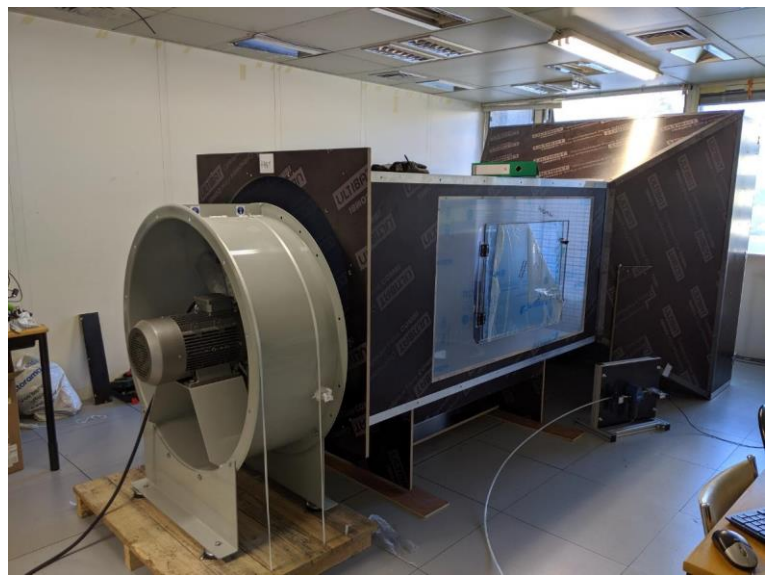
16

Assembly of the wind tunnel



17

Assembly of the wind tunnel



18

Thanks

adeline.melois@cerema.fr

40th AIVC Conference
15-16 October 2019, Ghent, Belgium

CFD modelling of fan pressurization - The impact of wind on airtightness tests



Dimitrios Kraniotis | dimkra@oslomet.no

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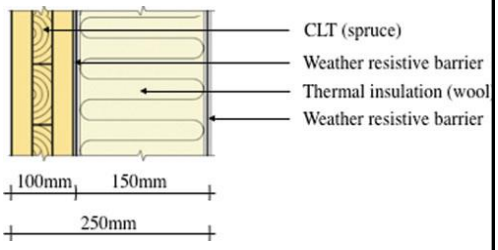
1

Some history in the countryside around Oslo..





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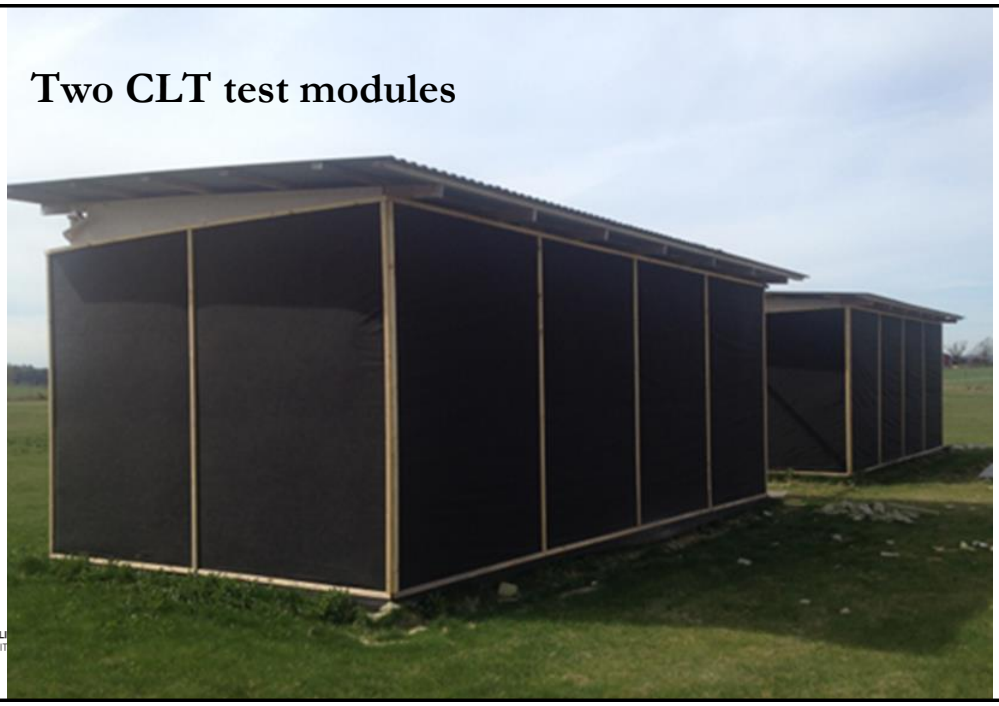
2

Two CLT test modules



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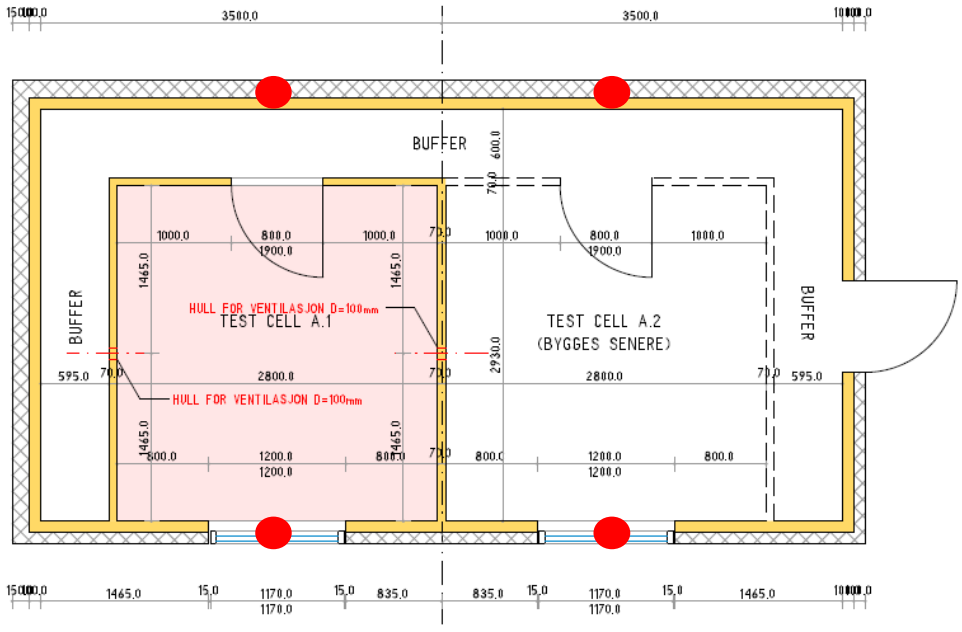
3

4 holes (+ 4)

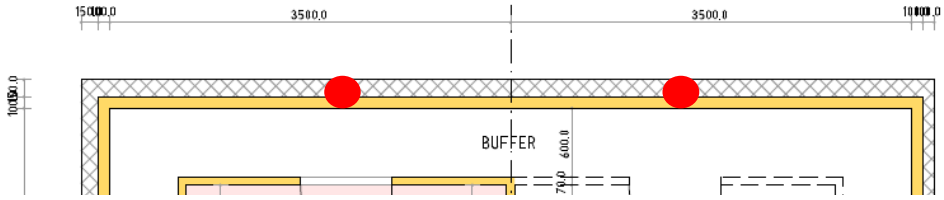






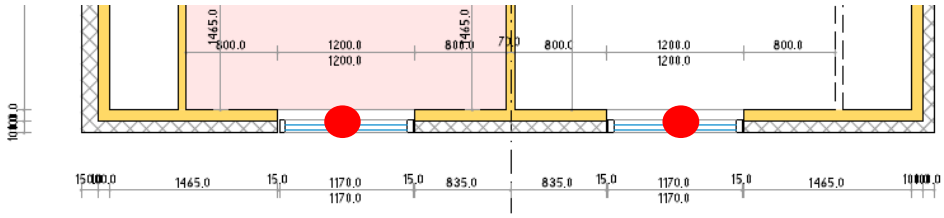
PLAN MODUL A 1:50

4



These 4 holes contribute to: 25 m^3/h at 50 Pa (6.2 m^3/h each)

Volume of enclosure: V = 58.8 m^3



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PLAN MODUL A 1:50

5

Methodology – Computational Fluid Dynamics

- Numerical simulation of cracks and small openings: **Very expensive!**
- Assumption of an airtight envelope – Only leakages: 4 holes
- n_{50} = 25 m^3/h / 58.8 m^3 = 0,43 h^{-1} (passive house standard ≤ 0.6 h^{-1})

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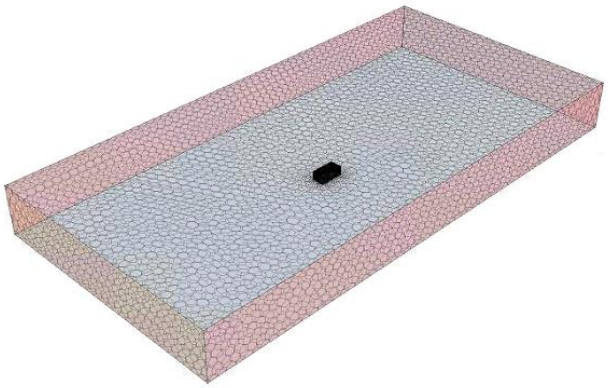
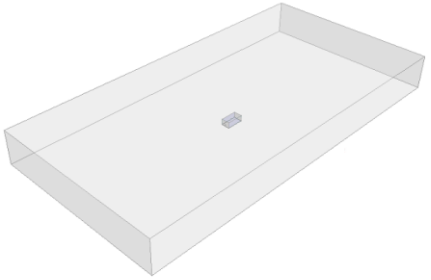
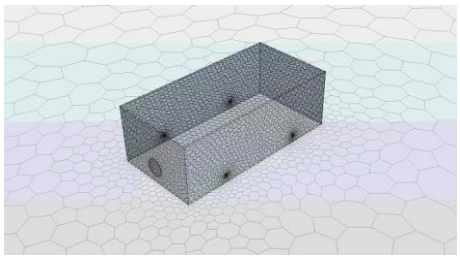
6

Methodology – Computational Fluid Dynamics

- Domain according to standard guidelines
- Around 5 million cells







Methodology – Simulation of the pressurization test

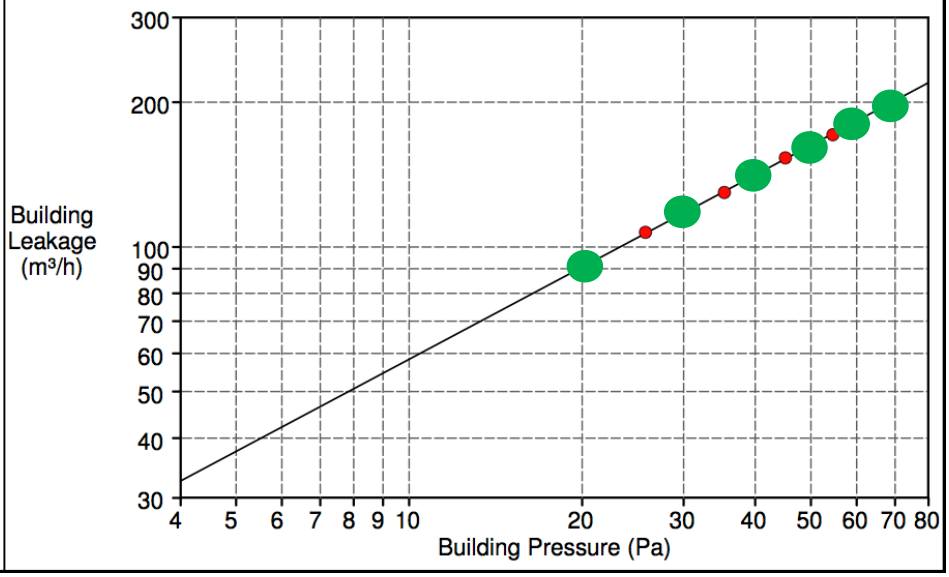
Run **quasi-steady** simulations

From **70 to 20 Pa**

U=0 m/s, 1 m/s, 3 m/s, 6 m/s

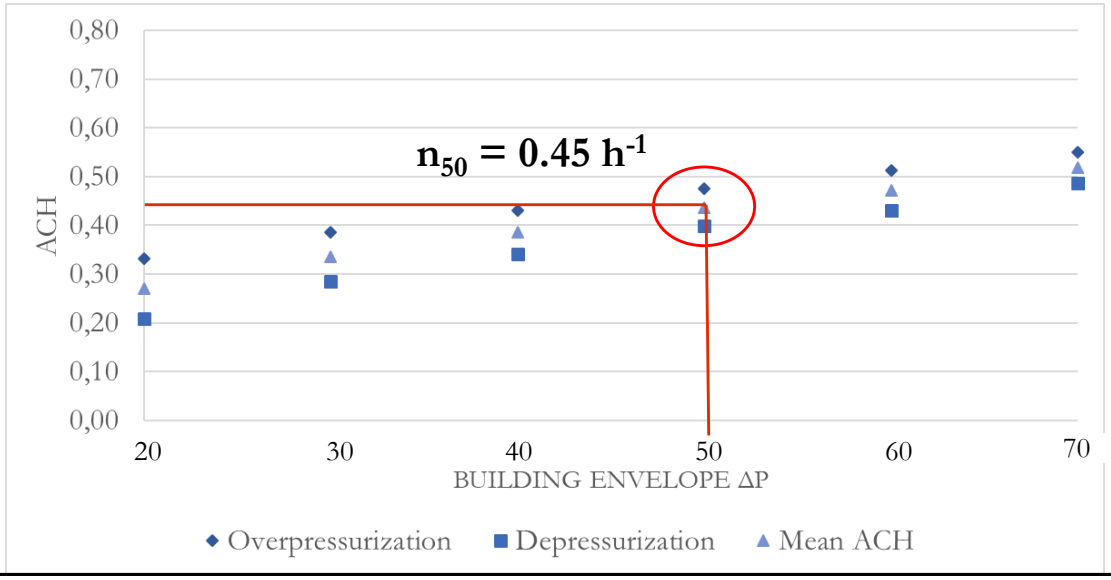
Fan: **windward/ leeward**

Run **several times** to eliminate the simulation convergence error

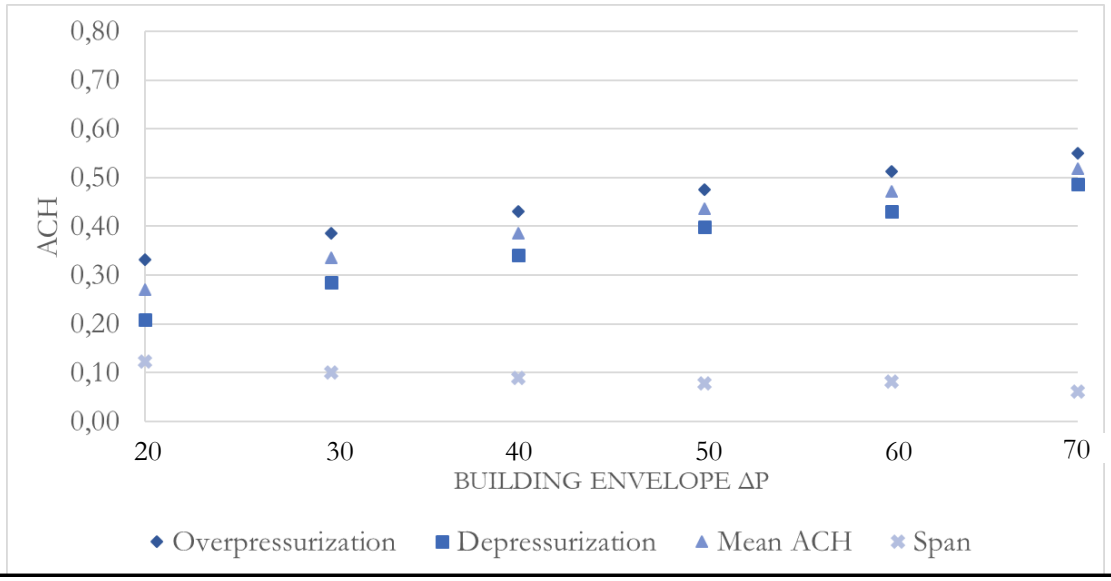


Results – Fan in the windward side

Wind velocity U = 0 m/s

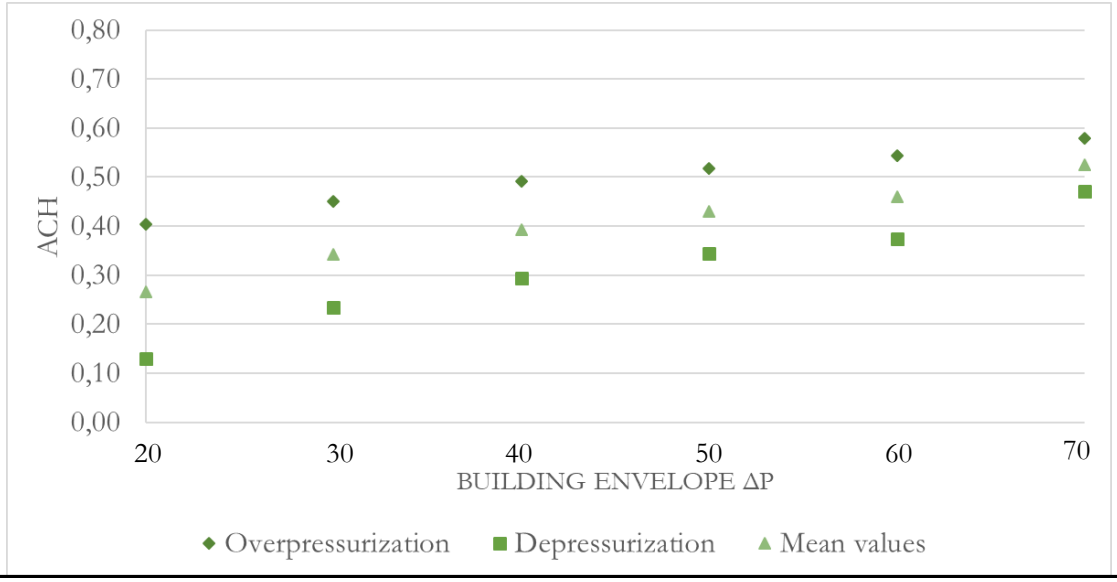


Wind velocity U = 0 m/s



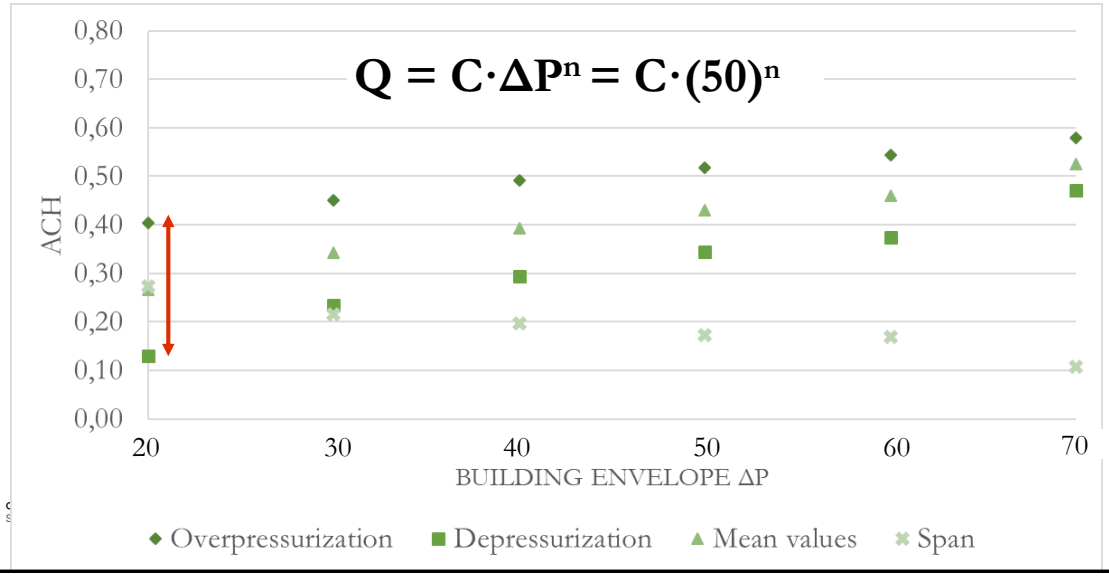
11

Wind velocity U = 1 m/s



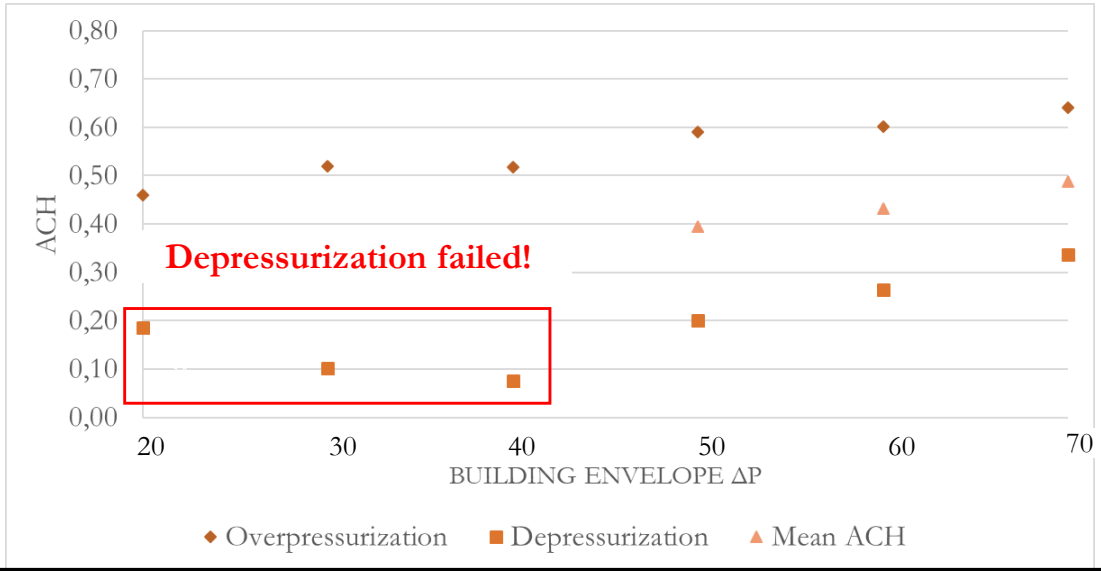
12

Wind velocity U = 1 m/s



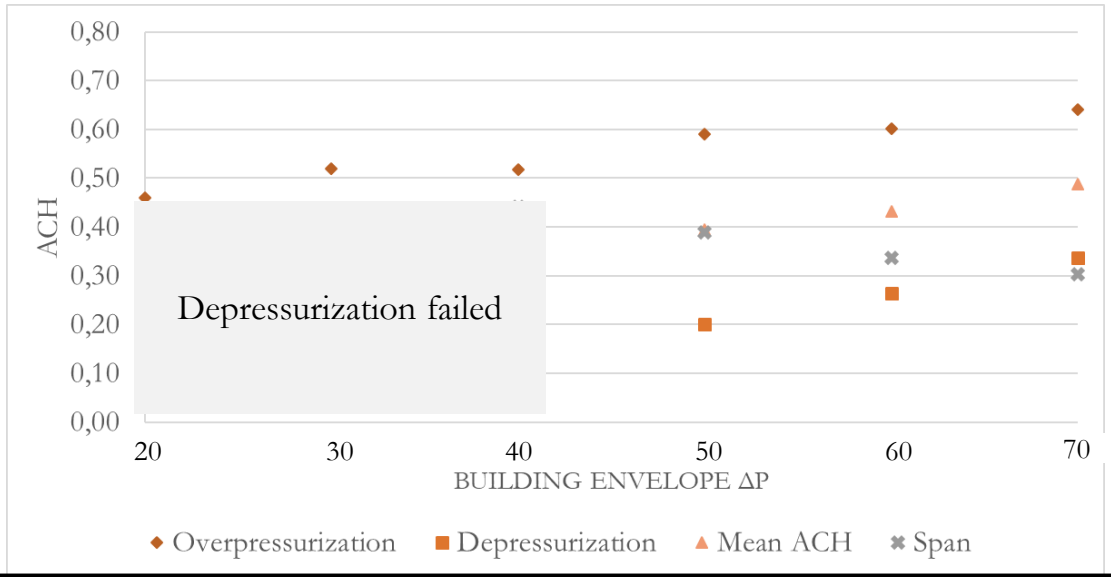
13

Wind velocity U = 3 m/s



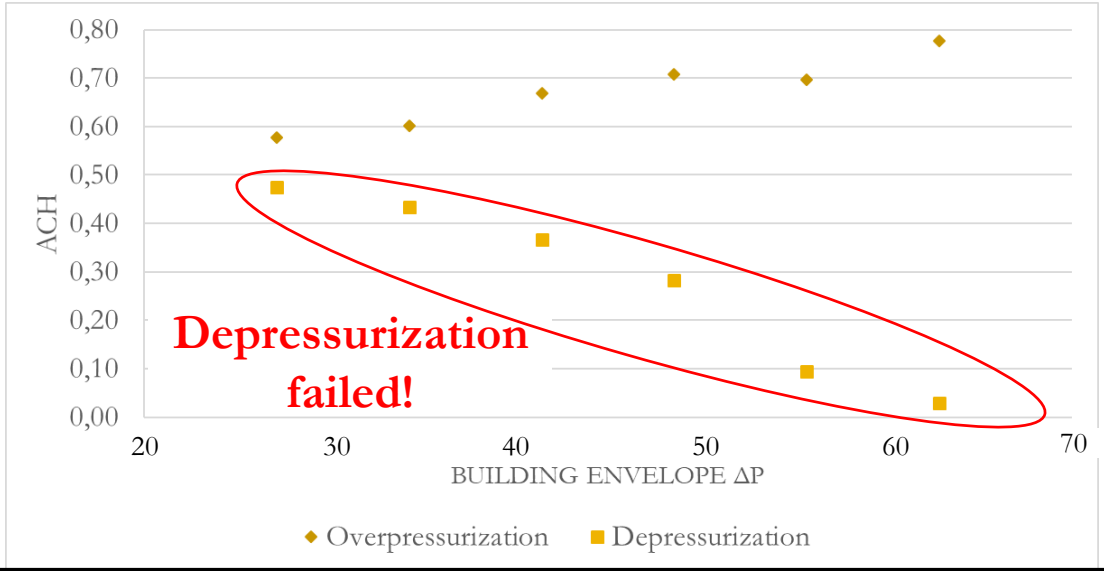
14

Wind velocity U = 3 m/s



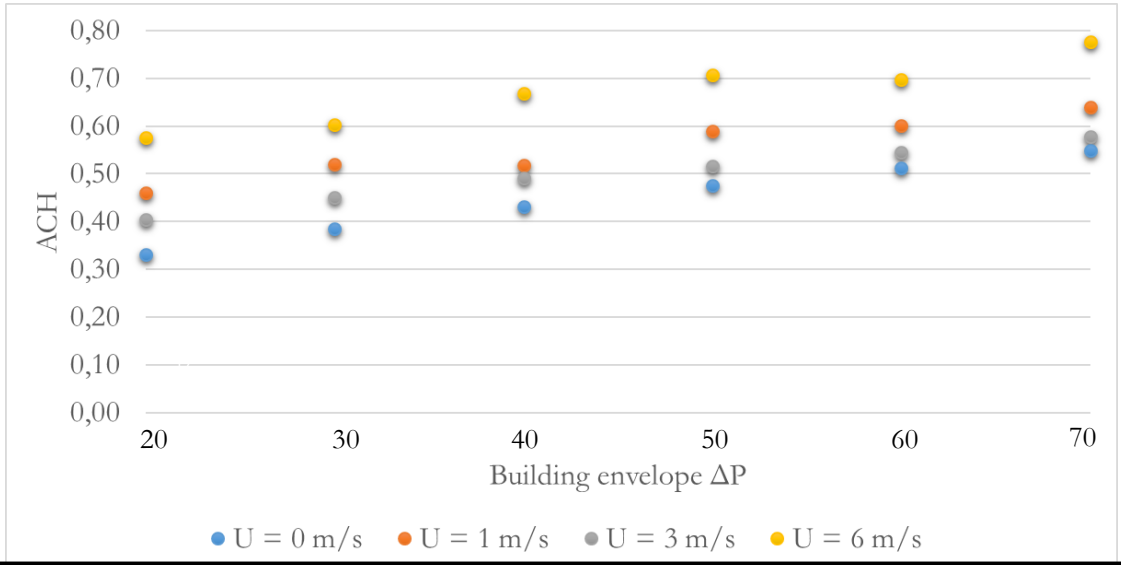
15

Wind velocity U = 6 m/s



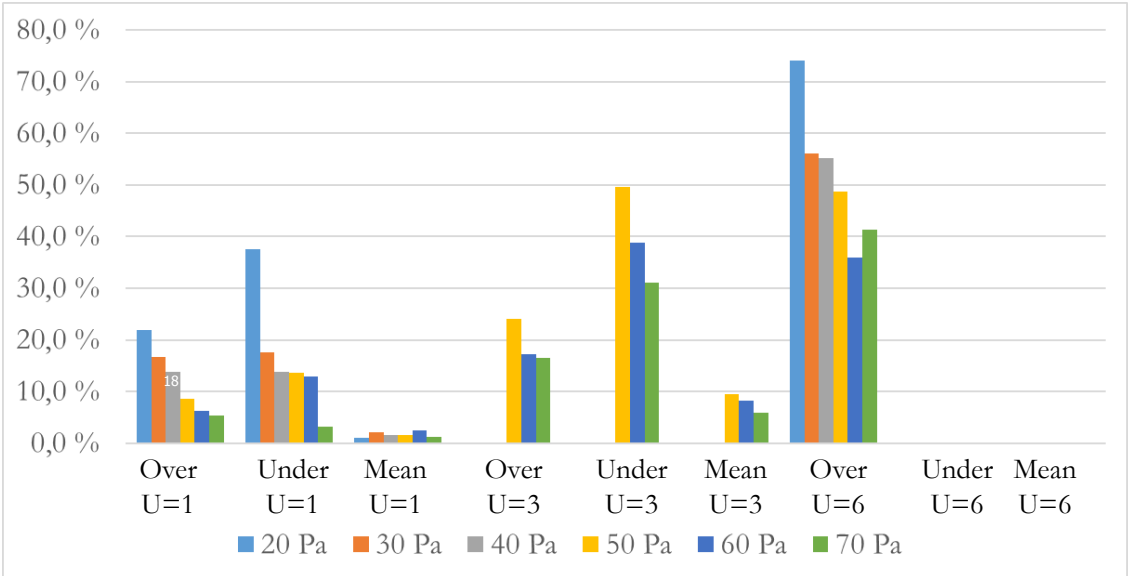
16

Comparison - Overpressurization



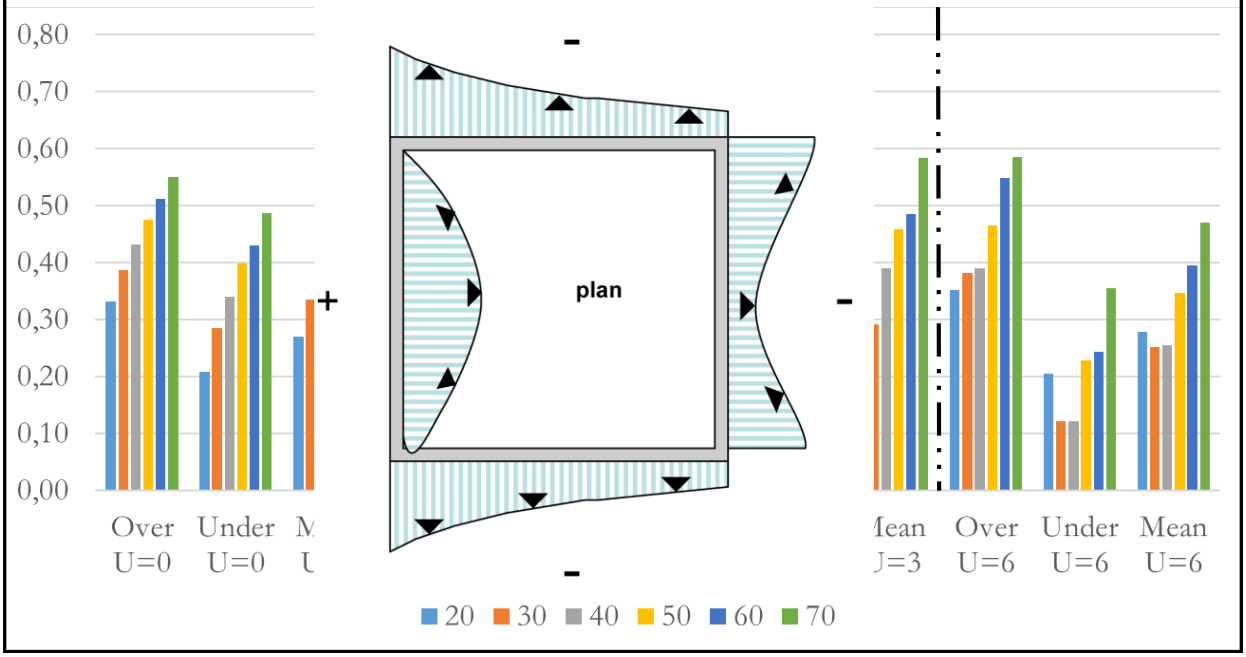
17

Deviation from the no-wind measurements



18

Results – Fan in the leeward side



Conclusions

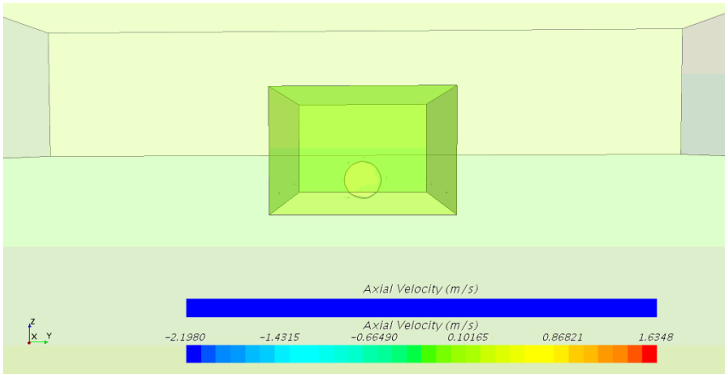
- the overpressurization results under windy conditions give significantly higher results (when fan windward)
- unable to succeed underpressurization (e.g. in this case under 40 Pa when U = 3 m/s)
- the underpressurization totally failed (when U = 6 m/s)
- performing both under- and overpressurization tests reduce the error due to the impact of wind. Does not help for U ≥ 3 m/s.

- Even when the fan is placed leeward, wind with U ≥ 6 m/s is expected to disturb the depressurization test, resulting in significant errors (e.g. 40% – 60%)

Conclusions – Quality of simulations

- Numerical simulation of cracks and small openings: **Very expensive!**
- Behavior of envelope, i.e. underpressurization & overpressurization, must be simulated: **moving mesh**

Thank you! Questions?



Using co-simulation between EnergyPlus and CONTAM to develop IAQ and energy-centric demand-controlled ventilation systems

Maria Justo Alonso, W. Stuart Dols, Hans Martin Mathisen
Maria.j.Alonso@ntnu.no





1

Pollutants

- Not all hazardous for health, nor the same emission rates.
- WHO's values=> threshold for health effects.
- Many pollutant levels based on perceived odour or general irritation.
- CO_2 concentrations may be associated with cognitive performance and health issues. Not conclusive research
- Others concluded on lower respiratory SBS symptoms already when peak CO_2 concentrations are below 1000 ppm

CO_2

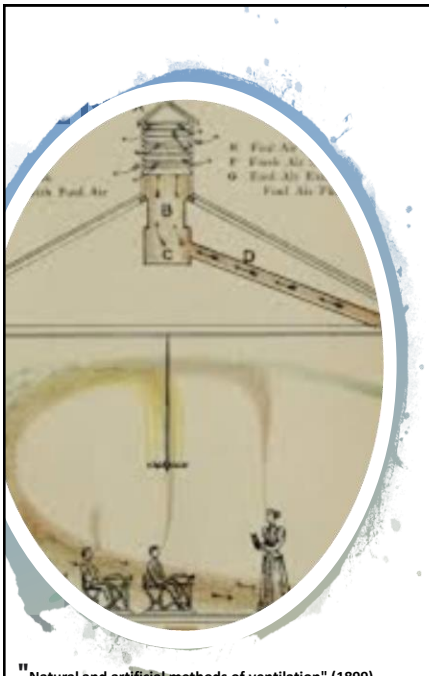
VOC

PM





2



"Natural and artificial methods of ventilation" (1899), R Boyle & Son, Ltd. (London)

Ventilation

- Ensures good indoor air quality by controlling indoor contaminant levels and thermal comfort.
- To reduce indoor contaminant levels:
  - Reduce or remove the source,
  - Remove contaminants from the indoor air,
  - Filtration or dilute with air having lower or no contaminant levels.

3

ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES

Recirculation of exhaust air?

- Application requirements for outdoor and recirculation ventilation vary between countries

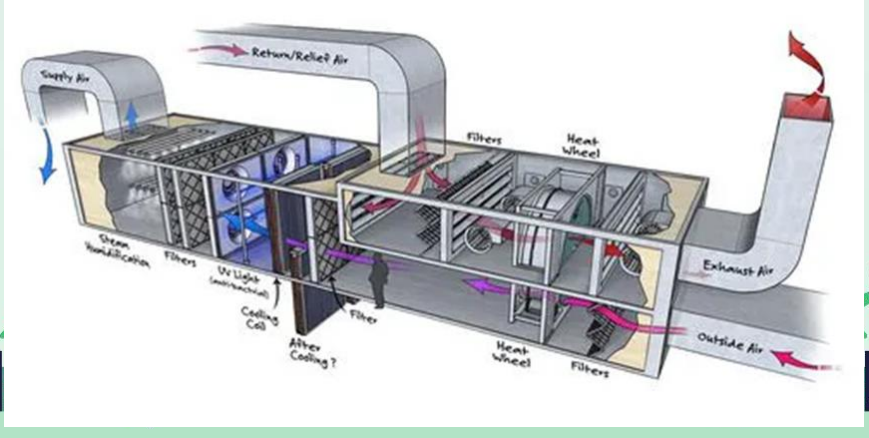


Photo: VR HVAC SYSTEM, http://www.esuppliersindia.com/vr-hvac-system/single-skin-air-handling-unit-pr5522413-sFP-swf.html

4

Recirculation of exhaust air?

- Application requirements for outdoor and recirculation ventilation vary between countries
- Jaakkola et al. (1994) looks into the effect of recirculating ventilation air on SBS symptoms.
- Differential impact of 0 % and 70 % recirculation rates
- 70 % recirculation rates, assuming acceptable outdoor contaminant levels, NO adverse health effects.
- However, they only looked at SBS symptoms and did not correlate it with building energy use.

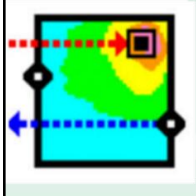
5

CONTAM- EnergyPlus

From ContamX to EnergyPlus:
- Zone infiltration airflows,
- Inter-zone airflows ,
- Controls values user-defined values exposed via the CONTAM controls network, e.g., a signal calling for ventilation airflow due to an elevated contaminant level.

Contam FMU
DLL

EnergyPlus to ContamX:
- Zone temperatures and relative humidity
- Ventilation system airflows for zone supply and return airflows,
- Outdoor airflow fractions of outdoor airflow controllers,
- Exhaust fan airflows,
- Outdoor environment data including temperature, barometric pressure, wind speed and wind direction,
- Output variables user-selected from numerous EnergyPlus output variables.



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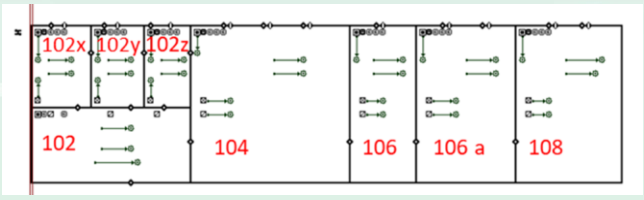
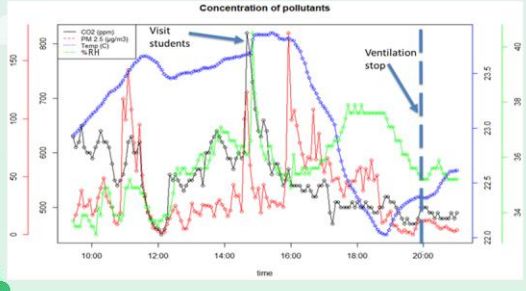


	102 (and x, y, z)	104 (5 occupants)	106	106a	108 (4 occupants)
Arrival	8:00	8:00-9:30	8:30	8:15	8:00-9:30
Lunch break	11:30-12:00	11:30-12:00	No vacancy	12:15-12:45	11:30-12:00
Departure	16:00	17:00-18:30	16:30	17:00	17:00-18:30
Weekends	Vacant	Vacant	Vacant	Vacant	Vacant

7

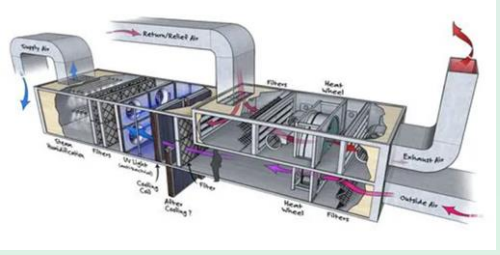
Parameter	Sensor type	Uncertainty
Relative humidity	Capacitive	±3 % RH at 25°C
CO_2	Non dispersive infrared (NDIR)	±10 % (500 ppm to 1500 ppm)
Temperature	10K NTC Thermistor	± 0.4 in the selected range
Particle concentration	Optical sensor	±10 %



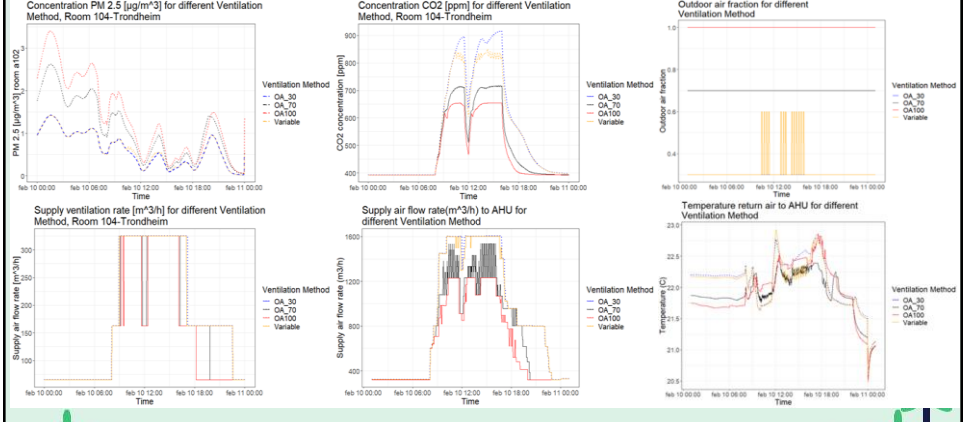
8

Simulated cases

Name	Outdoor Air Fraction Control	Supply Airflow Control
OA_100	Constant 100 % OA	$CO_2 \leq 400$ = 20% DAFR $400 < CO_2 \leq 1000$ = 50% DAFR $1000 < CO_2$ = 100% DAFR
OA_70	Constant 70 % OA	
OA_30	Constant 30 % OA	
Variable	$CO_2 \leq 750$ = 30 % OA; $750 < CO_2 \leq 900$ = 60 % OA; $900 < CO_2$ = 80 % OA	



9



10

Results

↓%OA, ↑ # discomfort hours

	100 % OA (h)	70 % OA (h)	30 % OA (h)	Variable (h)
Time setpoint not met during occupied heating	816	905	1263	1233
Time not comfortable based on simple ASHRAE 55-2004	1976	1990	1958	1966





Results

↓%OA, ↓ Energy use

	100 % OA (kWh/m²a)	70 % OA (kWh/m²a)	30 % OA (kWh/m²a)	Variable (kWh/m²a)
Heating	188	137	67	73
Fans	28	30	37	36
Total	216	167	104	109





Conclusions

- % Recirculation of extract air and required ventilation airflow rates are correlated. A minimum level of OA should always be maintained.
- DCV should base on several pollutants, e.g. CO_2, $PM_{2.5}$, temperature
- Pollutant levels and energy use are correlated, and the ventilation control needs to be programmed considering a hierarchy.
- The study presented here serves as the initial phase of a project that will study, in detail, how to reduce energy use in ventilation while ensuring IAQ in a multidisciplinary way.





13

Acknowledgements

The authors gratefully acknowledge the support from the Research Council of Norway and several partners through the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN), project number: 286183. The Indoor Air Quality and Ventilation Group at the National Institute for Standards and Technology is also hereby acknowledged.





14

ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES

Thank you for your attention!!!

Maria.j.alonso@ntnu.no





VENTILAIRSEC GROUP

PERFORMANCES OF A DEMAND-CONTROLLED MECHANICAL SUPPLY VENTILATION SYSTEM UNDER REAL CONDITIONS: INDOOR AIR QUALITY AND POWER DISTRIBUTION FOR THERMAL COMFORT

Clément LAFFETER – R&D engineer and Innovation Manager

40th AIVC – 15th & 16th October 2019, Ghent

AIVC GHENT UNIVERSITY TightVent Europe venticool INIVE

VENTILAIRSEC GROUP

1

SUMMARY

1. EXPERIMENTAL FIELD
2. VENTILATION SYSTEM DESCRIPTION
3. MONITORING & ANALYSES
4. RESULTS
5. CONCLUSION & PROSPECTS

2

1. EXPERIMENTAL FIELD



PART OF COMEPOS PROJECT

Location
Brest, Brittany

House type
180 m², 2 floors

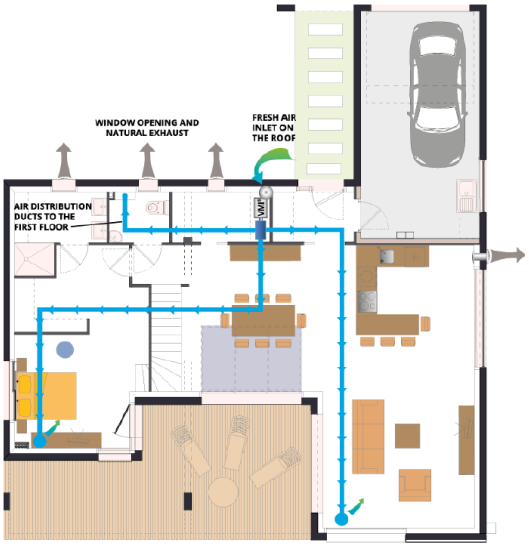
Ventilation system
Humidity-controlled mechanical supply ventilation (VMI in French)

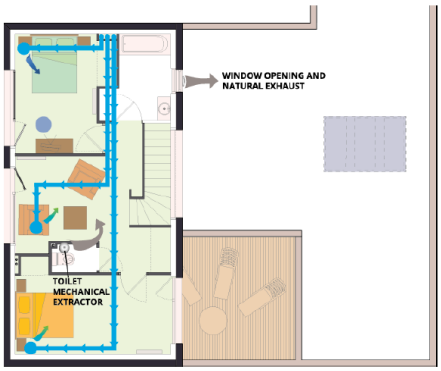
Heating and cooling production, domestic hot water
Geothermal water to water heat pump

Heating and cooling emission
Radiative ceilings and VMI with heat exchanger

3

2. VENTILATION SYSTEM DESCRIPTION





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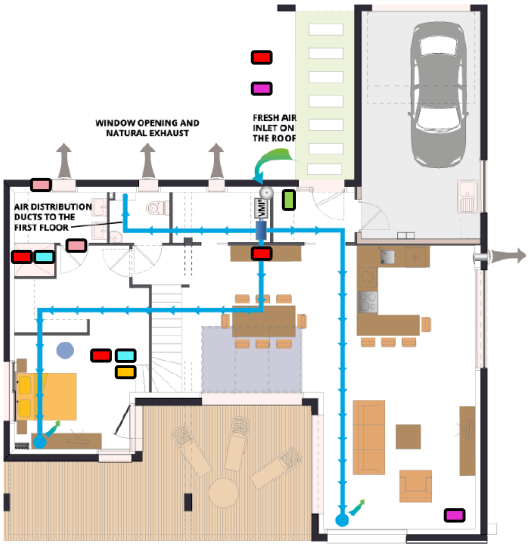
3. MONITORING & ANALYSES



- Temperature [° C]
- Relative humidity [%]
- CO_2 concentration [ppm]
- PM 2.5 concentration [µg/m^3]
- Thermal power and energy [W ou kW.h]
- Opening detector

3. MONITORING & ANALYSES

CONTAINMENT IN THE MASTER BEDROOM
Analysis of the CO_2 concentration

HUMIDITY EVACUATION IN THE BATHROOM
Analysis of the absolute humidity

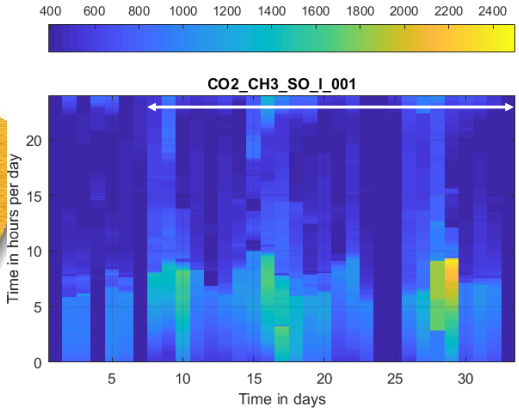
FILTRATION
Analysis of the I/O ratio

HEAT EXCHANGER
Analysis of the supplied air temperature

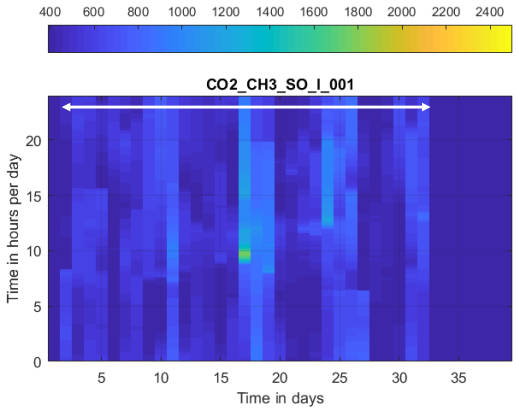
4. RESULTS

CONTAINMENT IN THE MASTER BEDROOM

Analysis of the CO_2 concentration



2017/12/25 to 2018/01/18: VMI OFF – 2 occupants



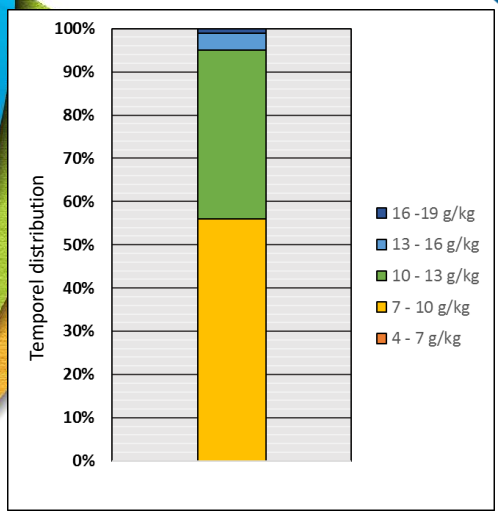
2018/12/11 to 2019/01/11: VMI ON – 2 occupants

7

4. RESULTS

HUMIDITY EVACUATION IN THE BATHROOM

Analysis of the absolute humidity



RANKINE, 21° C

Relative humidity :

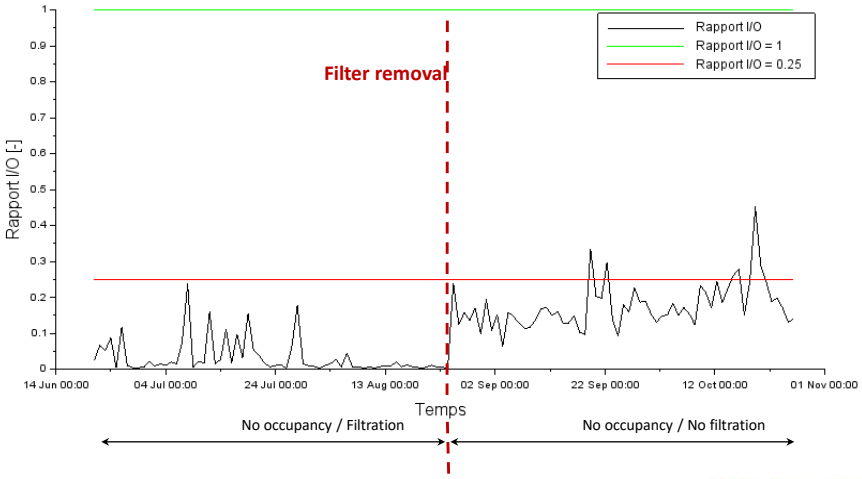
- One third of the time : between 40 % et 60 % ;
- 75% of the time : between 30 % et 70 % ;
- 90 % of the time : lower than 75 %.

8

4. RESULTS

IMPACT OF THE FILTER

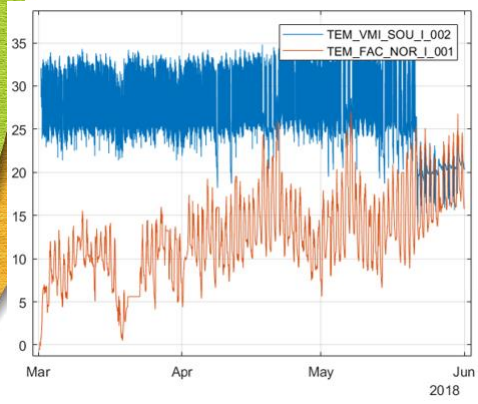
Analysis of the I/O ratio



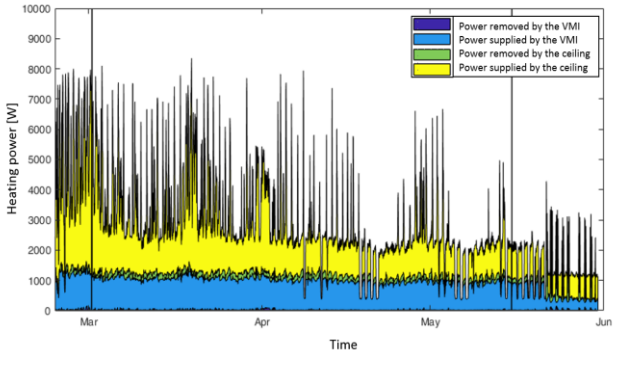
4. RESULTS

IMPACT OF THE HEAT EXCHANGER

Analysis of the supplied air temperature



Supplied air temperature = 28 °C



Heating needs cover = 25 % to 40 %

5. CONCLUSION AND PERSPECTIVES

Satisfying results in terms of:
- **CO_2 in the bedroom ;**
- **Humidity in the bathroom ;**
- **I/O in the living-room.**

Satisfying results in terms of:
- **Supplied air temperature ;**
- **Heating needs cover.**



VENTILAIRSEC GROUP

THANK YOU FOR YOUR ATTENTION

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Large-scale performance analysis of a smart residential MEV system based on cloud data

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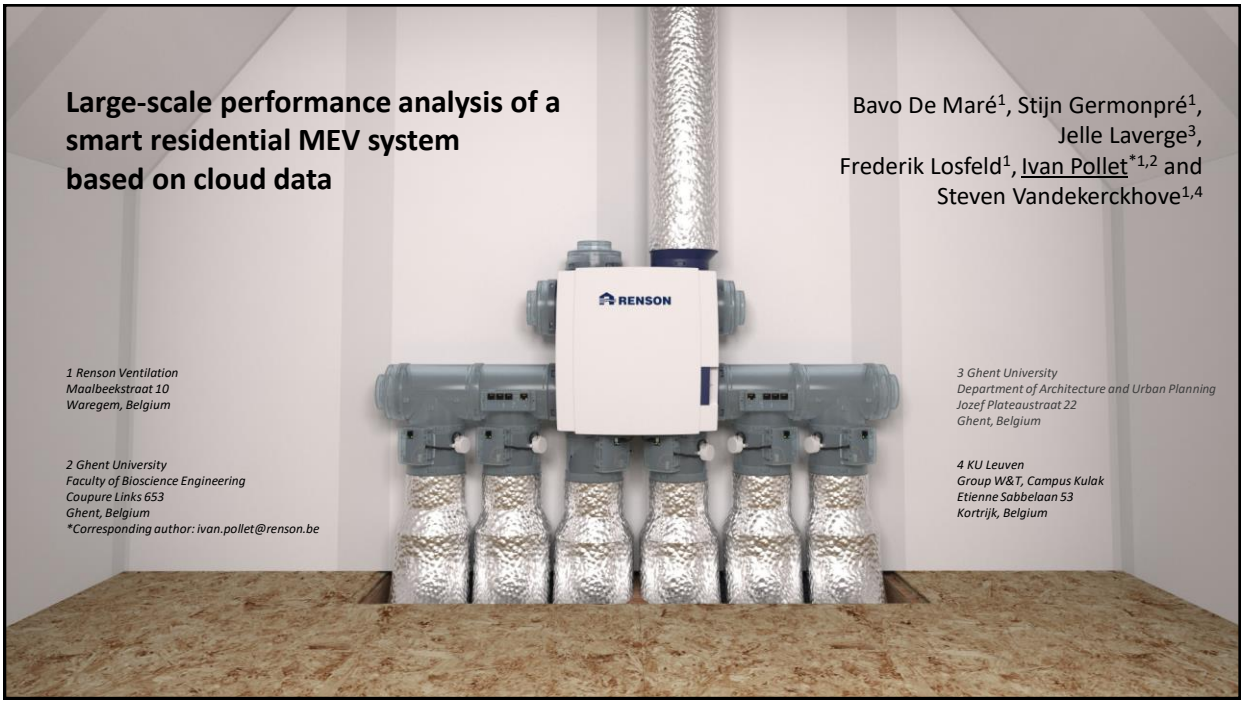
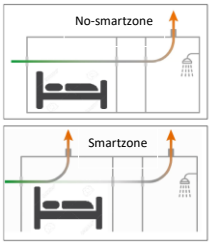


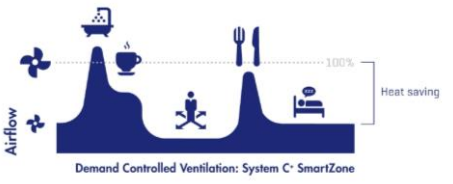
1

Mechanical extract ventilation system (MEV, system C or 3)

- **Residential ventilation:** new single/multi-family houses (~50/50%) in Belgium (n_{50} ~ 1,5-2 vol/hr)
- **Natural air supply** via window vents (at 2 Pa) > habitable rooms
- **Extraction** from **wet rooms** (= no smartzone) or from **wet + habitable rooms** (= smartzone)
- Room based extraction, **controlled on RH, CO_2 and VOC** (= DCV)
- **Without heat recovery**







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2

Large-scale in-situ performance analysis

- **Connected IoT device Healthbox 3.0:** cloud data of **IAQ** in extraction rooms and **fan characteristics** data
  - Relative humidity RH
  - CO_2
  - Fan pressure, air flow, power, consumption
  - Ventilation losses (heating consumption): estimation
- **Control algorithm** between min and max: step or proportional
- **Monitoring frequency**: per 5 min
- **Sensor accuracy**: 2.5%, 2% and 5%, for power input, RH and CO_2





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Large-scale in-situ performance analysis

- **4 months winter period**: Dec 2018 – March 2019 (temperate maritime climate)
- Ventilation units **installed as usual** (no extra commissioning) + **data not filtered** on outliers
- **Active ventilation** = ventilation at flow rates > minimum ~ most related (unknown) occupancy period
- **Large-scale: no smartzone** system (wet room data): 175 houses / **Smartzone** (all room data): 175 houses
  - Design IAQ criteria EN16798-1
  - Comparison with literature
  - Gap: theory ↔ practice ?



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Results of data analysis

- **Comfort level** > relative humidity RH

  > CO_2 concentration



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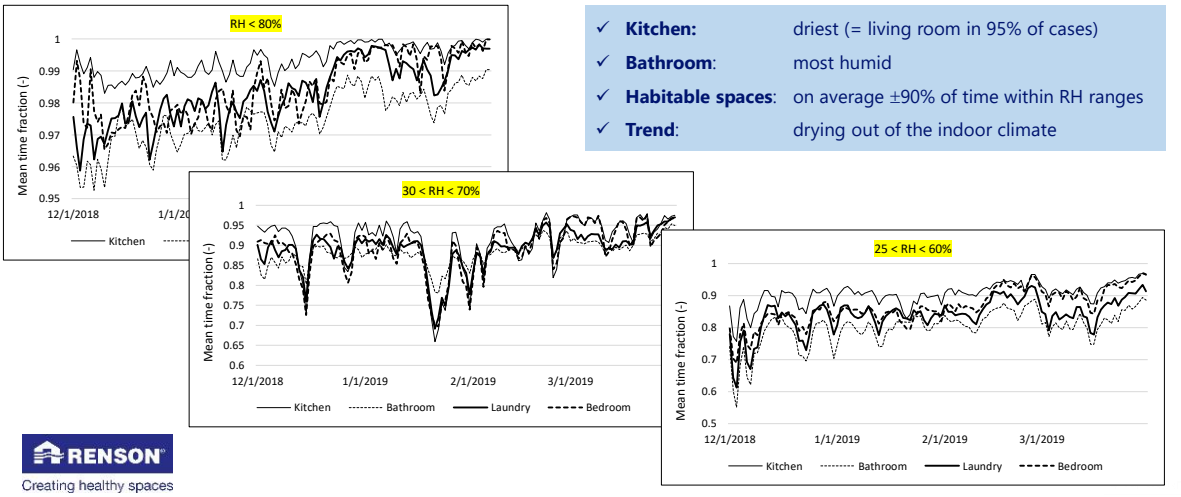
Relative humidity: mean time fraction

➢ **In kitchen, bathroom, laundry and bedroom**



✓	**Kitchen:**	driest (= living room in 95% of cases)
✓	**Bathroom**:	most humid
✓	**Habitable spaces**:	on average ±90% of time within RH ranges
✓	**Trend**:	drying out of the indoor climate

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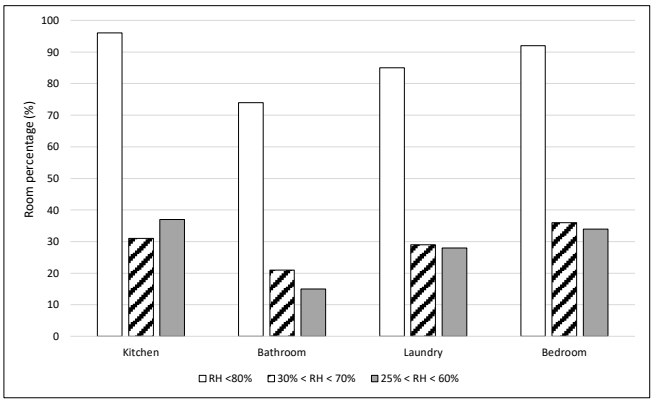
Relative humidity: room percentage permanently (= 99% of time)…

- **In kitchen, bathroom, laundry and bedroom**



- ✓ **< 80% RH:** at least 70% of rooms
- ✓ **30-70% or 25-60%:** at most 40% of rooms
- ✓ **Complaints** of too dry/humid limited
- ✓ Negligible risk on **mould growth**

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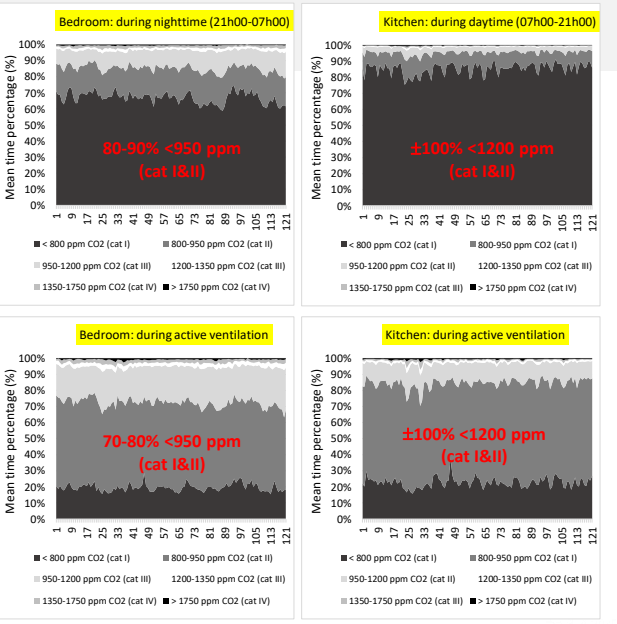
CO_2: mean time fraction

- **Bedroom:** only smartzone systems
- **Kitchen (95% open):** all systems
- **Period:** day/nighttime or active ventilation

- ✓ **Bedroom:**
  - 90% chance CO_2 <1200 ppm during ≥95% of time
  - Half of nighttime: ventilation = minimum flow
  - Without extraction: 1000 – 2000 ppm
- ✓ **Open kitchen:**
  - Nearly permanently <1200 ppm
- ✓ **Average daily exposure per house >1200 ppm:**
  - 245 ppm.h/day ↔ Monicair study: 733 ppm.h/day



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Results of data analysis

- **Fan characteristics**
  - > airflow rate: min/mean/max/installed
  - > working pressure



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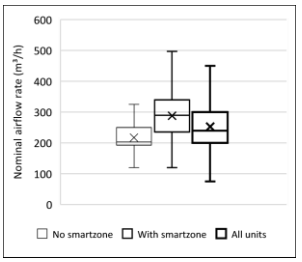
Fan characteristics

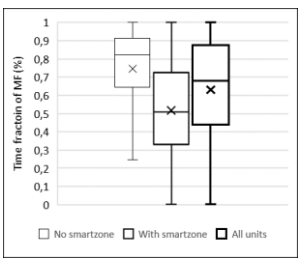
- **No smartzone (on average):**
  - **on minimum level** 75% of time
  - **extract rate** 38,8 m³/h
  - **operating pressure** 38,9 Pa

- **With smartzone (on average, guarantee IAQ):**
  - **on minimum level** 50% of time
  - **extract rate** 57,1 m³/h
    (Monicair: 76,9 m³/h)
  - **operating pressure** 40,1 Pa
  - **ctrl / reduction factor** 0,26
    = extract rate/nominal rate of no smartzone
    ↔ gap with theoretical ctrl factors: 0,43-0,50
    impact of crossflow ?

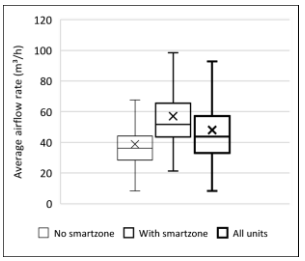
Nominal airflow rate (m³/h)



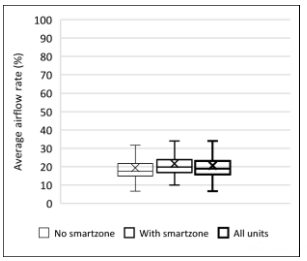
Time fraction of minimal flow rate (-)



Average airflow rate (m³/h)



Average airflow rate (%)



Results of data analysis

- **Ventilation energy consumption of smartzone system**

  > **total auxiliary fan consumption:** measured, including electronics and sensors

  > **ventilation heat losses:** based on: - measured extraction rate (q_v = 57,1 m^3/h)
  - estimated temperature difference (ΔT = 15°C)
  - estimated cross ventilation with air inlets (10 Pa, backflow valve)



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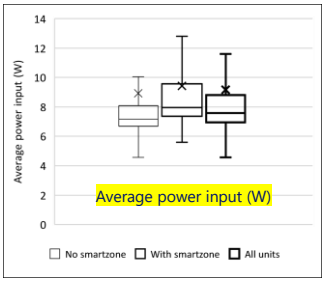
Mean ventilation energy consumption of smartzone system

➢ **Total auxiliary fan consumption**
- Average power input: 9.4 W
- Yearly consumption: ~ 80 kWh
- Yearly electricity cost: ~ € 20 (0,25 €/kWh)

➢ **Ventilation heating consumption (estimation)**
- Yearly consumption:
  - Extraction ~ 5350 MJ
  - Cross flow ~ 535 MJ (10%)
- Yearly heating cost: ~ € 82 (0,05 €/kWh)



➢ **Yearly mean total energy cost: ~ € 100**

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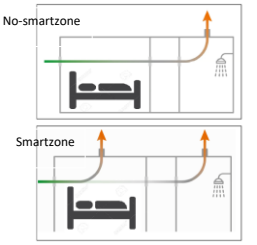
12

Conclusions





Smart connected MEV and **large-scale data reveal:**



- **All room IAQ-controlled extraction** (wet + habitable rooms) ensures
  - IAQ on room level (RH, CO_2)
  - minimize total ventilation energy consumption, without heat recovery: ~100 € (Belgium)
- **Statistics:** time and number percentage > probabilistic values

  → *90% of bedrooms with extraction, CO_2 < 1200 ppm during at least 95% of nighttime*
- **Substantial differences in performance** compared with:
  - literature
  - simulations (difference in average presence/occupancy levels/activities)

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KU LEUVEN

40th AIVC conference

Individualised Dynamic Model-Based Monitoring of Occupant's Thermal Comfort for Adaptive HVAC Controlling

15-16 October 2019
Gent

Dr. Ir. Ali Youssef

M3-BIORES
KU Leuven

1

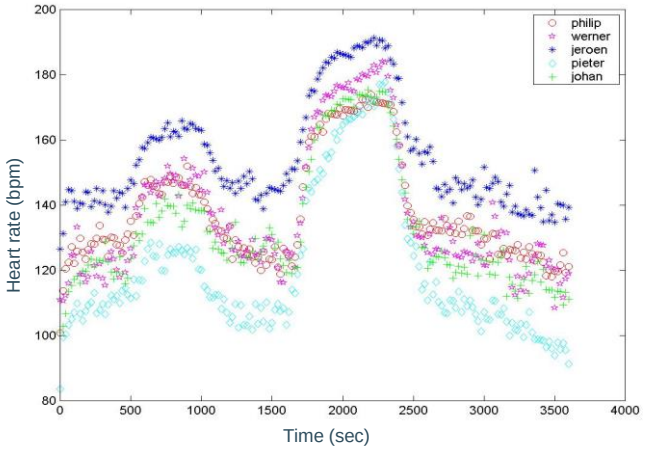
THE PROBLEM

- Currently, most of the HVAC control approaches, that consider thermal comfort regulation, are based on 'static thermal comfort models' that views the building occupants as passive recipients of their thermal environment.
- Assuming that occupants have relatively constant range of biological comfort requirements.

2

Living systems (human) are:

Complex **Individual** **Time-Varying** **Dynamic**



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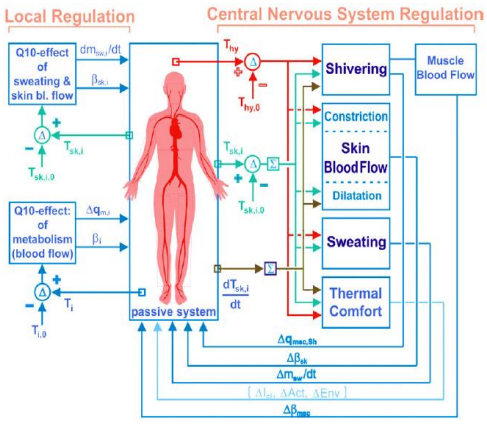
3

Dynamic thermoregulations models:

- Most of available dynamic thermoregulation/thermal comfort models are:
  - too complex (not suitable for real-time applications)
  - depend on not-easily or invasively measured variables (e.g., core body temperature and metabolic rate)

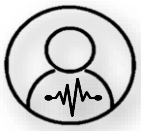


e.g., Fiala Physiological Comfort (FPC) model (Fiala et al., 2012)

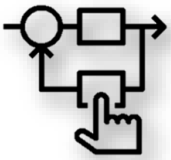
4

THE SOLUTION

- **Dynamic, simple and personalized thermoregulation models (that can run in real-time)**



- **Adaptive model-based control approach**

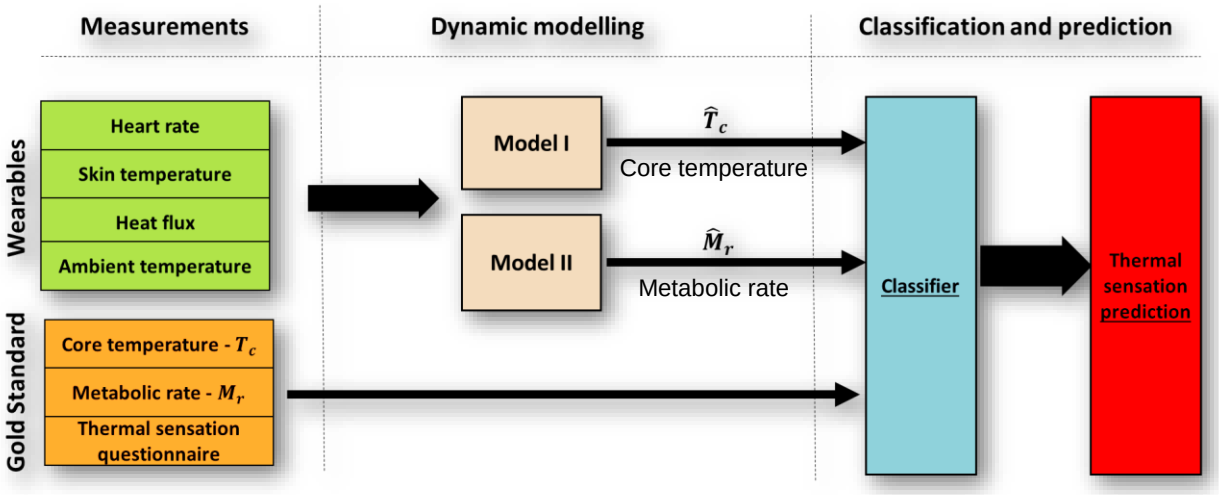


- **Wearable sensing technology**



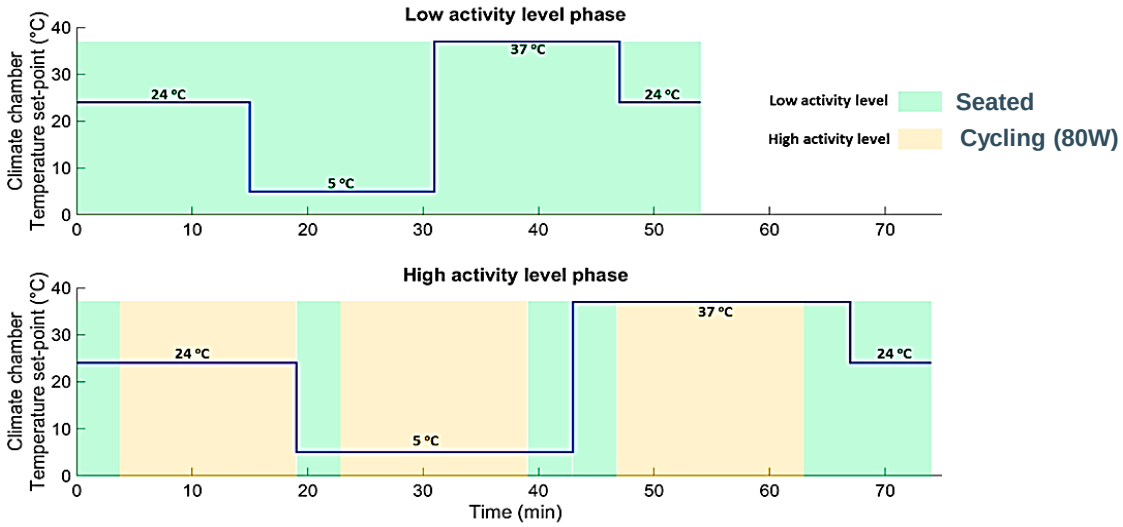
5

General Methodology



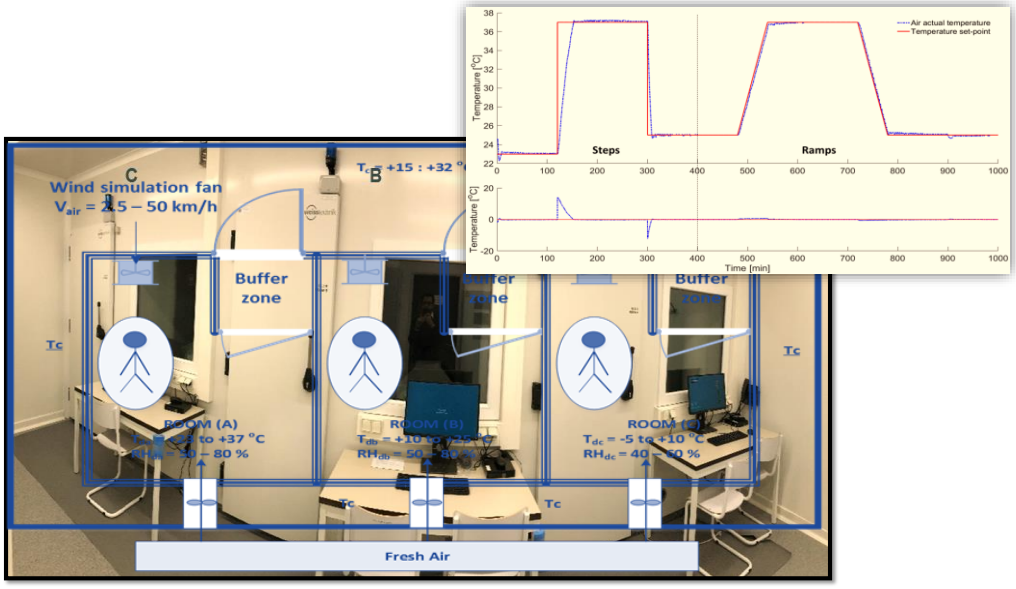
6

EXPERIMENTAL PROTOCOL



7

Climate chambers (BODY & MIND ROOMS)



8

PARTICIPANTS & MEASUREMENTS

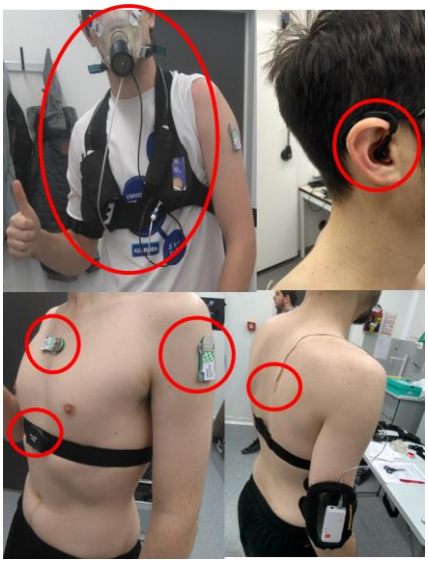
- 25 participants, age 26 ± 4, weight 70 ± 13 kg with 19 males and 6 females.

Wearable sensors

- Average Skin temperature & Heat flux → 2 gSkin® bodyTemp patch
- Heart rate monitor → Apple watch
- Scapula skin temperature → Shimmer® sensor

Gold standards

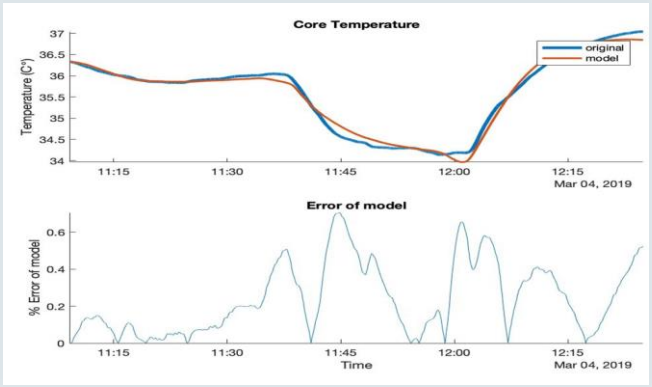
- ASHRAE 7-point thermal sensation scale
- Heart Monitor → Polar H7
- Aural temperature → Cosinuss™ One
- Metabolic rate → MetaMAX 3B



- **Dynamic modelling and estimation: of core body temperature (Model I)**

MISO discrete time transfer function

$$\begin{bmatrix} \frac{B_1(z^{-1})}{A(z^{-1})} & \frac{B_2(z^{-1})}{A(z^{-1})} \end{bmatrix} \cdot \begin{bmatrix} T_{sk}(k-\delta_1) \\ \bar{q}_{sk}(k-\delta_3) \end{bmatrix} + \xi(k) = \hat{M}_r(k)$$



Fixed structure and parameters (offline estimation)

- *Low activity*
  - 2nd order model
  - $R^2 = 0.88 \pm 0.27$
- *High activity*
  - 2nd order model
  - $R^2 = 0.81 \pm 0.25$

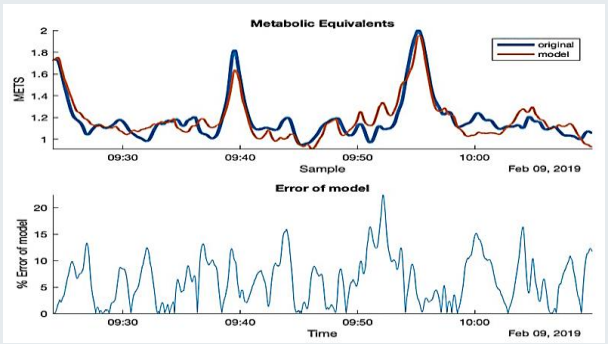
Fixed structure and varying parameters (online estimation)

- 2nd order model
- $R^2 = 0.92 \pm 0.14$

Dynamic modelling and estimation: of metabolic rate (Model II)

MISO discrete time transfer function

$$\begin{bmatrix} \frac{B_1(z^{-1})}{A(z^{-1})} & \frac{B_2(z^{-1})}{A(z^{-1})} & \frac{B_3(z^{-1})}{A(z^{-1})} \end{bmatrix} . \begin{bmatrix} T_{er}(k-\delta_1) \\ H_R(k-\delta_2) \\ \bar{q}_{sk}(k-\delta_3) \end{bmatrix} + \xi(k) = \hat{M}_r(k)$$



Fixed structure and parameters (offline estimation)

- *Low activity*
  - 2nd order model
  - $R^2 = 0.60 \pm 0.18$
- *High activity*
  - 2nd order model
  - $R^2 = 0.78 \pm 0.21$

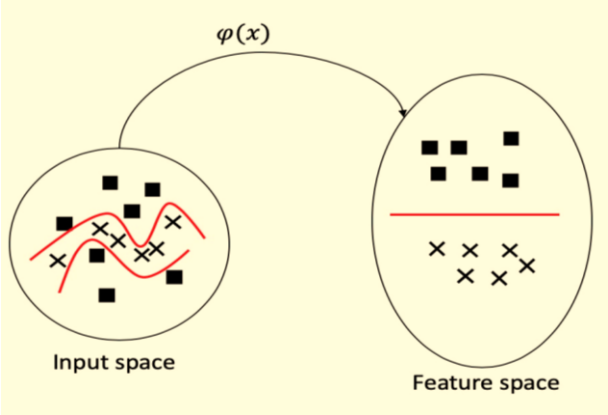
Fixed structure and varying parameters (online estimation)

- 2nd order model
- $R^2 = 0.85 \pm 0.16$

Classification model and prediction of thermal sensation (T_s):

Support Vector Machine (SVM): suitable for non-linear problems

Inputs		Output
x_1	x_2	Class
.	.	.
.	.	.
.	.	.
.	.	.



Which decision boundary to be chosen?!!!

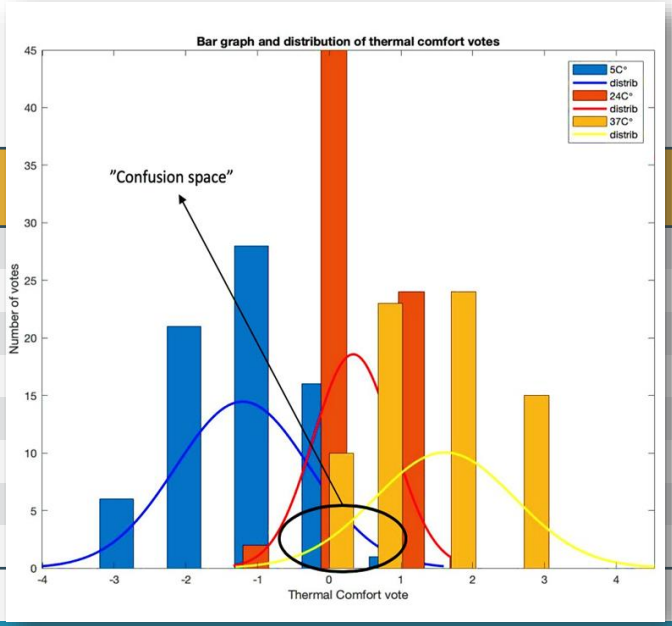
SVM suggests to choose the decision boundary that maximizes the margin.

Margin: the distance between the closest points of the different classes.

Selected Input Space

Started by 57 input features

	Variance	Mean
Measured variables		
T_{er}	×	×
H_R	×	×
$\overline{q}_{sk}$	×	×
$\overline{T}_{sk}$	×	×
$\Delta\overline{T}$	×	×
$\widehat{M}_r$	×	×
T_{arm}	×	×
T_{scap}	×	×



13

Finally, a classification model is developed based on the selected 25 input features for 7-classes thermal sensation classification problem

Measure	Value
Accuracy	0.76
Sensitivity	0.82
Precision	0.87
F1 score	0.84

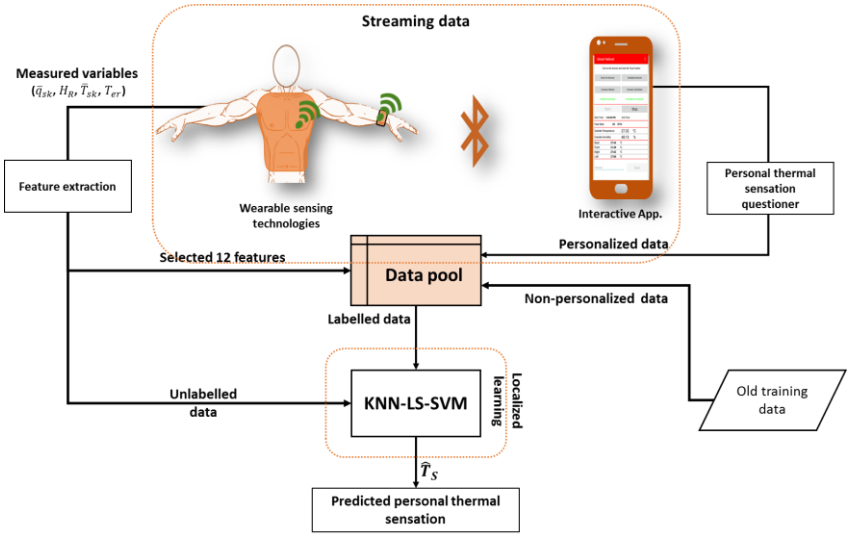
- $\text{Accuracy} = \frac{TP+TN}{ALL}$,
- $\text{Sensitivity} = \frac{TP}{TP+FN}$
- $\text{Precision} = \frac{TP}{TP+FP}$,
- $\text{F1 Score} = \frac{2*\text{Precision}*\text{Sensitivity}}{\text{Precision}+\text{Sensitivty}}$

Number of votes \ Thermal sensation votes	-3	-2	-1	0	1	2	3
-3	0	0	0	0	0	0	0
-2	2	0	1	0	0	0	0
-1	0	1	6	1	0	0	0
0	0	0	0	14	2	0	0
1	1	0	0	1	8	0	0
2	0	0	0	1	0	3	1
3	0	0	0	0	0	1	1

14

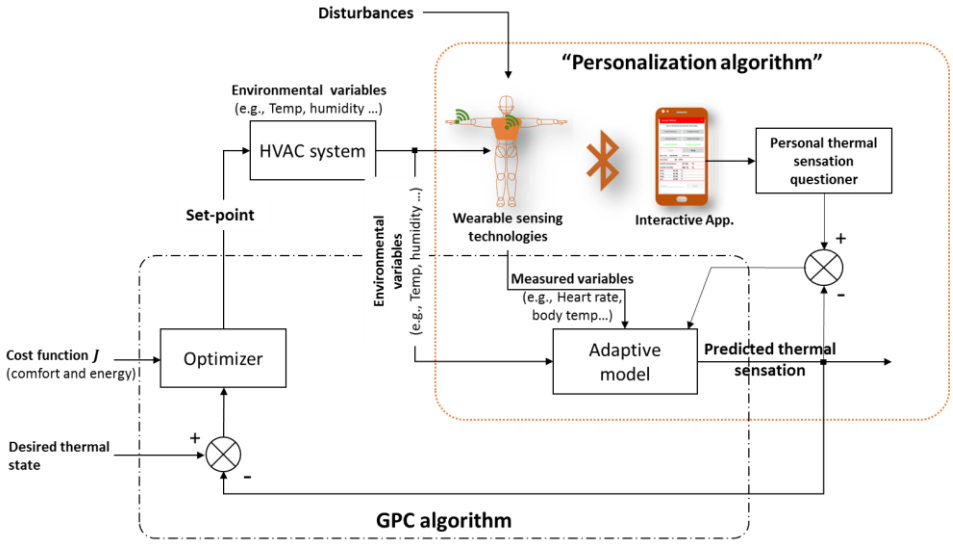
Personalized prediction model using KNN-LS-SVM

- Three classes classification problem
- 12 features
- Overall accuracy: 86%
- Overall F1-Score: 90%



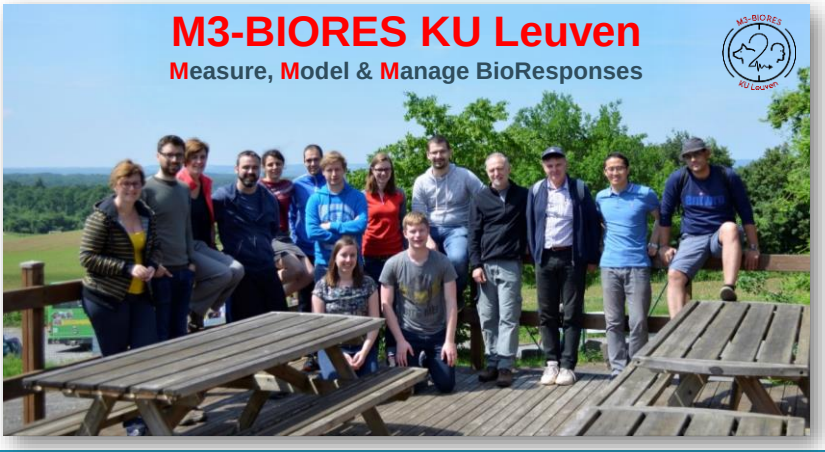
Youssef, et. al. Towards Online Personalized-Monitoring of Human Thermal Sensation Using Machine Learning Approach. Appl. Sci. 2019, 9, 3303.

Integration of the personalized thermal sensation model in HVAC control system



Youssef, et. al. Model-Based Monitoring of Occupant's Thermal State for Adaptive HVAC Predictive Controlling. *Processes* **2019**, *7*, 720.

Thank You



SCAN ME

Resilient Cooling

Topical Session 6C, linked to the new IEA EBC Annex 80

1. Introduction of IEA EBC Annex 80: Peter Holzer
2. Outlook on Resilient Cooling Technologies: Bjarne Olesen
3. Experience with Resilient Cooling Technologies in Australia: Wendy Miller
4. Resilience Indicators of Cooling Technologies: Shady Attia

Chairs: Peter Holzer and Per Heiselberg

EBC
Energy in Buildings and Communities Programme

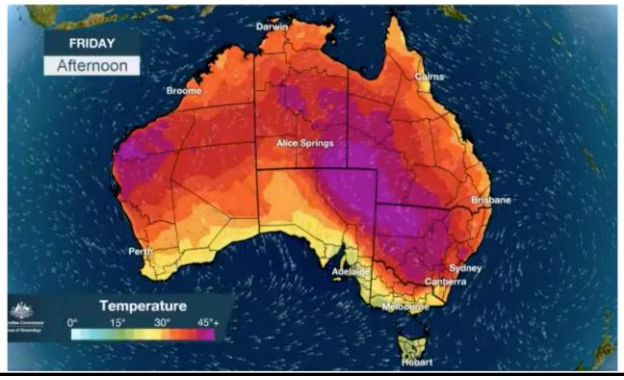
iea
Energy Technology Network

1

Australia heatwave: overnight minimum of 35.9C in Noona sets new record

On fifth day of record-breaking extreme weather, temperatures in parts of Victoria, ACT and NSW forecast to soar above 40C, including in Sydney's west

- **25 January - Australia extreme heatwave: Victoria and Tasmania face bushfire threat - live updates**
- **Extreme heat Melbourne: city expecting 44C as Victoria faces hottest day since Black Saturday**



Source: https://www.theguardian.com/australia-news/2019/jan/18/australia-heatwave-sydneys-west-to-hit-45c-after-week-of-extreme-weather, 10.04.2019

2

2

After decades of comfort research and efficiency research:

It is not only about comfort.

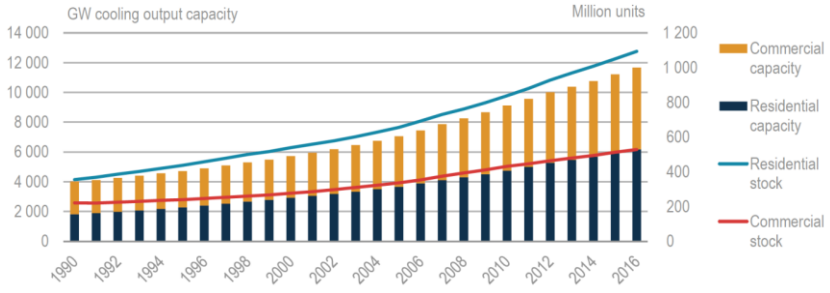
It is about survival.

It is not only about efficient cooling.

It is about sufficient and resilient cooling.

The Surge of Air Conditioning

Last 25y development of stock and capacity of AC worldwide

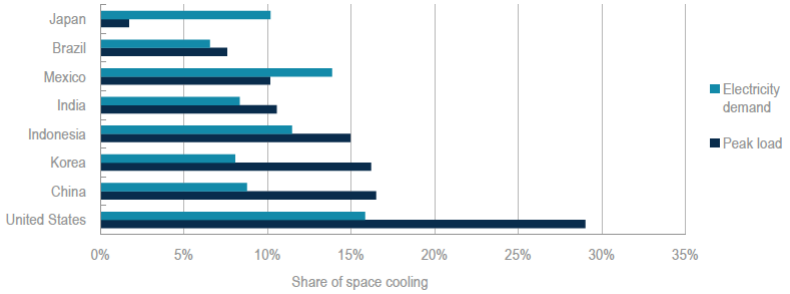


Tripling within 25 years !

Installed stock and cooling capacity of AC
Source: IEA Report Future of Cooling, 2018

The Share of Space Cooling

a) in Electricity Annual Demand
b) in Electricity Peak Load



- IEA estimates space cooling accounts for 10% of electricity demand world wide. USA 16%, Middle East 15%, Mexico 15% show highest shares
- Peak Load Demand can reach up to 50% (e.g. Singapore)

Source: IEA Report Future of Cooling, 2018

Causes of the "AC Surge"

- Growing economic prosperity
- Demographic growth in hot regions
- Urbanisation
- Climate Change
- Change in Demographic Structure

Source: IEA Report Future of Cooling, 2018

Threats of the “AC surge”

- Making houses even more vulnerable
- Making outdoor spaces
  even hotter and less livable
- Challenging the goals of decarbonisation
  and climate protection
- Raising the danger of grid blackouts

Source: IEA Report Future of Cooling, 2018

Resilient Cooling Requirements

- Reliability & Failure Safety
- Affordability & Accessibility
- Energy Efficiency & Carbon Neutrality
- Social Inclusiveness

Resilient Cooling Fields of Technologies

1. Reduction of externally induced heat gains
2. Personal comfort improvements apart from room cooling, e.g. offering adaptive options
3. Removing heat from indoor spaces, i.e. sensible cooling both passive and active
4. Removing humidity from indoor spaces, i.e. latent cooling

Definition

of Resilient Cooling in Annex 80

Affordable low energy and low carbon cooling solutions,

strengthening the ability of individuals and community

to withstand and prevent the thermal - and other - impacts of changes in global and local climates.

Annex 80 Objectives

A **Identify and document** benefits, potentials, limitations and bottlenecks of resilient cooling systems.
Provide guidance on design, performance calculation and system integration.
→ Subtask A – Impact Assessment

B **Develop and improve** systems and technologies
Develop new solutions. Research towards implementation of emerging technologies. Extend boundaries of existing solutions, including user interaction and control strategies. → Subtask A – Solutions

C **Evaluate** the real performance of resilient cooling solutions.
Identify performance gaps as well as supporting conditions.
→ Subtask C – Field Studies

D **Identify and spread** best practice in policy actions.
→ Subtask D – Policy Actions

Annex 80 Subtasks

The Annex will be structured in four subtasks:

A Impact Assessment
Wendy Miller, Queensland University of Technology, Australia
Shady Attia, University of Liège, Belgium

B Solutions
Chen Zhang, Aalborg University, Denmark
Ongun Berk Kazanci, Technical University of Denmark

C Field Studies
Dahai Qi, Université de Sherbrooke, Canada
Gerhard Hofer, e7 Energie Markt Analyse, Vienna, Austria

D Policy Actions
Peter Graham, Global Buildings Performance Network, Australia

Subtask A – Impact Assessment

- **Objectives**:
  - Assessment of Cooling Technologies
  - Guidelines for integration in energy performance calculation
  - Technology Profile Sheets (deliverable)
  - Resilient Cooling Design and Operation Guidelines (deliverable)
- **Work Programme:**
  - Definition of Resilience in Cooling
  - Definition of criteria and KPIs (technical, social, ecological)
  - Definition of Technologies to assess
  - Doing the systematic multicriterial Technology Assessment
- **Prevailing Method**:
  - Concerted desktop research, comparative studies

Subtask B - Solutions

- **Objectives**:
  - Extension of range of resilient cooling systems
  - Derivation of rules for successful implementation
  - Resilient Cooling Source Book (deliverable)
- **Work Programme:**
  - R&D within National Research Items
  - Compilation of results
  - Write the Source Book Report
- **Prevailing Method**:
  - Desktop research
  - numeric modelling,
  - measurements in situ

Subtask C – Field Studies

- **Objectives**:
  - Analysis and evaluation of resilient cooling technologies
  - Performance gap examination
  - Identification of barriers
  - Field Studies Report (deliverable)
- **Work Programme:**
  - Creation of umbrella document for Field Studies Report, incl. KPIs
  - Carrying out the field studies
- **Prevailing Method**:
  - In Situ Measurements
  - Numeric modelling
  - Evaluation of monitoring data

Subtask D – Policy Actions

- **Objectives**:
  - Support mainstreaming of resilient cooling technologies
  - Develop recommendations for policies (labelling programmes, building regulations, standards and compliance requirements)
  - Policy Actions Recommendation Report (deliverable)
- **Work Programme:**
  - Creation of Assessment Matrix
  - Analysis of existing labelling programmes, building requirements, standards and compliance standards
- **Prevailing Method**:
  - Desktop research, Expert Surveys, Networking

Annex 80 attendending institutions

Austria	Institute of Building Research & Innovatio e7 Energie Markt Analyse GmbH Vasko und Partner
Australia	Queensland University of Technology University of Wollongong Global Buildings Peformance Network
Belgium	BBRI Belgian Building Research Institute University of Liège KU Leuven Ghent University Thomas More, Campus Geel
Canada	Concordia University, Montreal Université de Sherbrooke

Annex 80 attendending institutions

China	Hunan University Hunan University of Science and Technology
Denmark	Aalborg University Technical University of Denmark
France	Univérsité de la Rochelle
Italy	ENEA Politecnico Torino Politecnico Milano EURAC
Japan	Tokyo City University Building Research Institute Sunagawa Architectural Environmental Lab

Annex 80 attendending institutions

China	Hunan University Hunan University of Science and Technology
Netherlands	Eindhoven University of Technology W/E Consultants Sustainable Building
Singapore	National University of Singapore
Sweden	University of Gävle
UK	Brunel University Oxford Brookes University School of Architecture and the Built Environment Lincoln
USA	Lawrence Berkeley National Laboratory Center for the Built Environment

Annex 80 attendending institutions

UAE	Heriot Watt University (Dubai, Edingburgh)
India	CEPT University, CARBSE

Schedule, Efforts and Benefits

- Working Phase from June 2019 until June 2022
- Reporting Phase from July 2022 until July 2023
- Two Expert Meetings per year, on own expenses

- Most valuable exchange of expertise, experience, courage
- Platform to jointly develop new technologies an tools
- Platform to jointly publish papers and reports

A warm welcome to join Annex 80

http://annex80.iea-ebc.org/

EBC
Energy in Buildings and Communities Programme

iea Energy Technology Network



1

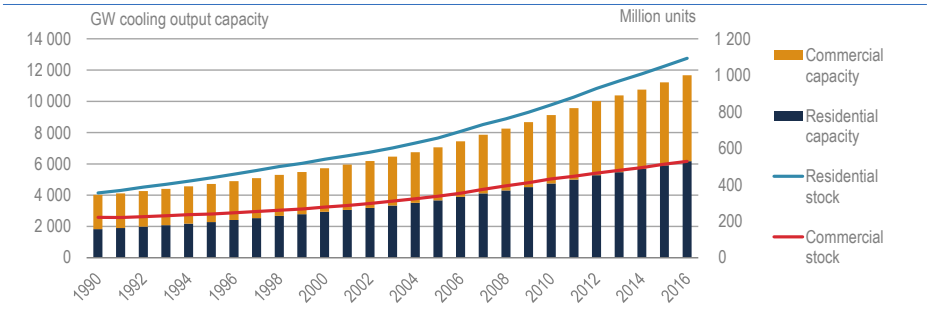
GLOBAL TRENDS for COOLING

- OECD/IEA 2018 The Future of Cooling:
  Opportunities for energy- efficient air conditioning
  - Using air conditioners and electric fans to stay cool accounts for nearly 20% of the total electricity used in buildings around the world today
  - Will grow as the world's economic and demographic growth becomes more focused in hotter countries.
  - As incomes and standards of living increase, more people will naturally want to buy and use air conditioners to keep cool.
  - Wider access to cooling is necessary, bringing benefits to human development, health, well-being and economic productivity
  - The use of energy for space cooling is growing faster than for any other end use in buildings, more than tripling between 1990 and 2016
  - Energy demand from air conditioners will more than triple by 2050, equal to China's electricity demand today

2

Air Conditioning

Figure 1.3 • Worldwide stock and capacity of ACs by sector

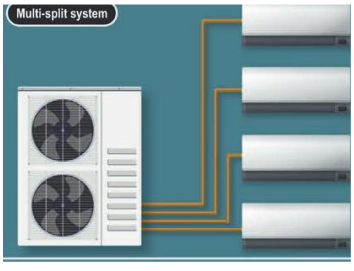


Key message • Sales of ACs, particularly to households, continue to grow briskly, pushing up the total stock of units and global cooling capacity.

3

Cooling in Residential

- Booming sales of split units or window units
- People think a split system also provide ventilation





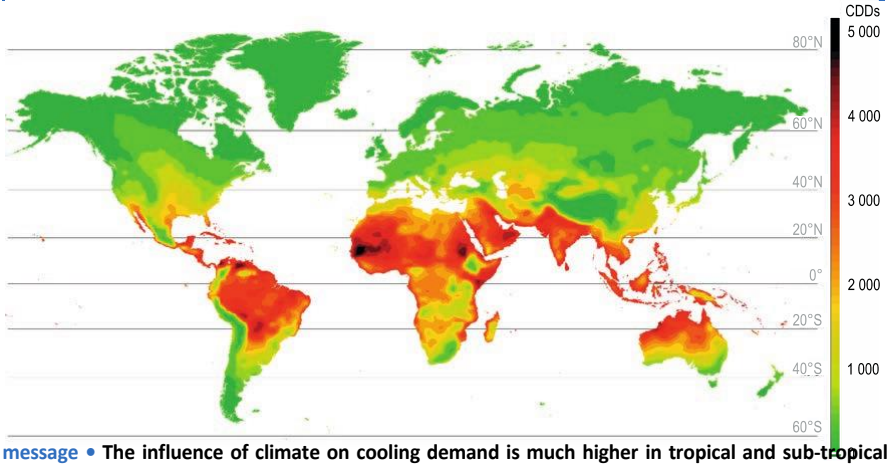
4

Refrigerants

- Refrigerants have a significant impact on depletion of the Ozone layer and Global warming
- Decreased cooling demand will result in decreased use of refrigerants
- Increased use of passive cooling techniques will result in decreased use of refrigerants
- Change to more environmental friendly refrigerants
- Change to more energy efficient refrigerants
- UNEP activities to reduce use and promote change to more environmental friendly refrigerants in developing economies.

Cooling Degree Days

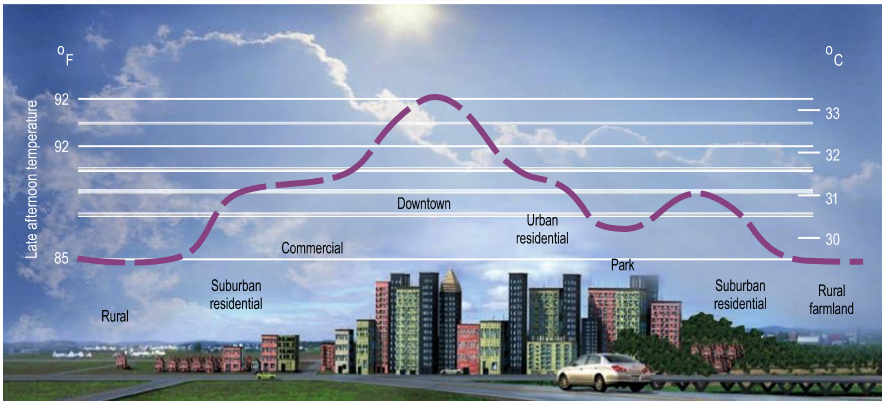
Map 2.1 • CDDs across the world, mean annual average 2007-17



Key message • The influence of climate on cooling demand is much higher in tropical and sub-tropical regions, but other factors such as humidity and building performance also play a role.

Heat Island Effect

Figure 2.2 • Illustration of the heat island effect

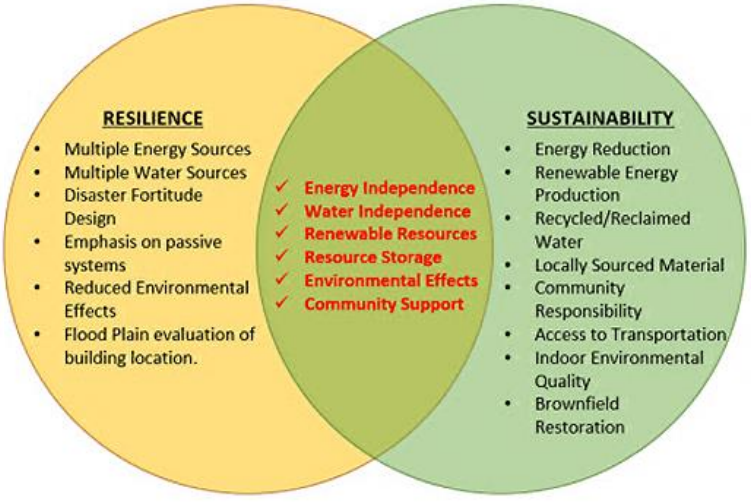


Source: LBNL (2013), Heat Island Group, http://heatisland.lbl.gov/.

Key message • Cooling is one of several contributors to the heat island effect, which creates a need for more cooling in a classic feedback loop.

7

RESILIENCE-SUSTAINABILITY



8

Actions to Decrease Energy Use for Cooling

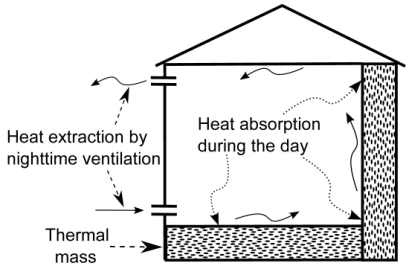
- Decrease cooling demand by improved building design
- Use of renewable energy sources
- Use of energy efficient cooling systems
  - High Temperature Cooling Systems
  - Improved room temperature control

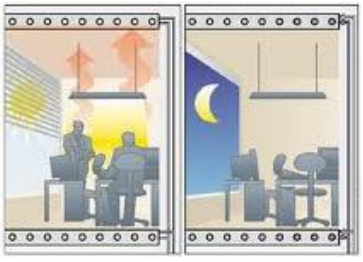
RESILIENT COOLING TECHNOLOGIES BUILDINGS

- Advanced Glazing Technologies
- Ventilated Facades
- Cool materials (white roofs, green roofs, etc.)
- Solar shading
- Thermal mass (Phase change materials, PCM)
  - Reduction of Peak Loads
  - Reduction of Peak Temperatures
  - Load Shifting

Thermal Mass in Buildings

- The heat capacity of massive buildings can be used to store thermal energy for cooling purposes.
- Passive (surface activation) vs. Active (core activation) thermal mass:
  - Night-time ventilative cooling
  - TABS system





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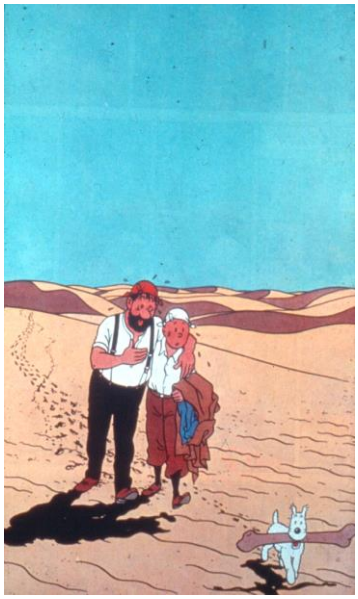
11

RESILIENT COOLING TECHNOLOGIES OCCUPANTS

- Clothing
- Working Schedule
- Adaptive Approach
- Activity Level

12

Resilient Cooling Technologies





13

PERSONAL CONTROL

Garment Description	Thermal Insulation clo	Change of Operative Temp. K
Sleeveless vest	**0,12**	**0,8**
Thin sweater	**0,20**	**1,3**
Light jacket	**0,25**	**1,6**
Normal jacket	**0,35**	**2,2**

14

Relative importance of clothing

0,1 clo ~ 0,7 K



Minister Yuriko Koike under the cabinet of Prime Minister Jun'ichirō Koizumi proposed COOL-BIZZ in Japan. Now May-October

RESILIENT COOLING TECHNOLOGIES RENEWABLE ENERGIE SOURCES

- Evaporative cooling
- Ventilative cooling
- Solar and adiabatic cooling
- Night time sky radiation
- Ground source heat exchangers and other natural heat sinks

VENTILATIVE COOLING IS A SOLUTION

EBC
Energy in Buildings and Communities Programme

VENTILATIVE COOLING IS AN ATTRACTIVE AND ENERGY EFFICIENT PASSIVE SOLUTION TO COOL BUILDINGS AND AVOID OVERHEATING.

- Ventilation is already present in most buildings through mechanical and/or natural systems
- Ventilative cooling can both remove excess heat gains as well as increase air velocities and thereby widen the thermal comfort range.
- The possibilities of utilizing the free cooling potential of low temperature outdoor air increases considerably as cooling becomes a need not only in the summer period.



POTENTIAL AND LIMITATIONS

EBC
Energy in Buildings and Communities Programme

OUTDOOR CLIMATE POTENTIAL

- Outdoor temperature lower than the thermal comfort limit in most part of the year in many locations
- Especially night temperatures are below comfort limits
- Natural systems can provide “zero” energy cooling in many buildings

LIMITATIONS

- Temperature increase due to climate change might reduce potential
- Peak summer conditions and periods with high humidity reduce the applicability
- An urban location might reduce the cooling potential (heat island) as well as natural driving forces (higher temperature and lower wind speed). Elevated noise and pollutions levels are also present in urban environments
- High energy use for air transport limit the potential for use of mechanical systems
- Building design, fire regulations, security are issues that might decrease the potential use of natural systems

RESILIENT COOLING TECHNOLOGIES ENERGY EFFICIENCY

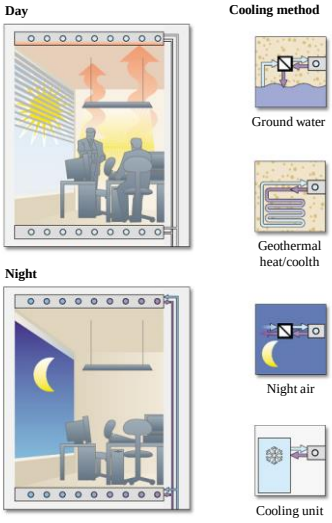
- High Temperature Cooling Systems
  - Radiant Cooling Systems
  - Chilled Beams
- Hydronic Cooling Systems
  - Energy Transport by Liquid
- Heat recovery systems
- Energy Efficient Products (Fans, Pumps, Valves, etc.)
- Energy Efficient Refrigerants

What is Low Temperature Heating/ High Temperature Cooling?

- Heat exchange through large surfaces (floor, ceiling, walls)
- Supply water temperatures:
  - Heating: 25 – 40 °C (77 – 104 F)
  - Cooling: 16 – 23 °C (61 – 74 F)
    - temperature limited by dew-point to avoid condensation)
- Wide range of systems, solutions both for residential and non-residential buildings

COMBINATION WITH LOW ENERGY SOURCES

- **Heating supply temp. : 25 - 40°C**
  - heat pumps
  - condensing boiler
  - ground coupling
  - waste heat
  - solar energy
- **Cooling supply temp. : 16 - 23°C**
  - reversible heat pump
  - ground coupling
  - free cooling
  - air cooled chillers

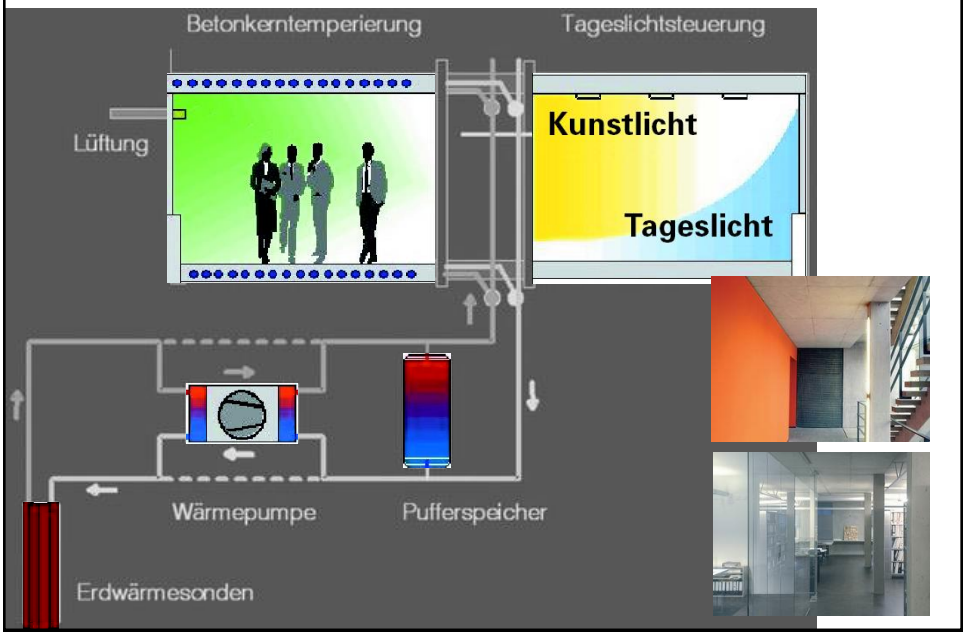


Balanced Office Building (BOB.1) Aachen, Germany

- Gross floor area 2,151 m²
- 4 storeys
- Efficiently insulated external envelope
- Ground-coupled heating and cooling with TABS
- Ventilation system with heat recovery
- Daylight-controlled lighting
- Rainwater collection for use in toilet flushing



Energy concept in BOB.1



23

The use of Phase Changing Materials for Cooling of Buildings combined with Night Sky Radiant Cooling



24

RESILIENT COOLING SOLUTIONS

- Cool materials like white roofs
  - Will not work when dirty, sandstorms
- Evaporative cooling
  - Will not work in humid areas
- Ventilative cooling
  - Will not work at high outdoor temperatures and polluted ambient air
- Ground source heat exchangers
  - Will not work at higher ground temperatures

RESILIENT COOLING SOLUTIONS

- No resilient cooling solutions in hot, humid locations with limited diurnal outside temperature changes
- Local production of electricity by natural energy sources
  - Wind turbines
  - Photo Voltaic
- Local production of thermal energy
  - Thermal solar collectors (hot water, absorption cooling)
  - PV/T, PV-Thermal collector (electricity, warm water, night radiative/convective cooling)

Resilient Cooling for Everyone

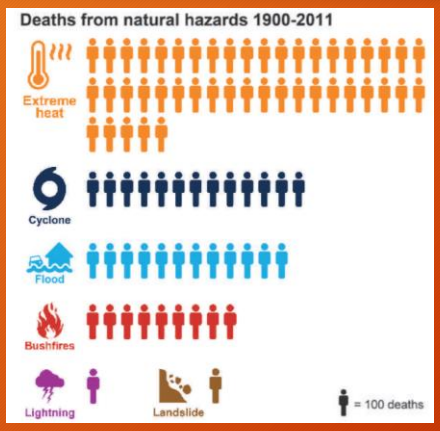
- Resilient cooling will benefit
  - Improved comfort
  - Reduced energy use compared to standard AC
  - Reduce use of refrigerants
  - Reduce heat island effects

Resilience Review: Of what? From What?

Australia

1

The Australian context

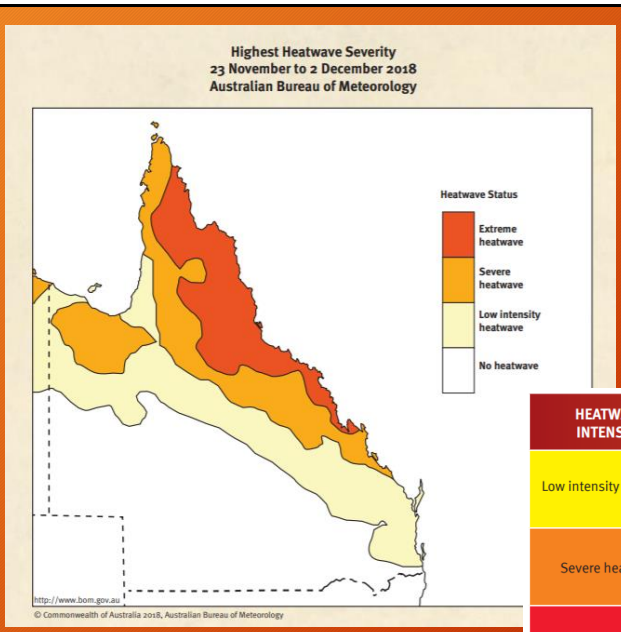


A heat wave is "*three days or more of high maximum and minimum temperatures that are unusual for that location*"

Australian Bureau of Meteorology

Queensland State Heatwave Risk Assessment 2019

2



Wide distribution

HEATWAVE INTENSITY	COLOUR CODE	POTENTIAL COMMUNITY IMPACT
Low intensity heatwave	Yellow	Most people expected to have adequate capacity to cope with this level of heat but begin to see health effects. Increased risk to vulnerable groups.
Severe heatwave	Orange	Increased morbidity and mortality for vulnerable groups, such as those over 65, pregnant women, babies and young children, and those with chronic illness (e.g. renal disease, ischaemic heart disease).
Extreme heatwave	Red	May impact normally reliable infrastructure, such as power and transport. Health risk for anyone who does not take precautions to keep cool, even those who are healthy.

3

DAILY TEMPERATURE FOR FEBRUARY 2015

BoM Station	17	18	19	20	21	22	23	24	25	26	27	28
Rosslyn Bay NTC AWS	27.2	27.3	27.1	27.6						29.1	29.5	29.6
033208	23.3	21.9	22.8	23.1	24.3	25.7				23.5	25.6	26.3
Yeppoon The Esplanade	28.7	28.3	27.1	28.3				29.8	30.2	29.3	30.2	29.7
033294	22.2	21.3	23.5	23.2	23.9			24.8	23.1	23.1	24.5	23.7
Samuel Hill Aero	28.4	28.7	26.1									
033308	22.1	21.1	23.3	22.5								
Rockhampton Aero	30.5	27.9	26.7	28.0	35.2	36.8	34.7	32.7	32.5	32.0	31.2	31.8
039083	21.0	20.1	21.4	22.7	23.9	24.9	26.4	24.8	23.7	22.3	23.7	22.3
Gladstone Radar	31.1	28.1	25.9	25.9	32.7	35.9	32.8	32.1	33.5	32.4	32.5	32.4
039123	21.7	21.2	23.1	22.5	23.6	24.2	24.4	23.5	22.9	22.3	23.8	23.4
Rundle Island	26.9	27.0	27.0	27.1	32.0	30.1	29.0	28.1	27.8	28.4	28.5	28.8
039322	23.4	22.3	23.8	23.0	24.7	25.2	26.2	25.0	24.5	24.0	25.4	25.7
Gladstone Airport	30.2	29.8	26.6	27.0	32.7	36.5	32.3	32.8	32.6	30.6	30.2	31.2
039326	22.6	21.3	23.7	23.3	24.2	24.7	25.4	23.4	22.6	22.0	24.1	22.3

Maximum Air Temperature (°C)
Minimum Air Temperature (°C)

MARCIA IMPACT
5 to 6° ABOVE AVERAGE
LOSS OF POWER
HEAT EVENT

Figure 1: Temperature records for the Livingstone, Rockhampton and Gladstone areas during the days immediately pre- and post-STC Marcia's impact. Blank cells indicate loss of telemetry from these stations during this period. The records indicate the possible presence of a severe heatwave with significantly elevated temperatures from 21 to 24 February 2015. Source: Bureau of Meteorology

Multiple hazards

- Heat waves linked to cyclones
- Cyclones linked to power outages
- Heat events linked to bushfires
- Bushfires linked to power outages and air quality

4

Index	Heatwave Index	Definition
HWF	Heatwave frequency	Number of heatwave days relative to number of days in an year - i.e. [number of heatwave days/365] x 100 (%)
HWD	Heatwave duration	Number of days of the longest heatwave of the year (days)
HWMt	Temperature of heatwave magnitude	Average mean[61] temperature (in °C) of all heatwave days across the year
HWAt	Temperature of heatwave amplitude	Average mean[62] temperature (in °C) of the hottest heatwave day of the year

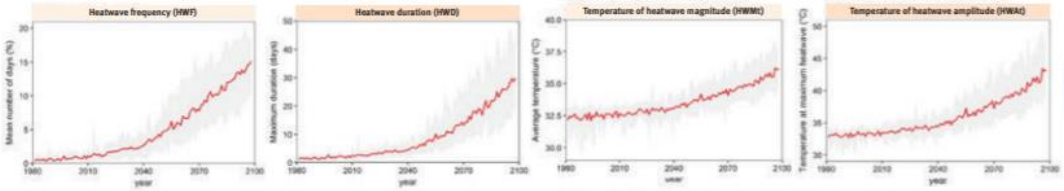


Figure 11a: Projected change in heatwave characteristics within Queensland (1981-2098). Source: Department of Environment and Science

5

UNDERSTANDING THE DATA

Index	Heatwave Index	Definition
HWF	Heatwave frequency	Number of heatwave days relative to number of days in a year - i.e. [number of heatwave days/365] x 100 (%)
HWD	Heatwave duration	Number of days of the longest heatwave of the year (days)
HWMt	Temperature of heatwave magnitude	Average mean temperature (in °C) of all heatwave days across the year
HWAt	Temperature of heatwave amplitude	Average mean temperature (in °C) of the hottest heatwave days of the year
Hot Days	Days >35°C	Annual count of days with maximum temperature >35°C
Hot Nights	Nights >20°C	Annual count of nights with minimum temperature >20°C

Note: All figures represent an absolute change from the reference period (1986 to 2005) unless expressed in negative terms, based on RCP 8.5. Further information and guidance on the data represented within this infographic can be found at Appendix F.

CITY OF GOLD COAST						
Index	Heatwave Index	Reference	2030	2050	2070	2090
HWF	Heatwave frequency (%)	2.1%	3.1%	8.9%	18.4%	28.4%
HWD	Heatwave duration (days)	4	4	9	22	45
HWMt	Temperature of heatwave magnitude (°C)	27.4	27.7	28.1	28.7	29.1
HWAt	Temperature of heatwave amplitude (°C)	28.4	28.9	29.7	30.7	31.6
Hot Days	Days >35°C	1	3	6	13	34
Hot Nights	Nights >20°C	50	76	106	141	175

10 fold increase in frequency and duration
2-3°C increase in magnitude and amplitude
Significant increase in number of hot days/nights

6

MOUNT ISA						
Index	Heatwave Index	Reference	2030	2050	2070	2090
HWF	Heatwave frequency (%)	1.6%	3.1%	7.2%	14.7%	22.8%
HWD	Heatwave duration (days)	4	3	7	15	29
HWMt	Temperature of heatwave magnitude (°C)	34.3	34.6	35.0	35.5	36.1
HWAt	Temperature of heatwave amplitude (°C)	34.8	35.3	36.0	37.0	38.2
Hot Days	Days >35°C	148	168	203	223	267
Hot Nights	Nights >20°C	177	203	228	254	284

MACKAY						
Index	Heatwave Index	Reference	2030	2050	2070	2090
HWF	Heatwave frequency (%)	2.1%	3.2%	10.6%	24.3%	35.8%
HWD	Heatwave duration (days)	4	4	11	34	72
HWMt	Temperature of heatwave magnitude (°C)	29.0	29.3	29.7	30.2	30.7
HWAt	Temperature of heatwave amplitude (°C)	29.5	30.0	30.6	31.6	32.8
Hot Days	Days >35°C	4	9	20	33	67
Hot Nights	Nights >20°C	128	157	186	217	255

7

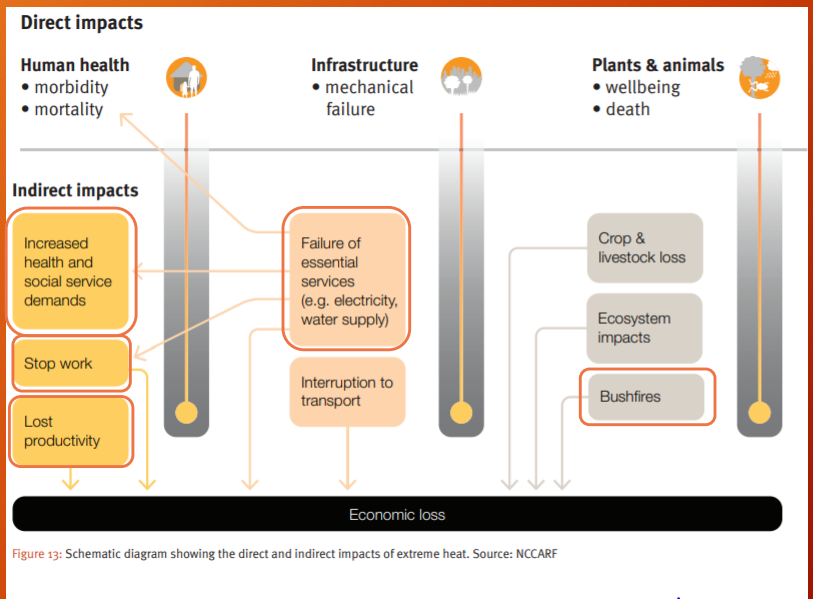
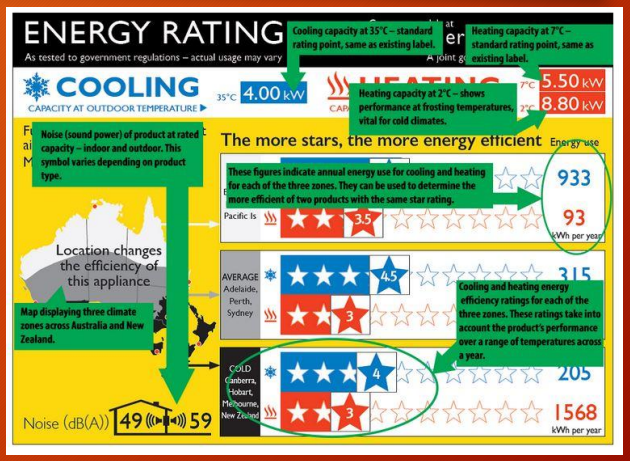


Figure 13: Schematic diagram showing the direct and indirect impacts of extreme heat. Source: NCCARF

8

Change to AC Energy Rating Label (zoned)

- Outdoor: 35°C$_{DB}$, 24°C$_{WB}$
- Indoor: 27°C$_{DB}$, 19°C$_{WB}$
- So what?
  - EER in extreme weather?
  - Energy affordability?
  - Peak demand?
  - Supply reliability?



9

Resilience Case Study – property portfolio

10

Climate Effects - Predicted Exposure

Climate effects	Summary of regional projections (2030-2070)	Credit
Climate Zone	Zone 2	
Mean temperature change	2030: Increase by 3% to 21.6°C 2070: Increase by 17% to 26.1°C	2
Extreme heat	Baseline: 16 days per annum > 35°C 2030: Increase by 150% to 40 days 2070: Increase by 300% to 64 days	3
Mean rainfall change	Baseline: 811 mm per annum 2030: Decrease by 14% to 698 mm per annum 2070: Decrease by 17% to 674 mm per annum	2
Extreme rainfall – inland flooding	Baseline: 17 days per annum >150 mm 2030: Increase by 29% to 22 days 2070: Increase by 47% to 25 days	3
Sea level rise – coastal flooding	The 1-in-100-year storm tide event is projected to increase by 51 cm.	1
Drought (see note below)	2030: Increase by 12% potential evaporation 2070: Increase by 22% potential evaporation	3
Wind and hail	See cyclone	3
Cyclones	10% increase in cyclone intensity and frequency, as well as a 130 km shift southwards in cyclone tracks.	3
Bushfires	Increase in bushfire risk – see map.	2
Relative humidity	7 -17% increase	2
	Overall Exposure Rating	**2.4**

Stockland

11

Vulnerability and Resilience Scorecard

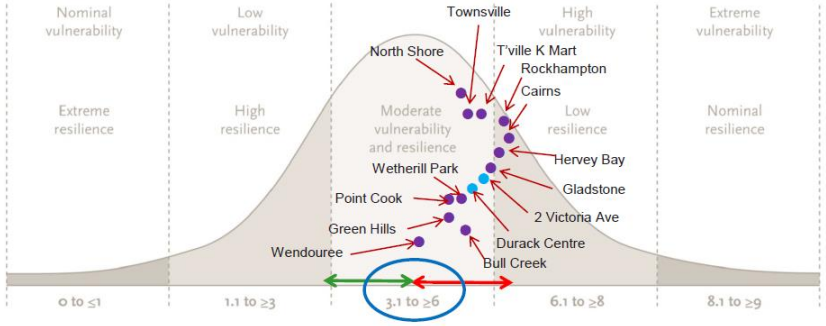
- A score from 1 to 3 is assigned to each criteria in each category
- Scores are aggregated and averaged for a category average
- Category scores are added for an overall score out of 9.

Assessment criteria	Rating
Climate effects – exposure	2.4
Property elements – sensitivity and adaptive capacity	1.8
Climate risks - potential impact	1.8
Overall climate vulnerability and resilience	**6.0**

12

Climate Change Vulnerability and Resilience

Figure 1 Overall climate vulnerability and resilience of property



13

Some adaptation actions identified ...

- Protect HVAC equipment against hail damage
- Model performance of existing HVAC systems to increase in extreme heat days
- Provide facility for 'plug in' emergency power supplies
- Specify heat reflective and thermal 'cool' roofing materials
- Design for increased extreme heat days over 35°C

14

Green Star Communities – Adaptation & Resilience

CREDIT CRITERIA

Up to four points are available in this credit. Each criterion is independent from the other.

Climate adaptation	Two points are awarded where a project specific Climate Adaptation Plan has been developed in accordance with ISO 31000:2009 and the AGO Climate Change Risks and Impacts: A Guide for Government and Business 2006.
Community resilience	Two points are awarded where a project specific Community Resilience Report (CRP) has been developed that addresses preparation, during, and post disaster communication, safety and response, in accordance with the "Community Resilience Report Checklist for developers" developed by Green Cross Australia as part of the Harden Up – Protecting Queensland project which is funded by the Natural Disaster Resilience Program.

15

What are we trying to do?

"what is important is to understand vulnerability and take action to improve resilience"

16

Key Performance Indicators for resilience

From Heat intensity

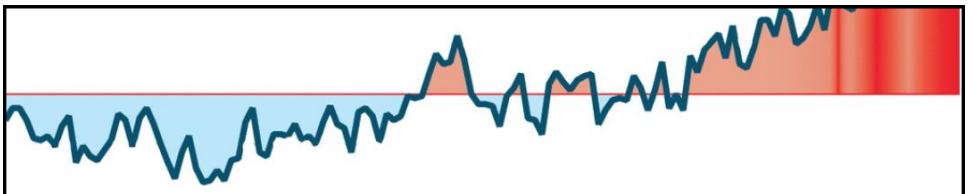
- Magnitude, Amplitude, Tmax
- Duration, Frequency

For what?

- Buildings and passive cooling
  - reduce heat gain
- Active cooling technologies
  - Remove heat (sensible)
  - Remove humidity (latent)
- Personal cooling devices

Cooling KPIs?

- Exposure, vulnerability, risk ratings
- Sensitivity and adaptive capacity
- Robustness, reliability specifications
- Energy
  - Efficiency, peak demand impacts
  - Supply reliability
  - Alternative energy supply



Resilience-Indicators of Cooling Technologies

Initial Definition and Indicators

Shady Attia, Ndongo Eileen, Dahai Qi, Chen Zhang, Ongun Berk Kazanci, X & Per Heiselberg

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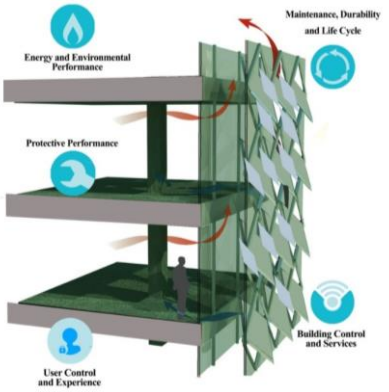
1

How to define resilient cooling and measure it in buildings?





2

IEA EBC Annex 80

OCCuPANt

COST Action TU14030

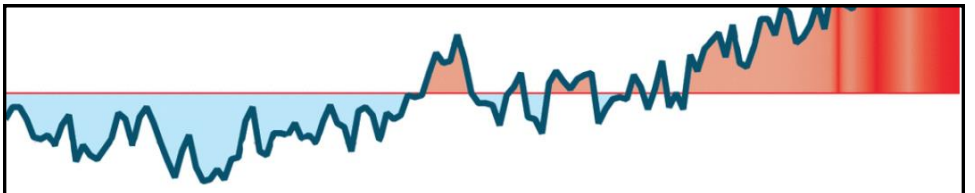
ISO/AWI 52022-5

ISO/TC 163/SC2/WG 15

Advanced Solar Shading

Content

1. Definition of Resilience in other fields
2. Disruptions in Buildings
3. Definition of Resilience of Buildings
4. Indicators of Cooling Technologies
5. Case Studies
6. Discussion and Conclusion



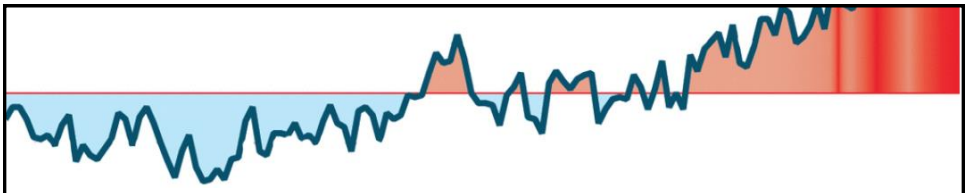
Definition of Resilience in other fields

5

What is Resilience?

- **In physic:** refering to the capacity of an object to return to its origin state after a choc.It's usually associated to the notion of elasticity in material science.
- **In ecology**: first introduced by Holling(1973) as the ability of an ecosytem to rearange its organisation outside of its equilibrium state to another one when facing a perturbation.
- **In engineering:** mesured by the ability of a system to resist perturbations outside of its equilibrium state and its speed to come back to it(Holling,1996).
- **In psychology**: as the capacity of an individual to endure and develop in the context of adverse conditions and to recover.
- **In urbanization:** refering to the capacity of an urban system to absorb a disturbance and recover its functions as a result of this disturbance.

6



Disruptions in Buildings

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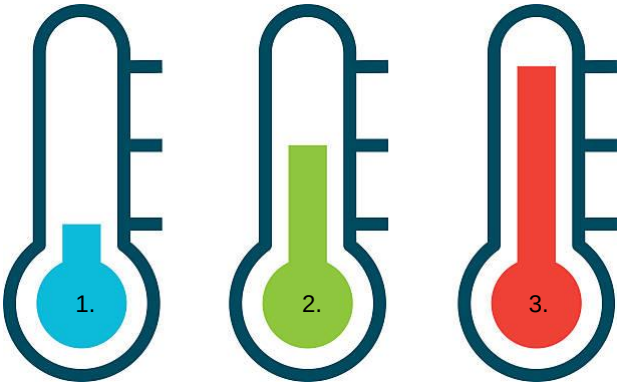
What type of Buildings ?

Several types of buildings exist and depending of their nature, factors of resilient cooling can change:



1. Fully space conditioned: mechanically cooled buildings
2. Hybrid building
3. Free running building: buildings without mechanical cooling during summertime

8

Disruptions in Buildings

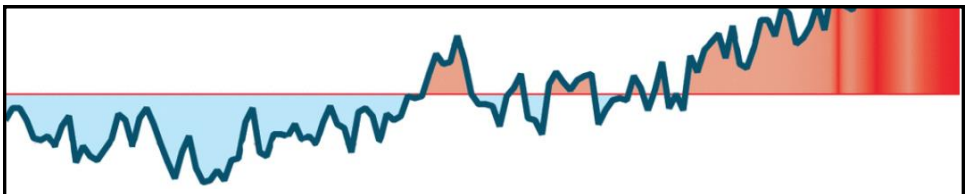
Several types of disruptions in buildings can occur including:

When	Why	How
Monthly Seasonally Daily	1. Flood 2. Contamination 3. Fire **4. Overheating**	• Solar control • Heat modulation • Heat rejection • Humidity control • Personalized systems

Definition of Overheating

With the climate change inducing an increase in mean temperatures, heat waves will become more intense and more frequent resulting into energy and comfort disruptions.

- ❑ Heat waves: a prolonged period of extremely high temperatures for a region
- ❑ Associated Phenomenon :
  - ➢ Building scale
    - ➢ Increase in temperature
    - ➢ High humidity
    - ➢ Direct solar radiation
  - ➢ Urban scale
    - ➢ Heat island effect:artificial microclimate observed in big cities which is characterized by an increase in temperature during the day and at night.Its due to human activities and urbanization.



Definition of Resilience of Cooling Technologies

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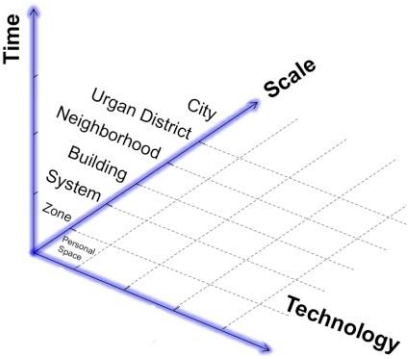
Definition of Resilience of Cooling Technologies

- ❑ Resilient cooling entails the capacity to cool a building passively during an extreme heat wave
- ❑Resilience implies that the disruption (heat wave) has a negative impact on the system (occupant's thermal comfort) but that the building can recover to its original state.



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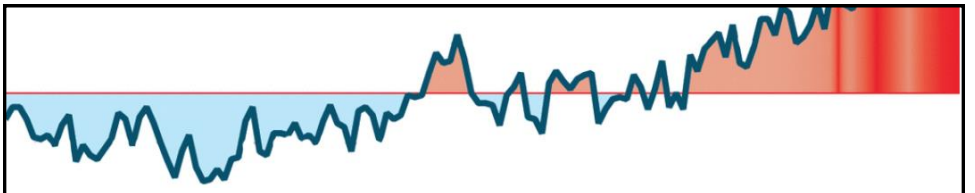


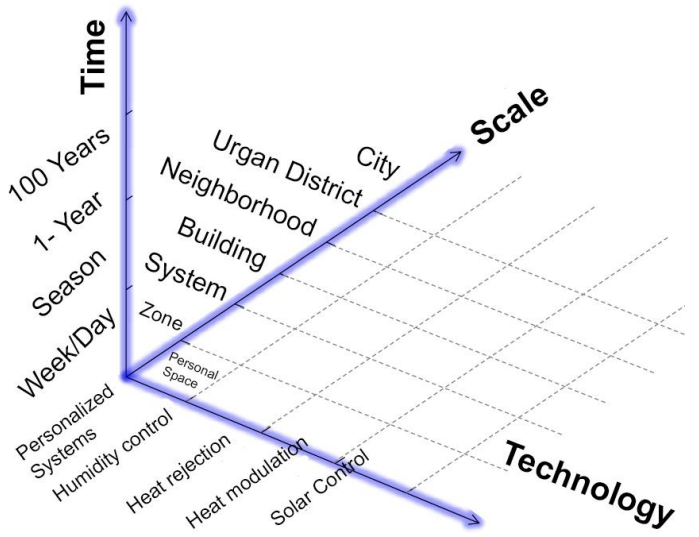
Indicators of Cooling Technologies

Resilience Indicators

- We propose new resilience indicators at two levels:
  - **Indicators of resilient cooling of buildings (Level 1)**

1. Solar control
2. Heat modulation
3. Heat rejection
4. Humidity control
5. Personalized systems

Resilience Indicators

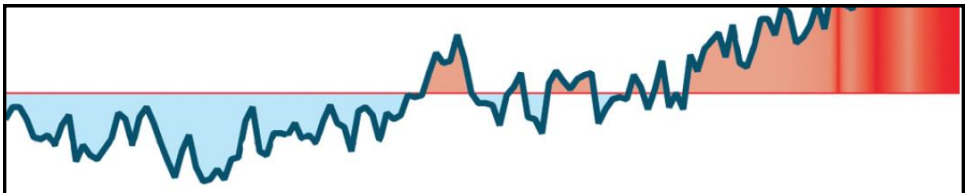


Resilience Indicators

- We propose new resilience indicators at two levels:

  - Indicators of resilient cooling (Level 1)
    1. Solar control
    2. Heat modulation
    3. Heat rejection
    4. Humidity control
    5. Personalized systems

  - **Time factors (Level 2)**
    6. Escalation factor
    7. Potential of ventilative cooling
    8. Urban heat island effect



Case Study

Building 2226

(Baumschlager Eberle Architekten) Austria



- Designed to work without cooling, heating and technical ventilation system
- Heat produced by warmth of human bodies and technical equipment
- Massive building structure used as a thermal mass(wall inner layer provides stability,the outer insulates the building)
- Temperature in the rooms is controlled by sensors (open and close narrow openings that are integrated into the windows) and complemented by optimal lighting conditions

Case Study Evaluation

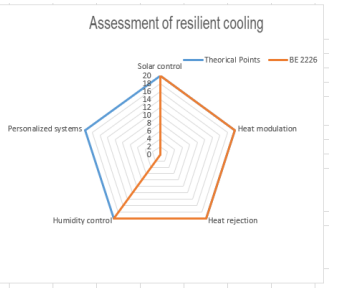


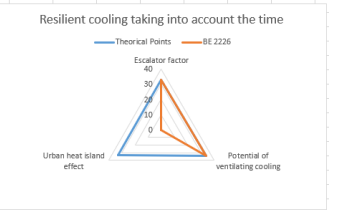
Technologies	Points
Landscaping and vegetation(for insulation)	1.25
Water surface	1.25
multilayer glazing	1.25
vacuum glazing	1.25
electrochromic glazing	1.25
solar cell glazing	1.25
aerogel glazing	1.25
low emissitivity coatings	1.25
photovoltaic ventilated	1.25
thermotropic glazing	1.25
overhangs	1.25
horizontal louvers	1.25
light shelf	1.25
Experimental shading device	1.25
blind systems	1.25
double skin facades	1.25
PCM integration in wallboard	4
PCM integration in ceilings	4
PCM integration in roof	4
PCM integration in window	4
Free cooling	4
Wind driven ventilation	2.5
Buoyancy driven ventilation	2.5
Trombe wall	2.5
Solar chimney	2.5
Direct evaporative cooling (DEC)	2.5
Indirect evaporative cooling (IDEC)	2.5
Nocturnal radiative cooling	2.5
Radiant cooling	2.5
Dessicant dehumidification	10
Humidity control materials(Mesostructured silica-n,Sepiolite,Polyacrylic acid fibers...)	10
Personalized systems	20

factors	Theorical Points	Residential buildings in U.A.E	BE 2226
Solar control	20	20	20
Heat modulation	20	20	20
Heat rejection	20	20	20
Humidity control	20	0	20
Personalized systems	20	0	0
		60%	80%

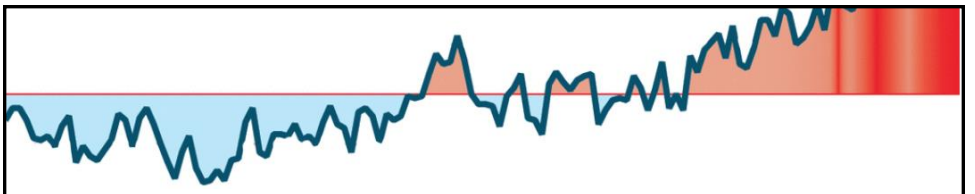
Time factors	Theorical Points	Residential buildings in U.A.E	BE 2226
Escalator factor	33		33
Potential of ventilating cooling	34		34
Urban heat island effect	33		0

solar control
heat rejection
heat modulation
humidity control
personalized systems





Cooling is resilient at 73%

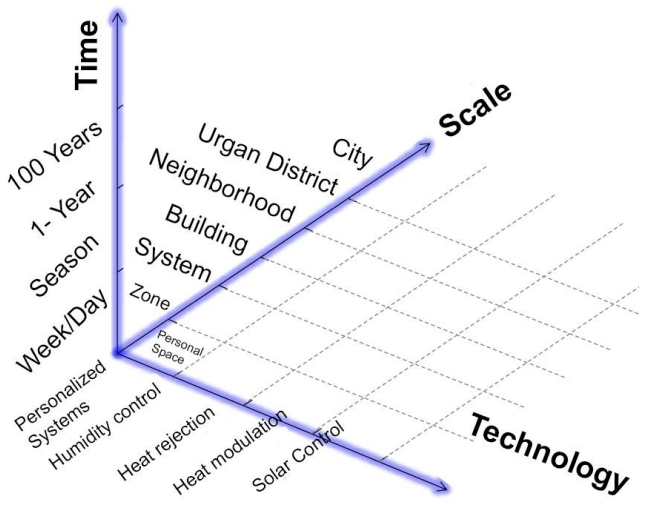


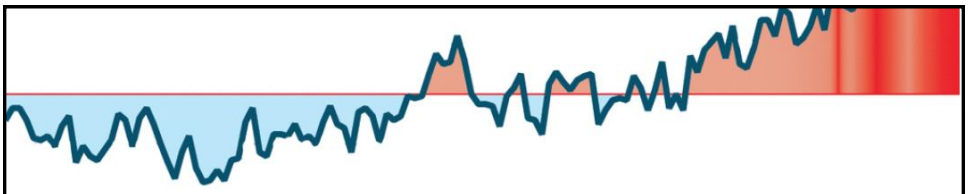
Discussion and Conclusion

Discussion and Conclusion

- How to define comfort and overheating (static or adaptive model) ?
- Will we take into account urban planning and street profile to assess the resilience of buildings ?
- Is climate change going to be part of the indicator ?
- What is the relationship between personalized systems and building type ?

Conclusions: Join Us !





Resilience-Indicators of Cooling Technologies

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❑ Hanan M. Taleb,Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings(2014)

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Assessment of long-term and mid-term building airtightness durability: *field study of 61 French low energy single-family dwellings*

Bassam Moujalled*, Sylvain Berthault, Andrés Litvak, Valérie Leprince, and Gilles Frances

*bassam.moujalled@cerema.fr

1

Introduction

- The French research project **DURABILITAIR (2016-2019)**
  - ✓ *to improve our knowledge on the variation of buildings airtightness through **onsite measurement campaigns (Task 2)** and accelerated ageing in laboratory controlled conditions (Task 3)*
- Literature review (task 1) showed an important evolution over time of the air permeability in real buildings, especially in the first 3 years
- The second task of the project deals with the quantification and qualification of the durability of building airtightness of single detached houses through **field measurement** at:
  - ✓ *mid-term scale (MT)*
  - ✓ *long-term scale (LT)*

2

Methodology

- MT and LT measurement campaigns based on two samples of single-detached low-energy dwellings:
  - ✓ *All dwellings measured upon completion* **[measurement n0]** *and treatment of airtightness well known*
- MT measurement campaign (1-3 years):
  - ✓ *Sample of 30 new single-detached dwellings*
  - ✓ *The airtightness of each dwelling was measured once per year over the 3-year period* **[measurements n1, n2 & n3]**
  - ✓ *Five dwellings were measured twice per year (impact of seasonal variations)*
  - ✓ *For six dwellings, the airtightness of an installed window was measured once per year over the 3-year period*

3

Methodology

- LT measurement campaign (5-10 years):
  - ✓ *Sample of 31 single-detached dwellings constructed during the last 10 years*
  - ✓ *The airtightness of each dwelling was measured once* **[measurement nx]**
- Measurement protocol based on ISO 9972 and its French implementation guide, with additional requirements:
  - ✓ *Measurements to be performed under the same conditions as the measurement upon completion both in pressurization and depressurization*
  - ✓ *Detailed qualitative leakage detection to be performed*
  - ✓ *Questionnaires for occupants to be filled at each measurement regarding the action of the occupants on building envelope*

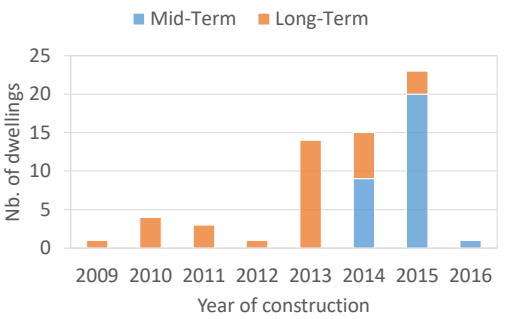
4

RESULTS

5

Characteristics of buildings

Year of construction



Average timespan between measurements

MT sample:

n0-n1 : 1.7 yr (from 1.1 to 2.7)

n1-n2 : 0.7 yr (from 0.4 to 1.2)

n2-n3 : 0.9 yr (from 0.4 to 1.7)

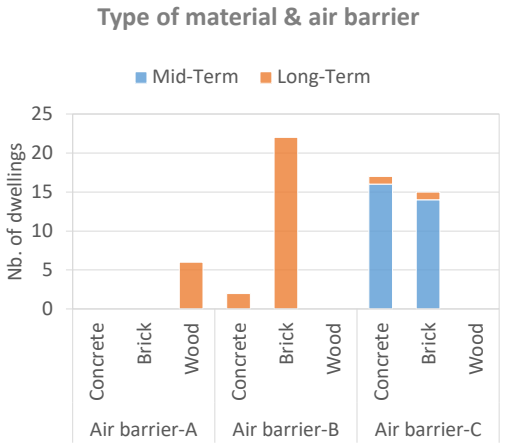
n0-n3 : 3.4 yr (from 2.8 to 4.2)

LT sample:

n0-nx : 4.6 yr (from 2.6 to 8)

6

Characteristics of buildings



MT sample:

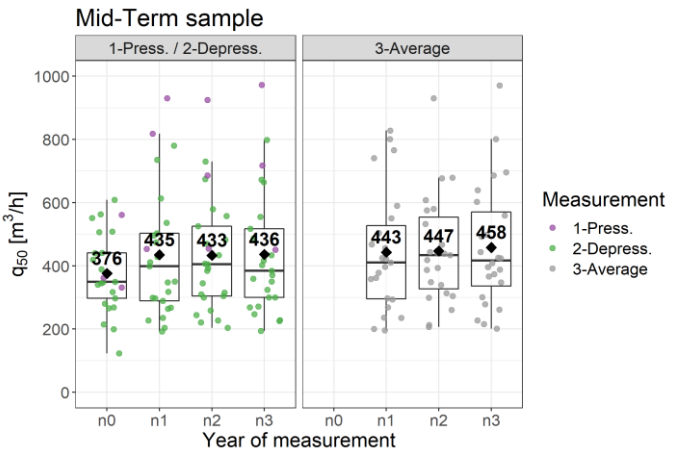
Masonry walls with interior insulation: Airtightness by plasterboards and mastics at the inside facing of the walls (C)

LT sample:

Masonry walls with interior insulation: Airtightness by coating on the masonry (B) or by plasterboards and mastics at the inside facing of the walls (C)

Wood frame houses with insulation between studs: Airtightness by the vapour barrier (A)

Evolution in q_{50}
MT sample



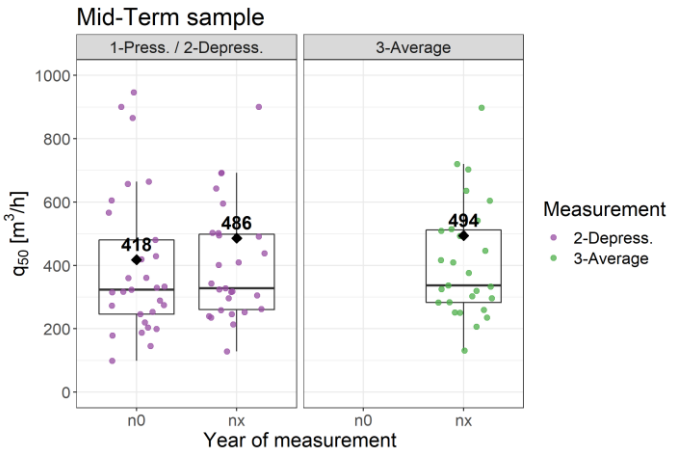
Evolution of mean q_{50}:

n0-n1: +58.9 $m^3.h^{-1}$ / +18%
(p-value = 0.037)
Timespan = 1.7 years

n0-n2: +57.2 $m^3.h^{-1}$ / +18%
(p-value = 0.026)
Timespan = 2.7 years

n0-n3: +60.4 $m^3.h^{-1}$ / +19%
(p-value = 0.037)
Timespan = 3.4 years

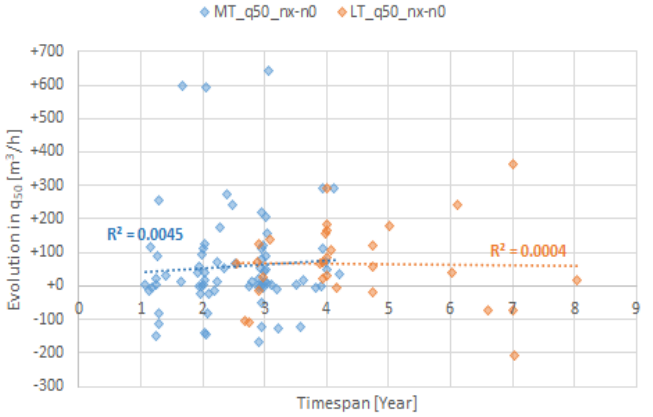
Evolution in q_{50}
LT sample



Evolution of mean q_{50}:

n0-nx: +67.7 $m^3.h^{-1}$ / +20%
(p-value = 0.002)
Timespan = 4.6 years

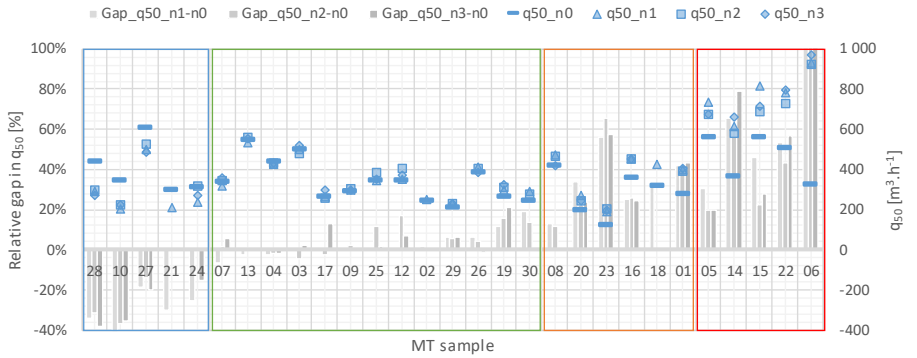
Evolution in q_{50} vs. Timespan
MT & LT samples



No correlation between the evolution in q_{50} and the age of the houses for both MT and LT samples

Analysis of explanatory factors

MT sample



Δq_{50}<-50m³.h⁻¹ — 5 houses

-50 <Δq_{50}<+50 — 13 houses

+50 <Δq_{50}<+150 — 6 houses

Δq_{50}>+150m³.h⁻¹ — 5 houses

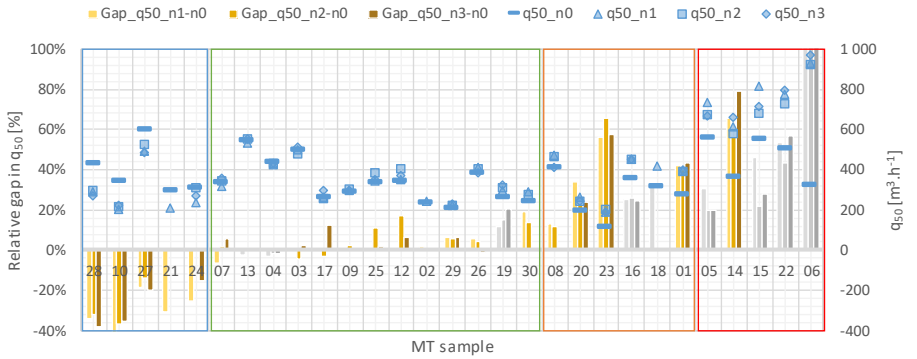
11

Analysis of explanatory factors

Nb. Of levels (MT)

1-storey (20)
2-storey (10)

2-storey houses seems to deteriorate more than 1-storey houses
→ Structural movement?



Δq_{50}<-50m³.h⁻¹ — 5 houses

-50 <Δq_{50}<+50 — 13 houses

+50 <Δq_{50}<+150 — 6 houses

Δq_{50}>+150m³.h⁻¹ — 5 houses

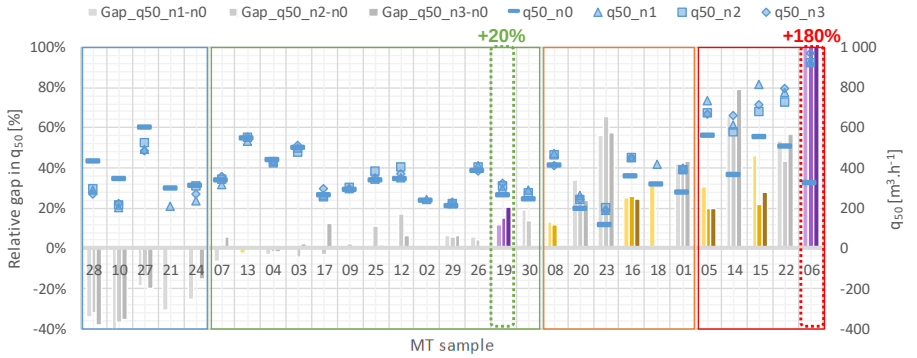
12

Analysis of explanatory factors

Type of roof (MT)

Light frame (20)
Traditional wood frame (8)
Exposed Traditional wood frame (2)

2 exposed wood frame houses with same type of air barrier: +20% vs +180%
→ conditions of implementation?



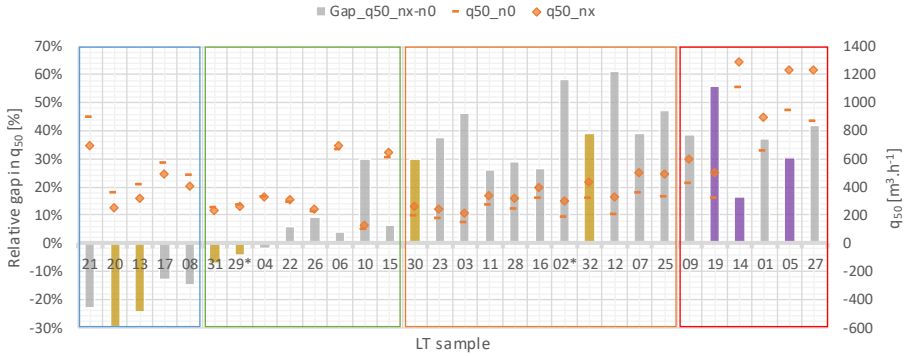
Δq_{50}<-50m³.h⁻¹ — 5 houses
-50 <Δq_{50}<+50 — 13 houses
+50 <Δq_{50}<+150 — 6 houses
Δq_{50}>+150m³.h⁻¹ — 5 houses

Analysis of explanatory factors

Type of material (LT)

Wood frame (6)
Hollow bricks (21)
Concrete blocks (3)

Wood houses tend to stabilise or even improve over years
→ expansion of wood with humidity?



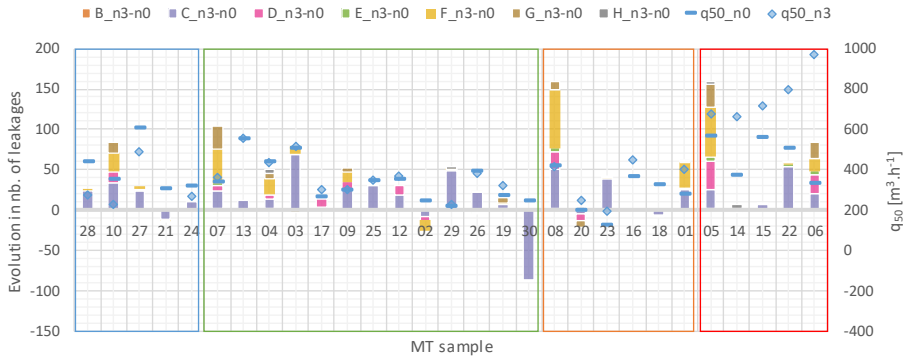
Δq_{50}<-50m³.h⁻¹ — 5 houses
-50 <Δq_{50}<+50 — 8 houses
+50 <Δq_{50}<+150 — 11 houses
Δq_{50}>+150m³.h⁻¹ — 6 houses

Evolution of leakages

MT sample: n3-n0

Increase of leakages C, F, D & G
NO CORRELATION with the evolution in q_{50}

B: junctions wall/slab
C: doors and windows
D: penetration through envelope
E: trapdoor
F: electrical components
G: junctions wall/window
H: other leakages



Δq_{50}<-50$m^3.h^{-1}$ | -50 <Δq_{50}<+50 | +50 <Δq_{50}<+150 | Δq_{50}>+150$m^3.h^{-1}$

15

CONCLUSIONS

16

Conclusions

- **Same evolution of airtightness at mid and long term**
  - ✓ Similar increase in q_{50} at mid and long-term (+18% and +20% respectively)
  - ✓ No correlation with the age of construction
  - ✓ Deterioration mainly during the first 2 years and then stabilisation
- **Significant increase in the number of leakages for:**
  - ✓ Doors and windows, electrical components, penetrations through envelope & junctions between walls and windows
  - ✓ But no correlation with the variation in q_{50}

Conclusions

- **Explanatory factors of the evolution of the airtightness:**
  - ✓ No impact for constructor, type of air-barrier, type of floor, type of heating, specific HVAC equipment
  - ✓ No impact for seasonal variation
  - ✓ The airtightness of wood houses tend to stabilise or even improve over years
  - ✓ 2-storey houses seems to deteriorate more than 1-storey ones
  - ✓ Studied factors unable to explain the variations:
    - ✓ **Other factors, such as conditions of implementation of the air-barrier, need to be explored**

Thanks…

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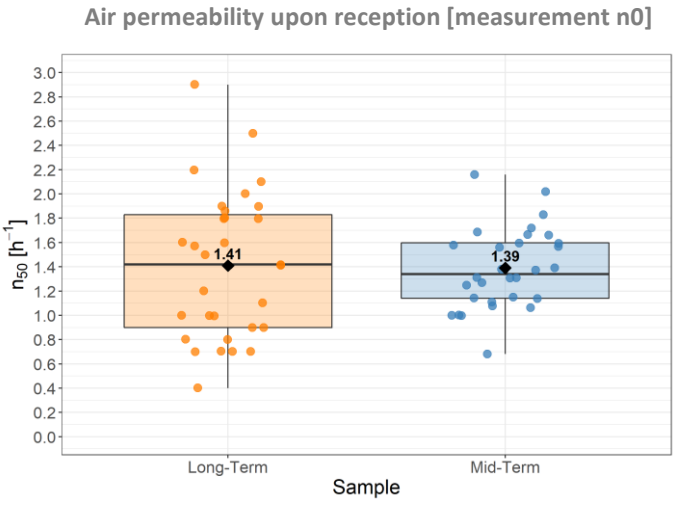
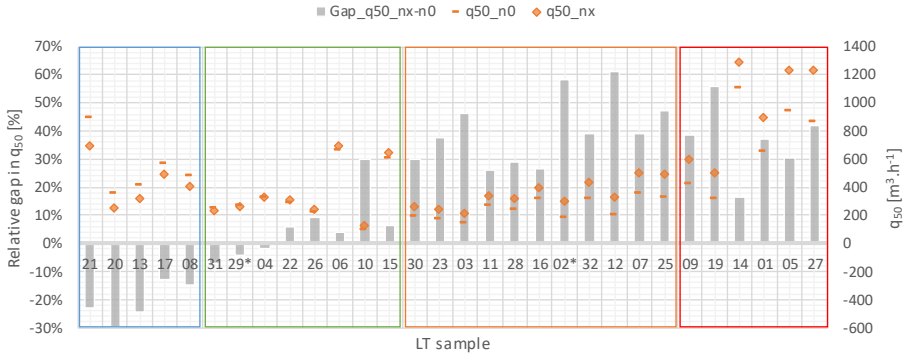
Characteristics of buildings



Analysis of explanatory factors

LT sample



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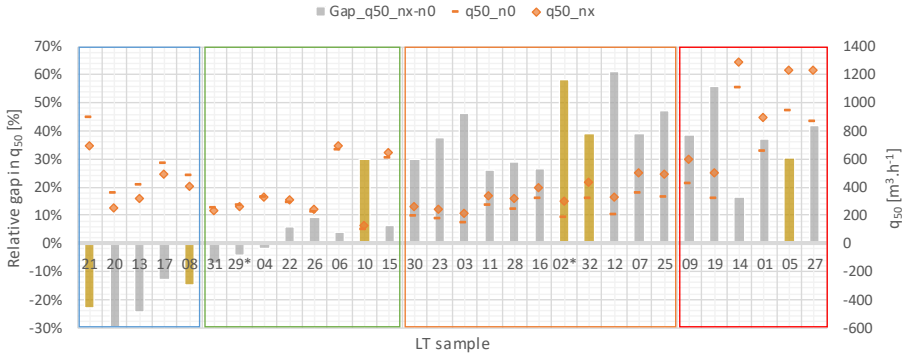
+50 <Δq_{50}<+150 — 11 houses

Δq_{50}>+150m³.h⁻¹ — 6 houses

Analysis of explanatory factors

Nb. of levels (LT)

1-storey (6)
2-storey (25)



Δq_{50}<-50m³.h⁻¹ — 5 houses

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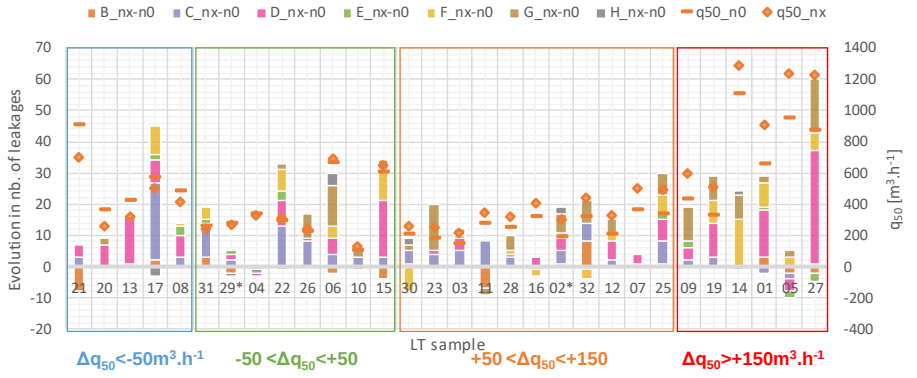
Δq_{50}>+150m³.h⁻¹ — 6 houses

Evolution of leakages

LT sample: nx-n0

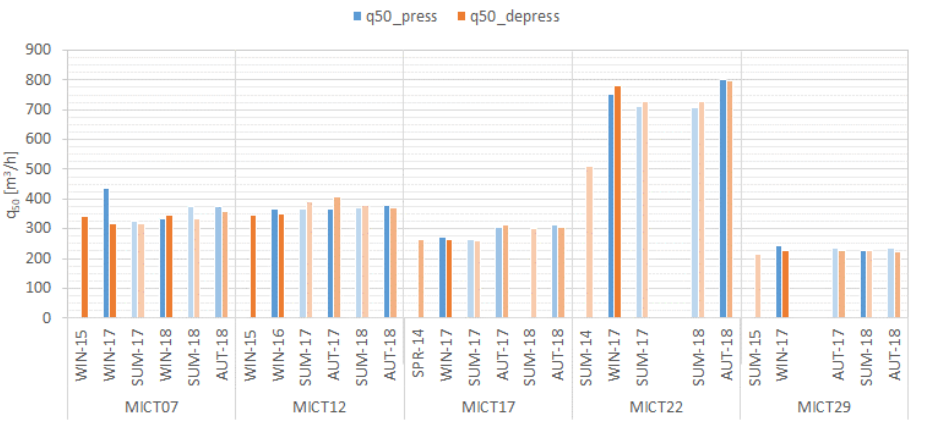
B: junctions wall/slab
C: doors and windows
D: penetration through envelope
E: trapdoor
F: electrical components
G: junctions wall/window
H: other leakages

Increase of leakages C, F, D & G
NO CORRELATION with the evolution in q_{50}



Impact of seasonal variations

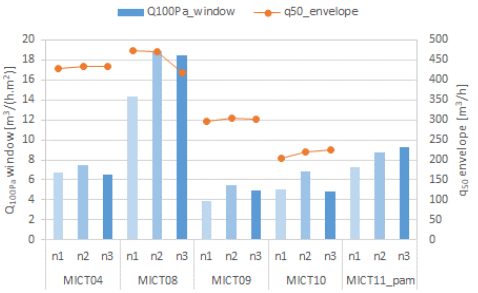
Not possible to identify seasonal variation of q_{50}



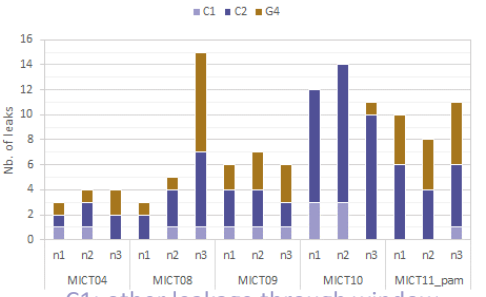
Evolution of windows air permeability

Small variations in the air permeability of windows
NO CORRELATION with the detected leakages

Air leakage rate at 100 Pa



Nb. of leakages



C1: other leakage through window
C2: junction window leaf/frame
G4: junction window/wall

25

Assessment of the durability of airtightness products in laboratory controlled conditions: *development and presentation of the experimental protocol*

Andrés LITVAK*, Fabien Allègre, Bassam Moujalled and Valérie Leprince,

*andres.litvak@cerema.fr

1

- The French research project **DURABILITAIR (2016-2019)**
  - ✓ *to improve our knowledge on the variation of buildings airtightness through onsite measurement campaigns (Task 2) and **accelerated ageing in laboratory controlled conditions (Task 3)***

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40th AIVC - 8th TightVent & 6th Venticool Conference
15-16 October 2019 | Ghent, Belgium

2

Introduction



- Literature review (task 1) pointed the importance of **well defining the sample to be tested** (products assembly v/s product alone) and the **ageing protocol conditions**.
- Due to the diversity of airtightness products, it is probably **impossible to define an accelerated ageing universal protocol** that would be equivalent to a known amount of years of natural ageing.

3

Introduction



- No standardized protocol / General conclusions can be drawn:
  - ✓ ***Implementation*** *has a strong impact on durability*
  - ✓ *Products do not have the same reaction* ***under normal*** *conditions as when they are subjected to* ***extreme conditions*** *(temperature, humidity or pressure);*
  - ✓ *A* ***standardized procedure*** *for the ageing of sealants is lacking to characterize products and especially* ***assemblies*** *regarding airtightness performance;*
  - ✓ *The results of ageing tests on* ***products alone*** *are not necessarily consistent with the ageing observed when these products are* ***put in situation****;*
  - ✓ ***Product performance*** *against conventional test procedures (peel, shear, etc.) does not necessarily correspond to their* ***performance in terms of airtightness***
  - ✓ *The ageing strategy must be consistent with the* ***loads*** *of the products. The strategy may differ depending on the* ***position of the air barrier****.*

4

Methodology

- We developed an experimental protocol for accelerated ageing of airtightness assembled products.
- The protocol definition consisted in :
  1) *developing an experimental chamber,*
  2) *choosing representative samples,*
  3) *defining the accelerated ageing conditions.*

5

Methodology

- Environmental chamber
  - ✓ *An accelerated weathering chamber (see A)*
  - ✓ *A pressure test bench for differential pressure exposure and airtightness measurement (see B)*
  - ✓ *A sample holder, between both enclosures (see C)*

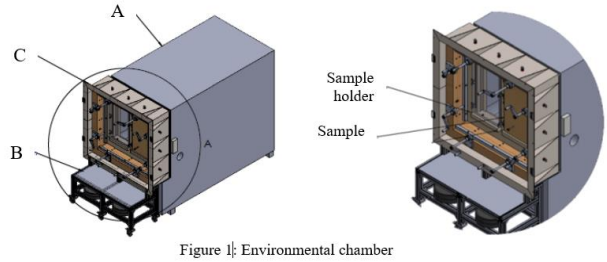
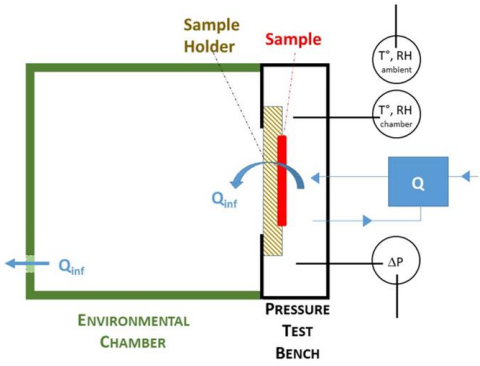


Figure 1: Environmental chamber

6

Methodology

- Environmental chamber



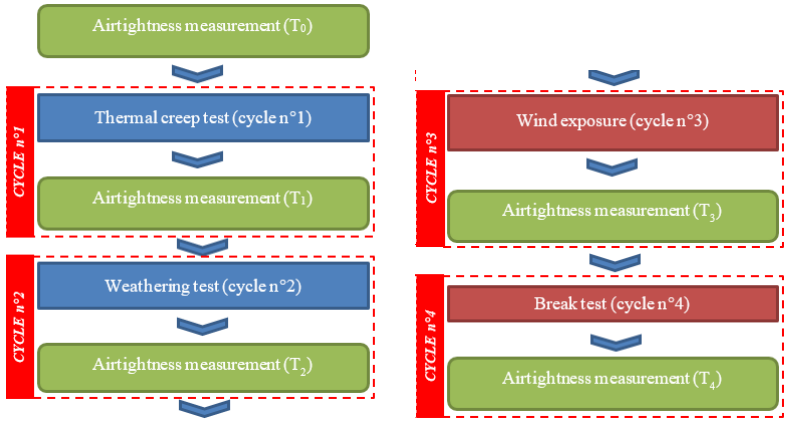




7

Methodology

- Exposure cycles and airtightness measurements



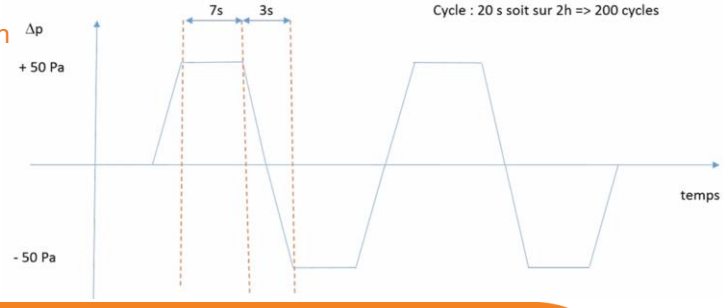
8

Methodology

- Exposure cycles and airtightness measurements

Cycle n°1 : « Thermal creep test »

- ✓ 60°C & 50%RH (for 21h)
- ✓ Wind cycle ±50 Pa for 200 cycles (2 h)
- ✓ Duration : ≈ 24h



9

Methodology

- Exposure cycles and airtightness measurements

Cycle n°2 : « Four seasons »

- ✓ Summer : 30 °C & 45 % RH (24 h)
- ✓ Autumn : 5°C (24 h)
- ✓ Spring : 15°C & 60 % RH (24 h)
- ✓ Winter : -10°C (24 h)
- ✓ Stabilization period (12 h)
- ✓ Duration : (4,5 days)



10

Methodology

- Exposure cycles and airtightness measurements

Cycle n°3 : « wind test »

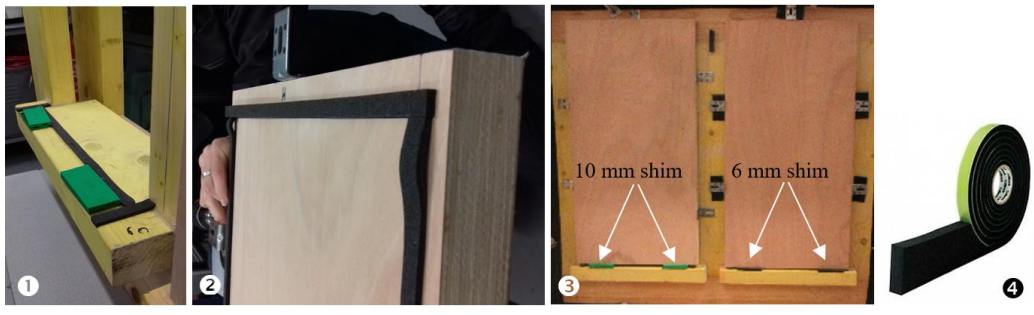
- ✓ Pressure cycles from -250 Pa to +250 Pa, (50 Pa steps)
- ✓ 8 hour cycles / 3 times
- ✓ total duration = 24 hours

Cycle n°4 : « Break test »

- ✓ Temperature increase : 1°C/min until T < 180 °C
- ✓ If no leakage, T = 180 °C for 1 hour

Methodology

- Samples :
  - ✓ Expansive weather seal foam ;
  - ✓ Sealant (mastic) with backing foam
  - ✓ Adhesive and membrane complex.



Methodology

- Samples :
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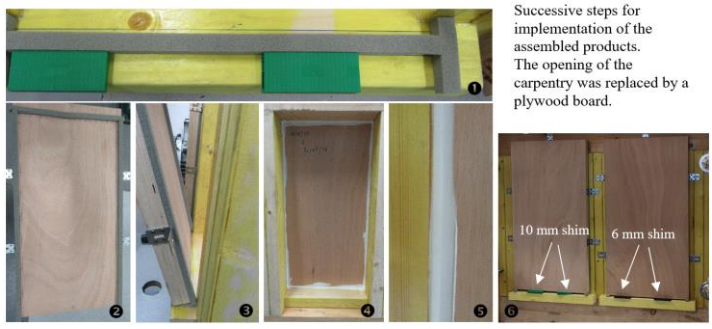
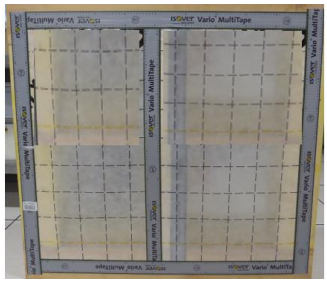


Successive steps for implementation of the assembled products. The opening of the carpentry was replaced by a plywood board.

13

Methodology

- Samples :
  - ✓ Expansive weather seal foam ;
  - ✓ Sealant (mastic) with backing foam
  - ✓ Adhesive and membrane complex.



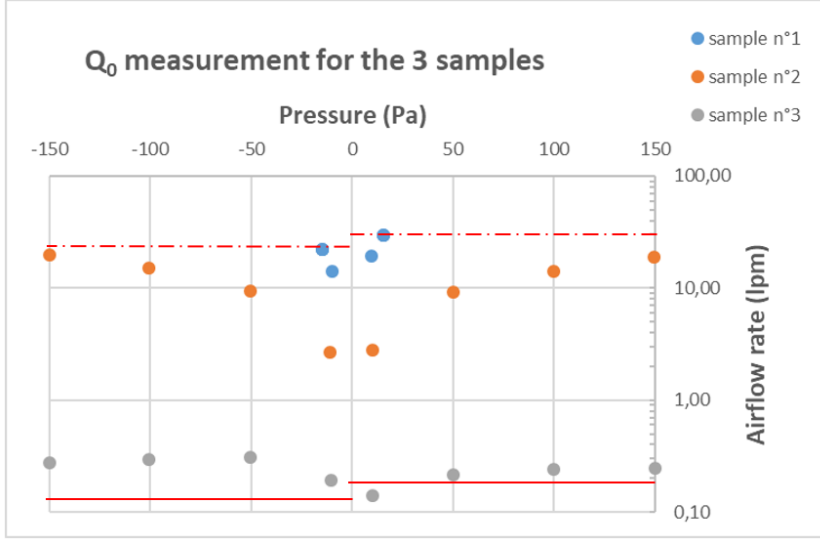
- the cut-out membrane was positioned flat on the sample support at 3 cm from the edge of the left upright and centered in height
- the membrane was stapled on all edges by positioning a staple every 5 cm around orienting the staples at 45 °
- Adhesive tape was pasted on the central part taking care not to fold

14

RESULTS

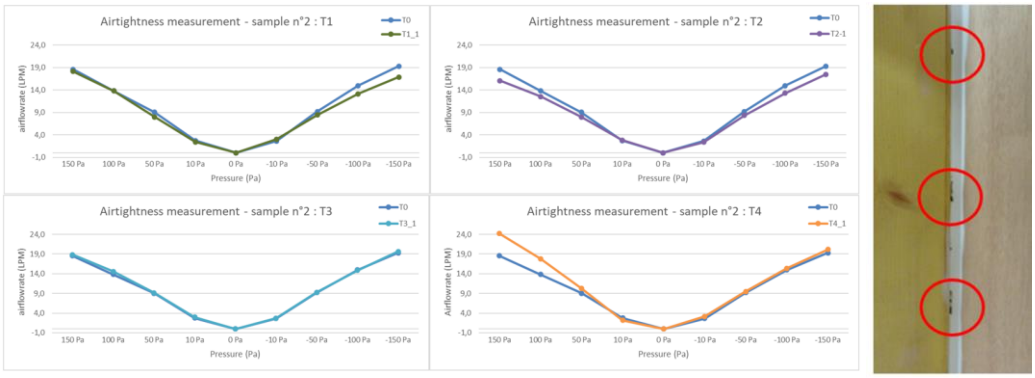
15

Initial measurements :



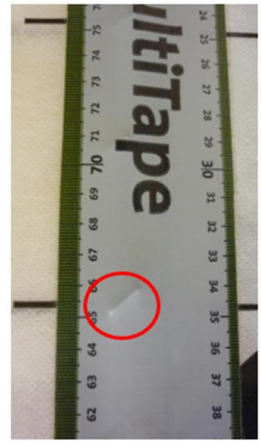
16

Evolution of air permeability flowrates for sample 2 for the weathering cycle (4 tests):



Evolution of air permeability flowrates for sample 3 for the weathering cycle (4 tests):

- Sample 3 was very airtight, thus, it was very sensitive to pressure variations (both positive and negative).
- We did not notice any significant deterioration of the air permeability flowrates for the first 3 tests of the cycle.
- For the break test (test n°4), the rupture occurred after 40 min, at the temperature of 60°C.





CONCLUSION

Conclusions

- The three types of samples made of assembled products as treatments of carpentry airtightness showed very different results, according to the maximum compensation capacity of the air permeability flow rate of the bench.
- Sample 1 (expansive weather seal foam) appeared to be too porous for our equipment, whereas Sample 3 (adhesive and membrane complex with staples) appeared to be too airtight.

Conclusions

- Sample 2 : The rupture occurred at 120 ° C and showed a significant decrease of the airtightness of the sample.
- We measured a slight deterioration of airtightness of up to +7%.
- Nevertheless, we could not draw any conclusion about the artificial ageing of the protocol, due to the elevated temperature of rupture. (the experimental conditions of test n°4 for sample 2 may probably contradict the statement “Never test products beyond their real life exposure conditions”)

Conclusions

- The improvement airtightness during the ageing cycle of sample 2 is probably due to the humidity for the “thermal creep test” and the “weathering test” ; thus we recommend to use inert materials as sample holders for future works.
- Field measurement results from Task 2 about airtightness durability showed that wood structure houses tend to improve over years (Moujalled, 2019) ; probably due to the expansion of the wood with the humidity, that would clog leakages.

Conclusions

- **The wind exposure test 3 of the ageing cycle on sample 2 shows a very moderated increase of air permeability. We think that the duration of this cycle was too short, and that exposure durations of at least 1000 h (approximately, 1.5 month) should be necessary.**

- For future works, we plan to investigate a better **compromise** between **signal stability, usage range and control reactivity** on airflow rate, and the exposure protocole conditions.

Thanks…

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Cerema PLEIAQ CETIE RESCOLL Centre Technologique

Durabilit'AIR

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➲ **internet website ( ) : www.durabilitair.com**

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MOISTURE IMPACT ON DIMENSIONAL CHANGES AND AIR LEAKAGE IN WOODEN BUILDINGS

FREDRIK DOMHAGEN
PAULA WAHLGREN

1

BACKGROUND

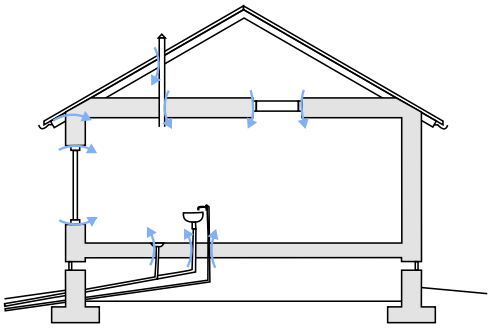
- Increased use of wood
  - Reduced carbon footprint (compared to conventional building materials)
  - Production cost
  - Increased competitiveness



2

BACKGROUND

- Challenges with wood constructions:
  - Fire resistance
  - Sound propagation
  - Durability
  - **Airtightness**



BACKGROUND

- Field measurements
- Moisture induced dimension changes
- Air leakage calculations
- Tape durability
- Drying time calculations
- Leakage change and heat exchanger

BACKGROUND

- **Field measurements**
- Moisture induced dimension changes
- Air leakage calculations
- **Tape durability**
- Drying time calculations
- **Leakage change and heat exchanger**

FIELD MEASUREMENTS

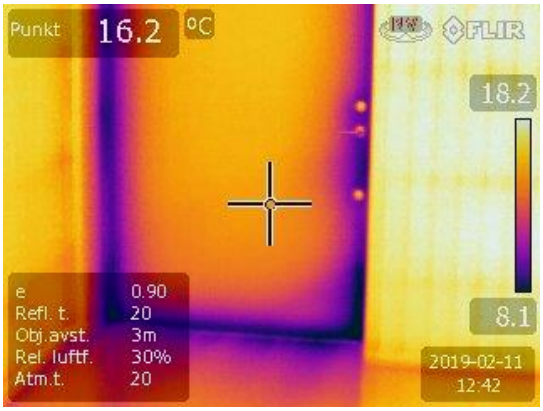
- School Building
- Wooden window frames
- Blower Door tests



FIELD MEASUREMENTS

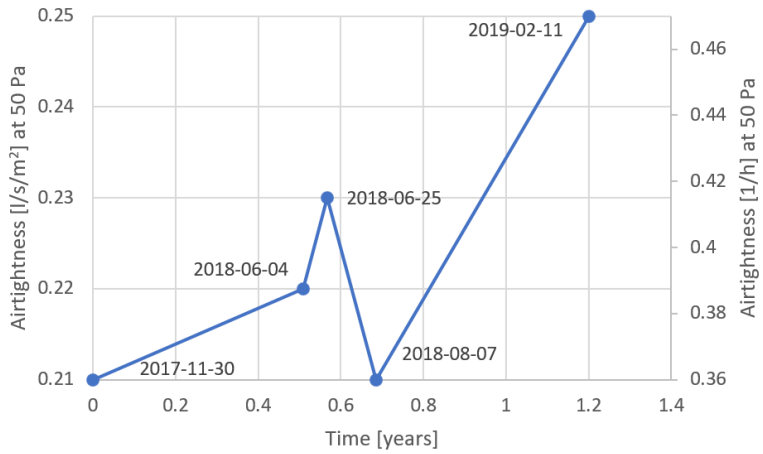


Window



Door

FIELD MEASUREMENTS



FIELD MEASUREMENTS

- Cause: inbuilt moisture drying
- Dimensional changes caused by moisture
- Thermal expansion may affect airtightness



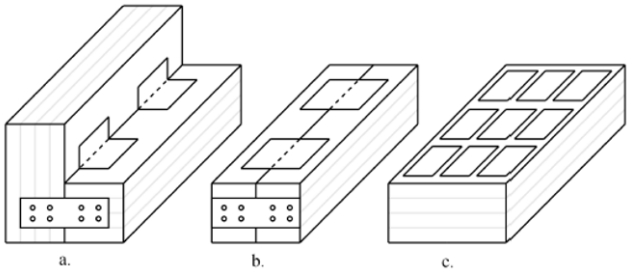
TAPE DURABILITY

- Tape common method in CLT-constructions
- Tape durability is tested in lab



TAPE DURABILITY

- 50 cycles (RH: 80% to 10%)
- Corners (a), Joints (b) and Imperfect underlay (c)



TAPE DURABILITY

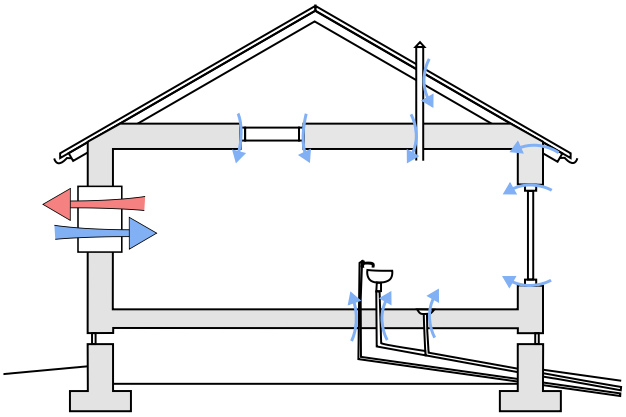
- Creases and Bubbles (dusty surfaces) worse after cycling





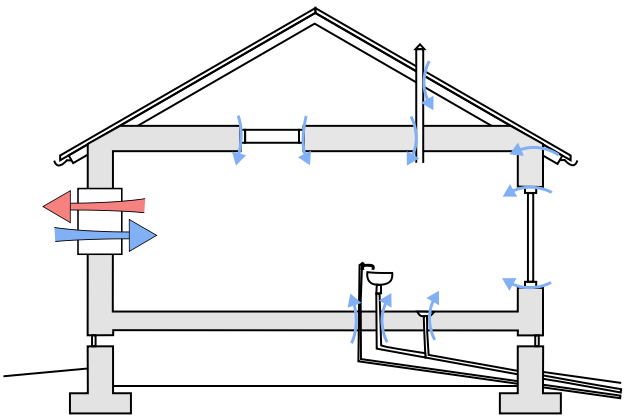
HEAT EXCHANGER

- Infiltration Model
  - Heat exchanger
  - Output: air leakage and airflow through heat exchanger
- Climate
  - Calm day
  - Temperature exterior: -4 °C



HEAT EXCHANGER

- Airtightness change: 0.6 – 1.2 [l $s^{-1}m^{-2}$] at 50 Pa
- Efficiency increase: 1.2 %
- Heat loss from increased air leakage: 320 W



CONCLUSIONS

- Field measurements: 20 % decrease in airtightness
- Tape durability: Depends on craftmanship
- Heat exchanger: minor effects on efficiency



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FACULTY OF ENGINEERING AND ARCHITECTURE

DEPARTMENT OF ARCHITECTURE AND URBAN PLANNING
BUILDING PHYSICS, CONSTRUCTION AND SERVICES RESEARCH GROUP

ASSOCIATION BETWEEN INDOOR AIR QUALITY AND SLEEP QUALITY

Chenxi Liao, PhD student

GHENT UNIVERSITY

1

OUTLINE

- Background
  - About sleep
  - Indoor air and sleep
- Methods
  - Study design
  - Sleep quality
  - Other parameters related to sleep
  - Indoor environment
  - Statistical analyses
- Results
- Conclusion
- Acknowledgements



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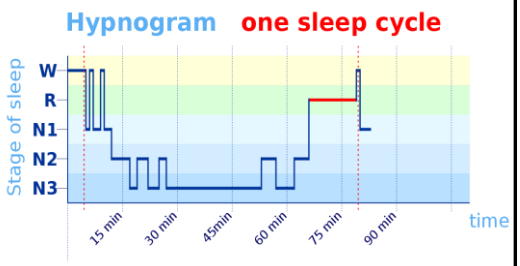
2

BACKGROUND

- About sleep
  - We spend 1/3 of our lives asleep
  - 4 stages of sleep during a normal night (N1, N2, N3 and REM sleep)
  - Stages progress cyclically (N1-3, then REM, restart back at N1)
  - One complete cycle takes about 90 minutes
  - Specific hormones increase during sleep (Melatonin)



Sleep cycle (Source: Wikipedia)

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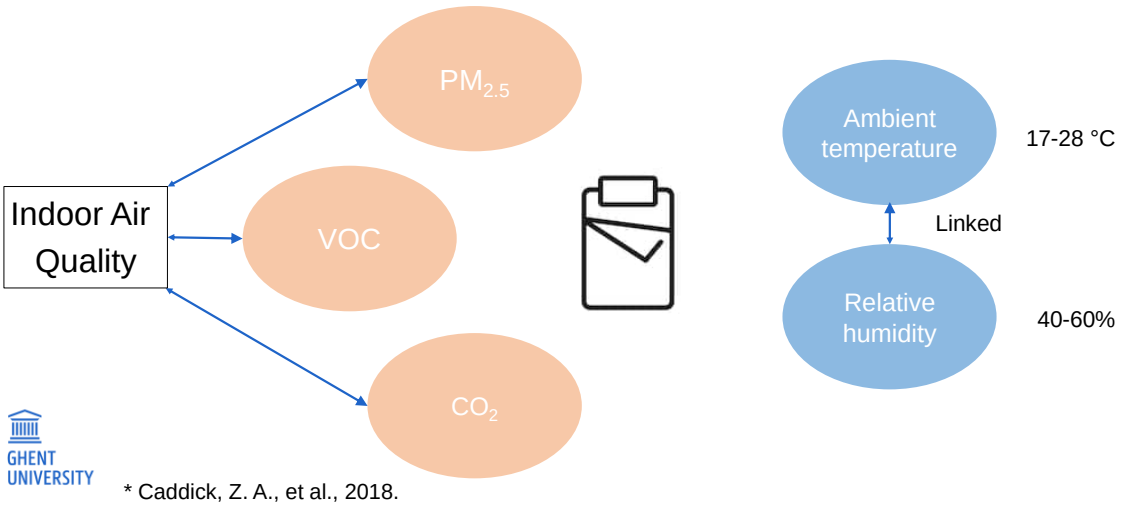
BACKGROUND

- Indoor air parameters and sleep *



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* Caddick, Z. A., et al., 2018.

METHODS: STUDY DESIGN

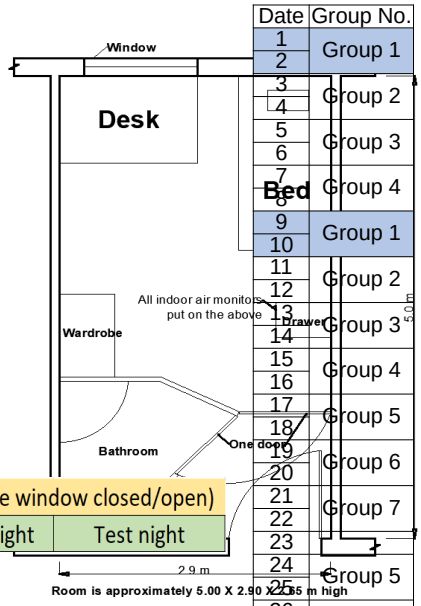
- Self-controlled case series method
- Base: 4 rooms next to each other and furnished uniformly in the university dorm (the same type of covers)
- Samples: 27 subjects 20-33 yrs.
- Pittsburgh sleep quality index (PSQI): ≤ 5
- Two phases - two nights in one phase (one adaptive, one test) - one-week washout period
- Experiment period: 1-30 April, 2019

Study schedule

Phase 1 (The window closed/open)		One-week washout	Phase 2 (The window closed/open)	
Adaptive night	Test night		Adaptive night	Test night

The 1st window conditions of the 4 rooms

Room	A	B	C	D
The 1st window condition	Open	Closed	Open	Closed



Top view of the room

Date	Group No.
1	Group 1
2	
3	Group 2
4	
5	Group 3
6	
7	Group 4
8	
9	Group 1
10	
11	Group 2
12	
13	Group 3
14	
15	Group 4
16	
17	Group 5
18	
19	Group 6
20	
21	Group 7
22	
23	
24	Group 5
25	
26	Group 6
27	
28	Group 7
29	

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5

METHODS: SLEEP QUALITY

- 4 Fitbit (Wake, light, deep and REM sleep)
- 2 sets of the home polysomnography (PSG) (Wake, N1, N2, N3, REM sleep)
- Groningen sleep quality scale (GSQS)

A	*B*	*C*	*D*
Fitbit PSG	*Fitbit PSG*	*Fitbit*	*Fitbit*



Fitbit Charge 2



The Nox A1 from Resmed (home PSG)

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METHODS: SLEEP QUALITY

- Sleepiness – Karolinska sleepiness scale (KSS)
- Performance – Attentional network test (ANT)
- Biomarker – Urinary melatonin metabolite – 6-sulfatoxymelatonin (aMT6s) (enzyme-linked immunosorbent assay (ELISA))



Melatonin-Sulfate Urine ELISA kit from IBL company

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METHODS: IMPACT FACTORS

- Personal characteristics: age, gender and BMI
- Food and drinks: coffee, alcohol, caffeine drinks, tea, tobacco and drug
- Intensive physical activities
- Psychological parameters: mood and stress (Profile of Mood States (POMS) and Perceived Stress Scale (PSS))

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METHODS: INDOOR ENVIRONMENT

Table 3: Indoor parameters and the monitors

Parameter	Monitor	Accuracy	Measuring range	Interval
Ambient temperature	Netatmo	± 0.3 °C	0-50 °C	5 min
Relative humidity		± 3 %	0-100 %	
CO_2		± 50 ppm (from 0 to 1000 ppm) ± 5% (from 1000 to 5000 ppm)	0-5000 ppm	
Noise		-	35-120 dB	
TVOCs	Awair	± 10 %	175-3500 ppb	
$PM_{2.5}$		± 15 %	0-500 µg/m³	
Bed temperature	HOBO U12-012	± 0.35 °C	-20-70°C	



Netatmo



Awair

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Sleep environment questionnaires (0-10 visual analog scales)

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METHOD: STATISTICAL ANALYSES

- Mann-Whitney *U* tests
- Spearman correlation analysis
- Multivariate linear regression models
- Agreement analysis (sleep parameters from Fitbit and PSG)

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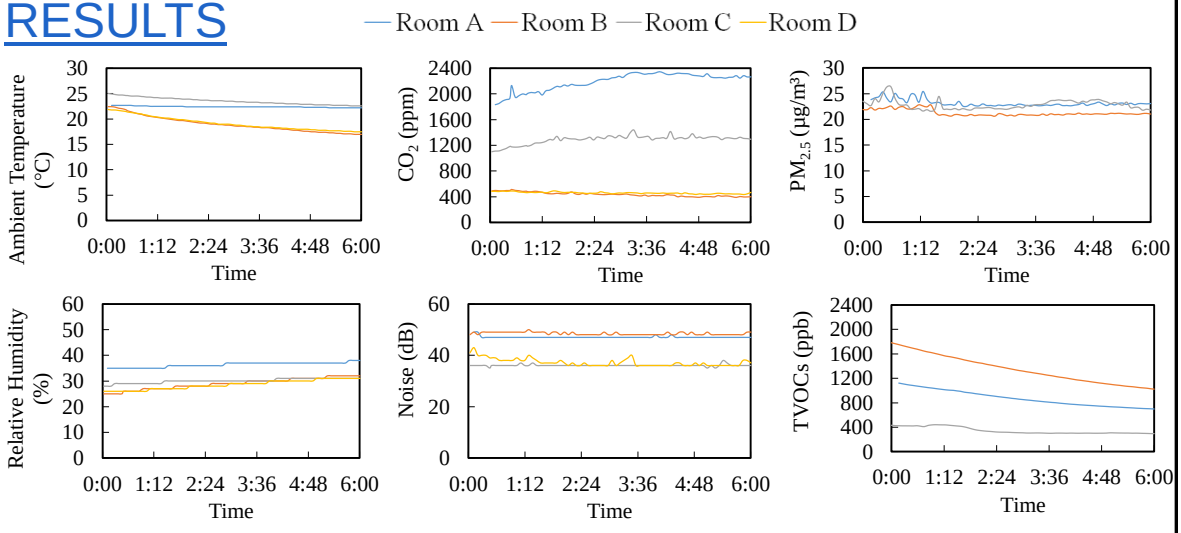
RESULTS



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Ambient temperature, relative humidity, CO_2, noise, $PM_{2.5}$ and TVOCs from 0:00 to 6:00 at a typical night (Rooms A & C with the windows closed; Rooms B & D with the windows open).

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RESULTS

Intraclass correlation coefficient (ICC) of the sleep parameters from Fitbit and PSG

Items (from Fitbit/PSG)	ICC (95% CI)	*p*-value
Sleep start time/Analysis start time	**0.859 (0.660-0.941)**	**< 0.001**
Sleep end time/Analysis stop time	**0.866 (0.665-0.945)**	**< 0.001**
Asleep/TST (min)	**0.858 (0.663-0.940)**	**< 0.001**
Awake/Wake (min)	0.144 (-0.299-0.530)	0.253
TIB/Analysis duration (min)	**0.823 (0.580-0.926)**	**< 0.001**
REM (min)	0.042 (-1.398-0.608)	0.463
Light/N1+N2 (min)	**0.531 (-0.143-0.806)**	**0.048**
Deep/N3 (min)	-0.209 (-1.966-0.502)	0.665
Sleep efficiency (%)	0.327 (-0.242-0.684)	0.055
REM (%)	-0.215 (-2.153-0.51)	0.663
Light (%)	-0.334 (-2.249-0.449)	0.743
Deep (%)	0.230 (-0.755-0.673)	0.270
Sleep latency (min)	**0.669 (0.221-0.861)**	**0.007**
Number of awakenings (times)/AI (times/h)	-0.035 (-0.224-0.246)	0.622
Number of awakenings/Arousal count (times)	0.041 (-0.229-0.373)	0.398
Number of awakenings/Arousal count in wake (times)	-0.005 (-1.244-0.569)	0.505

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Bold indicates *p*-value < 0.05. TST: total sleep time; TIB: time in bed; AI, arousal index.

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RESULTS

β and 95% confidence interval (CI) of sleep parameters and window/PSG conditions related factors from multivariate linear regression models adjusted by age, gender and BMI

Items	Window/PSG related	β (95% CI)	*p*-value
GSQS and window-condition related factors (average CO_2 and self-reported noise)			
GSQS	Noise (self-reported)	0.294 (0.016 - 0.572)	0.039
Sleep parameters from Fitbit and PSG-condition related factors (stress, average $PM_{2.5}$, the 95th percentile of ambient temperature and the 95th percentile of noise)			
TIB (min)	Stress	5.590 (0.903 - 10.278)	0.022
Asleep (min)		5.009 (0.831 - 9.186)	0.021
REM sleep (min)		2.435 (0.183 - 4.688)	0.036
Awake (min)	Average $PM_{2.5}$	1.546 (0.124 - 2.968)	0.035
Awake (%)		0.342 (0.091 - 0.592)	0.010
Sleep efficiency (%)		-0.342 (-0.592 - -0.091)	0.010
Number of awakenings (times)	The 95th percentile of ambient temperature	3.074 (0.331 - 5.816)	0.030

GSQS, Groningen sleep quality scale.

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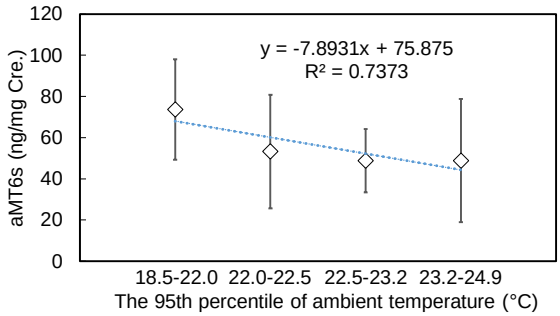
RESULTS

Multivariate linear regression analyses of ln-transformed urinary concentrations of aMT6s and related indoor parameters adjusted by BMI

Indoor parameters	β (95% CI)	p-value
The 95th percentile of ambient temperature	-0.104 (-0.211 - 0.003)	0.057
Average noise	-0.013 (-0.033 - 0.006)	0.183



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Average urinary concentrations of aMT6s and the 95th percentile of ambient temperature. Error bar indicates standard deviation.

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CONCLUSION

- The participants reported better sleep quality sleeping with quieter surroundings (windows closed).
- Higher $PM_{2.5}$ levels increased the time and percent awake and decreased sleep efficiency.
- Higher ambient temperature increased the number of awakenings.
- Urinary concentrations of aMT6s tended to be lower with the higher ambient temperature.

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ACKNOWLEDGEMENTS

- Evelien Bouwens from the Resmed company
- Koen Deventer, Nicolas Van Haecke and Péter Judák from the Doping Control Lab at Ghent University
- Benjamin Hanoune from University of Lille
- All the participants

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Thanks for your attention!

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9 MONTHS OF IN SITU-MEASUREMENTS ON
SMART VENTILATION SYSTEMS IN BELGIUM :

BIG BEDROOM DATA

AIVC 2019

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The Context:
IoT connected AHU

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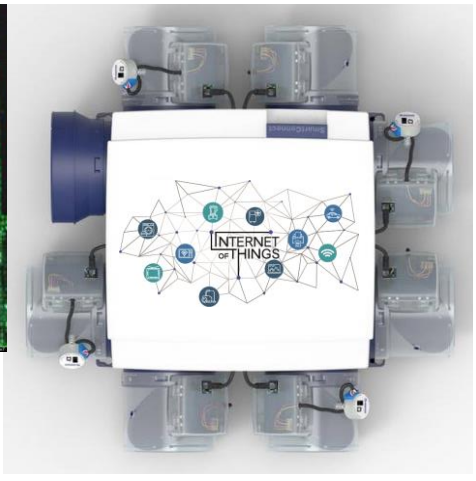
DCV IN THE BELGIAN MARKET





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4

The Research Objective

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RESEARCH OBJECTIVE

Use the recorded big data to verify our assumptions of ‘normal’ conditions in modern dwellings

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The Case Study

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THE SAMPLE

Valve type	May	June	July	August	September	October	November	December	January
BathRoom	113	151	192	268	374	454	534	682	789
BathRoomWithoutToilet	7	7	8	10	11	14	14	17	19
BedRoom	122	151	181	247	336	412	496	657	775
ClosedKitchen	2	2	2	2	5	7	7	10	9
Kitchen	92	122	152	205	285	350	418	535	632
LaundryRoom	92	123	150	191	258	320	400	502	589
LivingRoom	1	1	2	3	3	4	3	2	4
Office	4	4	6	6	7	10	9	10	10
Shower	6	6	9	11	10	11	13	12	9
Storage	0	0	0	0	0	1	4	6	6
Toilet	135	171	219	296	400	496	575	741	880

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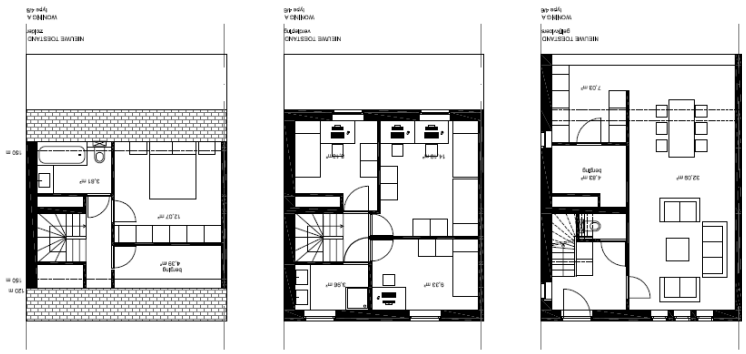

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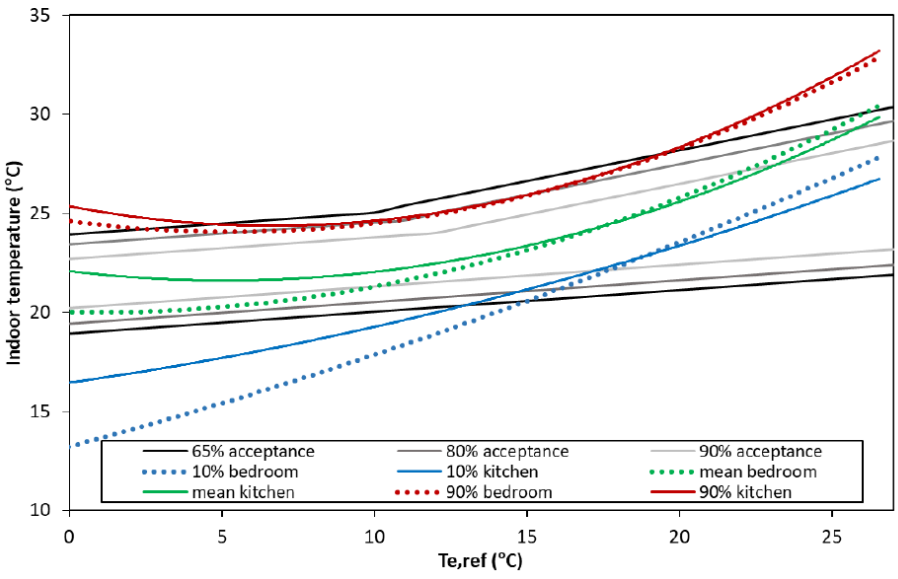
‘Smartzone’

11



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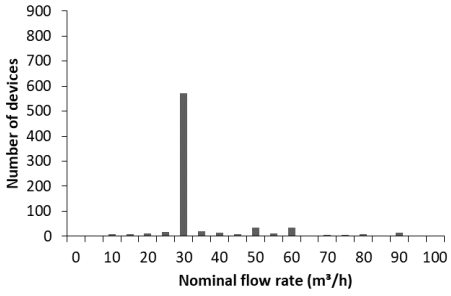

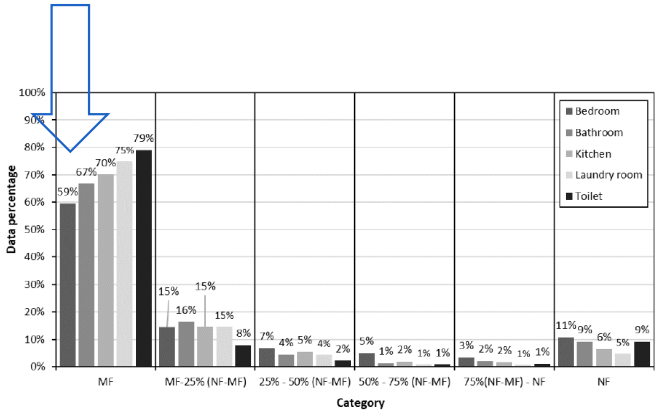

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The Results

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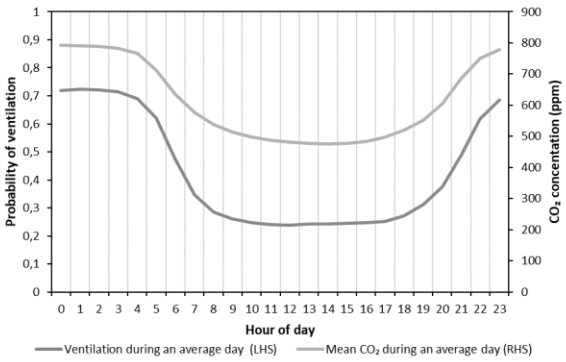
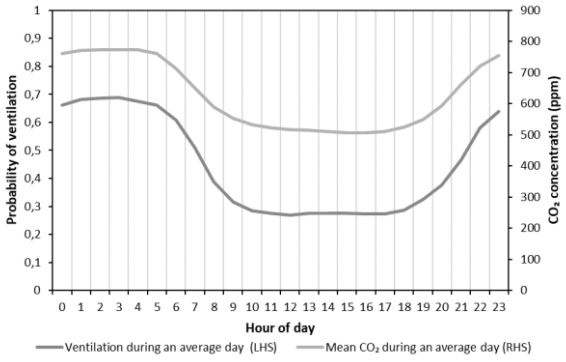
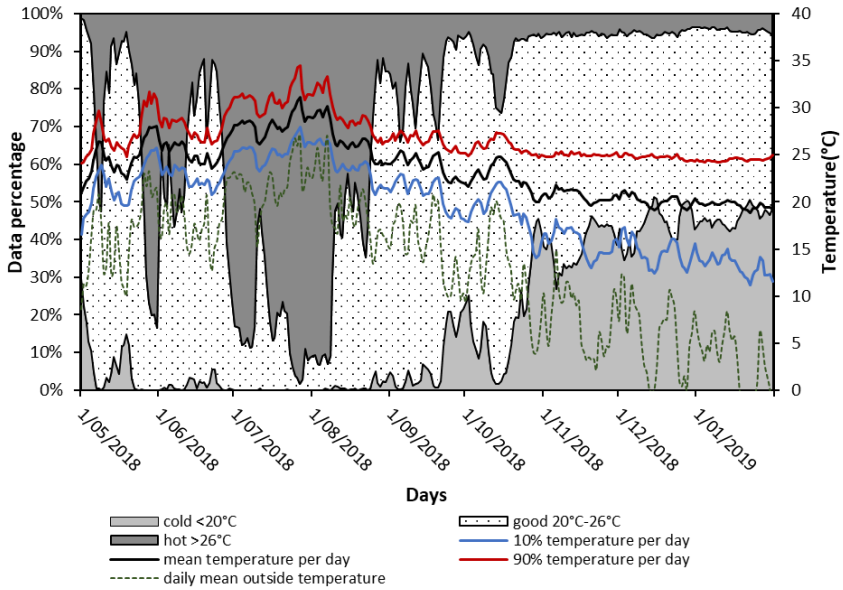

Probability of ventilation
CO₂ concentation (ppm)
Hour of day
Ventilation during an average day (LHS)
Mean CO₂ during an average day (RHS)


Probability of ventilation
CO₂ concentration (ppm)
Hour of day
Ventilation during an average day (LHS)
Mean CO₂ during an average day (RHS)

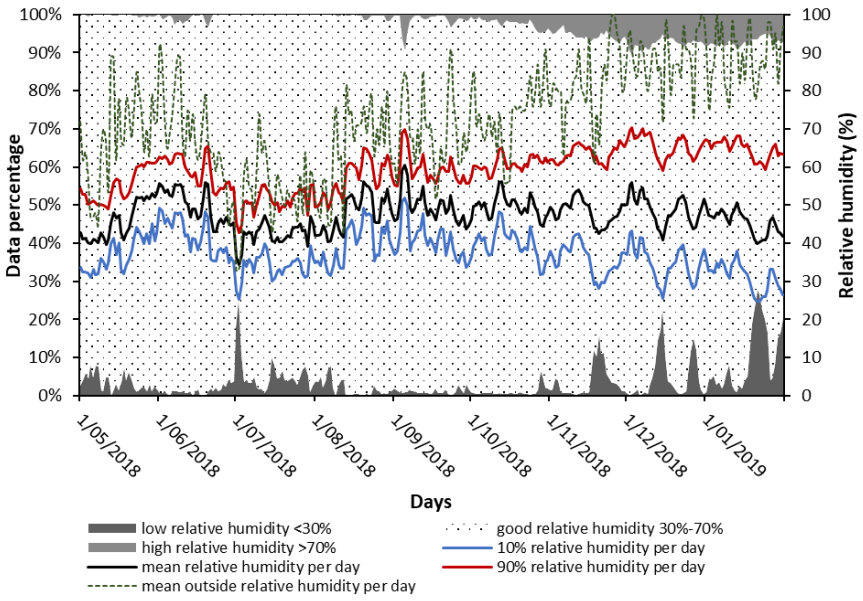
15

15


Data percentage
Temperature(°C)
Days
1/05/2018
1/06/2018
1/07/2018
1/08/2018
1/09/2018
1/10/2018
1/11/2018
1/12/2018
1/01/2019
cold <20°C
hot >26°C
mean temperature per day
daily mean outside temperature
good 20°C-26°C
10% temperature per day
90% temperature per day

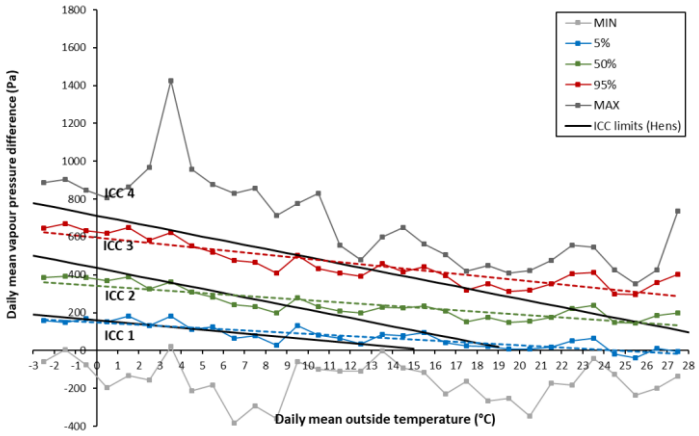
16

16

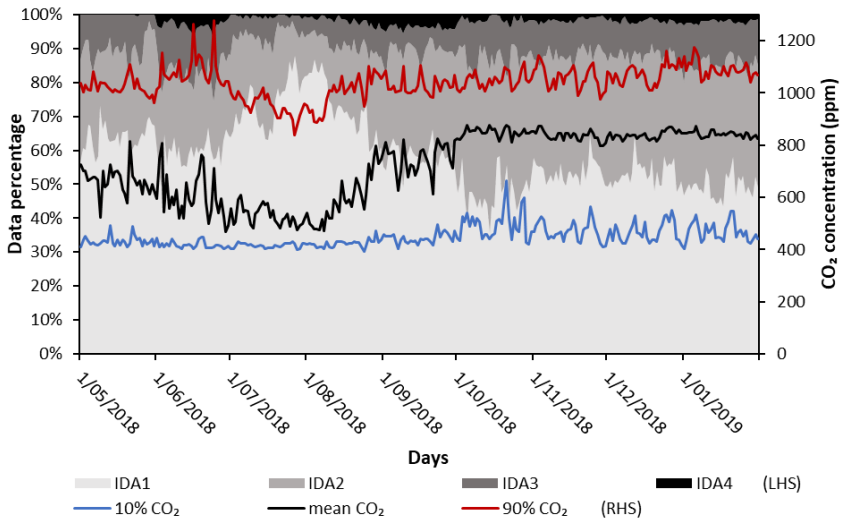

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Data percentage
100
90
80
70
60
50
40
30
20
10
0
Relative humidity (%)
1/05/2018
1/06/2018
1/07/2018
1/08/2018
1/09/2018
1/10/2018
1/11/2018
1/12/2018
1/01/2019
Days
low relative humidity <30%
high relative humidity >70%
mean relative humidity per day
mean outside relative humidity per day
good relative humidity 30%-70%
10% relative humidity per day
90% relative humidity per day

17

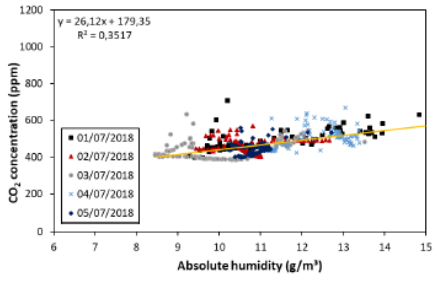
17


1800
1600
1400
1200
1000
800
600
400
200
0
-200
-400
Daily mean vapour pressure difference (Pa)
-3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Daily mean outside temperature (°C)
ICC 4
ICC 3
ICC 2
ICC 1
MIN
5%
50%
95%
MAX
ICC limits (Hens)

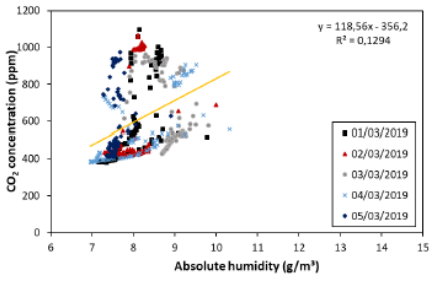
18



19



(a) *1 to 5 July 2018*



(b) *1 to 5 December 2018*

20

20

Mean [1-5/03/2018] [quarterly measurements]						
180219P0050	Bedroom	Bedroom	Bedroom	Laundry room	Bathroom	Kitchen
Bedroom	1,00					
Bedroom	0,68	1,00				
Bedroom	0,29	0,27	1,00			
Laundry room	0,25	0,35	0,69	1,00		
Bathroom	0,24	0,33	0,40	0,49	1,00	
Kitchen	0,34	0,49	0,46	0,43	0,32	1,00
Mean correlation coeff. dry and wet rooms						0,39

Mean [1-5/03/2018] [quarterly measurements]						
180219P0060	Bedroom	Bedroom	Living room	Office	Kitchen	Bathroom
Bedroom	1,00					
Bedroom	0,78	1,00				
Living room	0,44	0,53	1,00			
Office	0,93	0,62	0,28	1,00		
Kitchen	0,62	0,68	0,27	0,55	1,00	
Bathroom	0,91	0,61	0,29	0,94	0,50	1,00
Mean correlation coeff. dry and wet rooms						0,61

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BIG HUMIDITY DATA

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Measurements of sleep quality with low-cost sleep monitors: Effect of bedroom air quality and sleep quality

Pawel Wargocki
Technical University of Denmark

1

DTU

Why sleep is relevant?

- People sleep over 20 years during their life time
- High quality sleep is vital for humans
- Sleep improves cognitive performance (memory and learning, and creativity), reduce health risks (dementia, Alzheimer's disease), regulates hunger and fullness (obesity), reduce risks for car accidents, improves concentration and next-day performance
- People are getting more and more deprived of sleep, length (<7,5 hrs) and quality



Source: Walker (2017)

2



Previous studies

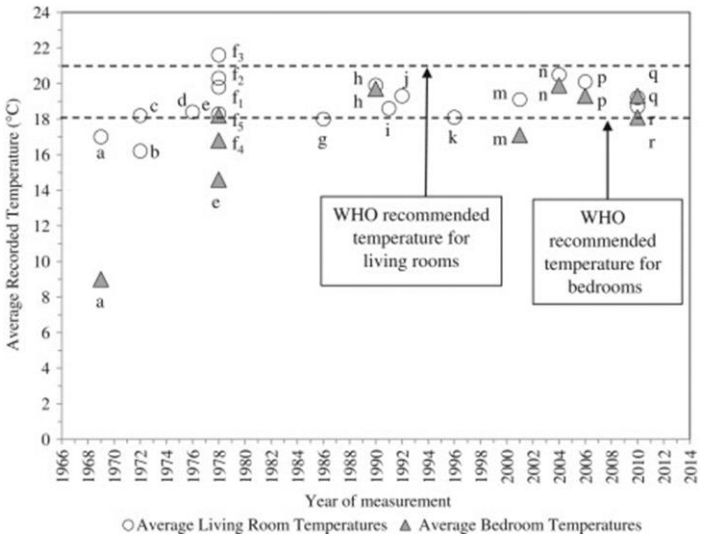
DTU

Bedroom IAQ and temperature in buildings today

- Split AC in the Tropics reduce temperature and RH but reduce air quality due to need to conserve energy
- Housing insulation conserve energy but increase bedroom temperatures during summer
- CO2 levels in bedroom reach 5,000 ppm indicating very poor ventilation

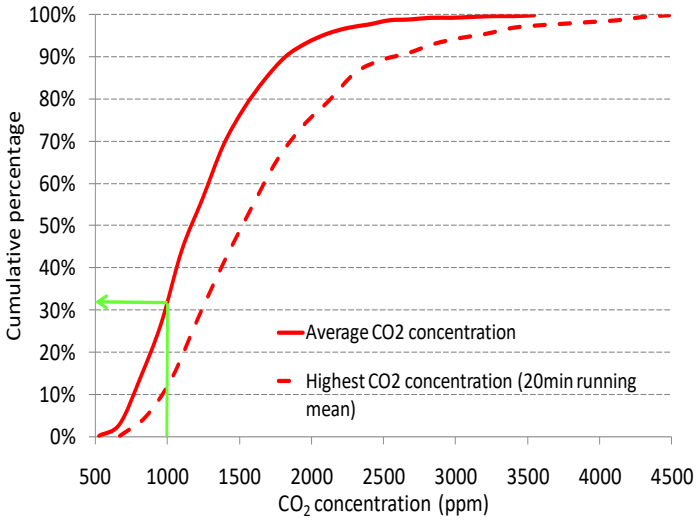
Source: Bekö et al. (2010); Sekhar & Goh (2011)

Bedroom and living room temperatures in UK



Source: Vadoraria et al. (2016)

IAQ in Danish bedrooms

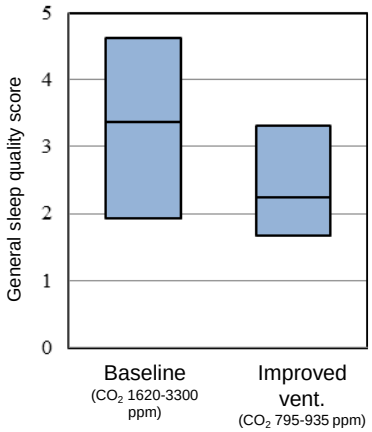


Source: Bekö et al. (2010)

Nr.	Author	Title
1	A. K. Mishra, A. M. van Ruitenbeek, M. G. L. C. Loomans, H. S. M. Kort, 2017	Window/door opening- mediated bedroom ventilation and its impact on sleep quality of healthy, young adults
2	Strøm-Tejsen, D. Zukowska, P. Wargocki, D. P. Wyon, 2016.	The effects of bedroom air quality on sleep and next-day performance P.
3	Zhangping Lei, Chuanping Liu, Li Wang, NaLi, 2017.	Effect of natural ventilation on indoor air quality and thermal comfort in dormitory during winter
4	Laverge, Jelle; Janssens, Arnold, 2012.	Analysis of the influence of ventilation rate on sleep pattern
5	Urlaub, S., Grun, G., Foldbjerg, P. and Sedl-Bauer, K, 2015	The influence of the indoor environment on sleep quality.
6	Daranee Jareemit, Panpisu Julpanwattana, and Jittapat Choruengwiwat, 2017	Impact of Outdoor Air Exchange Rates on Sleep Quality and the Next-Day Performance with Application of Energy Recovery Ventilator
7	Li Lan, Xhin Zhou	Experimental study on a bedside personalized ventilation system for improving sleep comfort and quality

Bedroom IAQ and sleep quality

- Both sleep quality and next-day performance can be negatively affected when the outdoor air supply rate to the bedroom is reduced



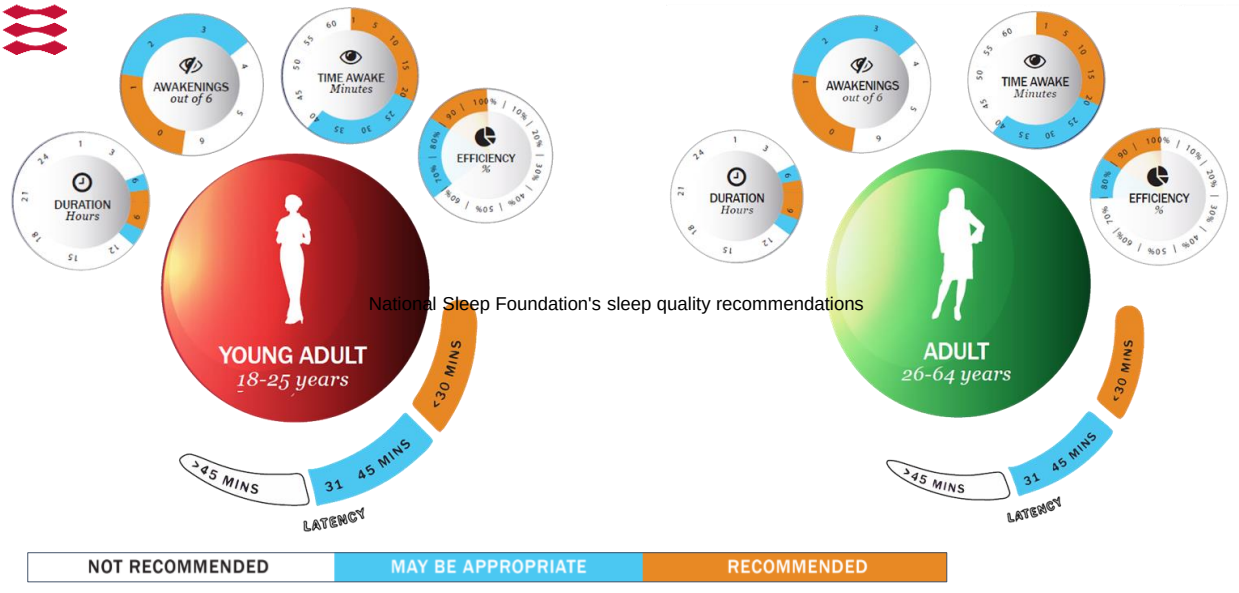
Source: Strøm-Tejsen et al. (2016)



What is a good sleep quality?

9

DTU



National Sleep Foundation's sleep quality recommendations

Source: National Sleep Foundation's sleep quality recommendations (2017)

10



Measuring sleep quality

11

DTU

Waerable

- Fitbit Alta HR
- Jawbone UP3
- GetFitPro
- Motiv Ring

Non-wearable

- Beddit
- Sleepace Sleep Dot
- S+ by ResMed











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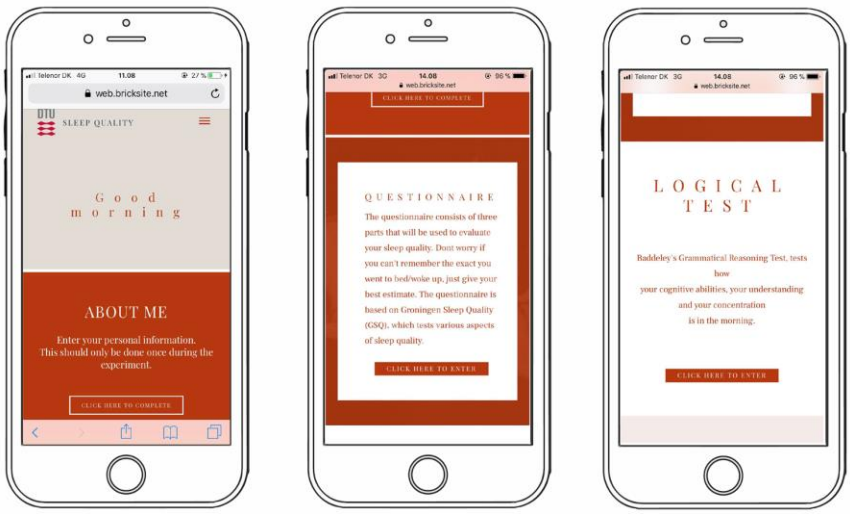
Sleep parameters	Fitbit	GetFitPro	Motive Ring	Beddit	Sleepace
Time in bed	X	X	-	X	X
Time asleep	X	X	X	X	X
Awakenings	X	X	-	X	X
Restless sleep	-	X	X	X	-
Restfull sleep	-	-	X	-	-
Time in REM	X	-	-	-	-
Time in Deep	X	-	-	-	X
Time in Light	X	-	-	-	X
Sleep efficiency*	-	-	-	X	X
Sleep quality**	-	X	-	-	-
Movements	-	-	-	-	X
Snoring	-	-	-	X	-

* Sleep efficiency refers to the ratio of time in sleep while in bed.
** GetFitPro rate the sleep quality on a scale from poor to ideal.

13



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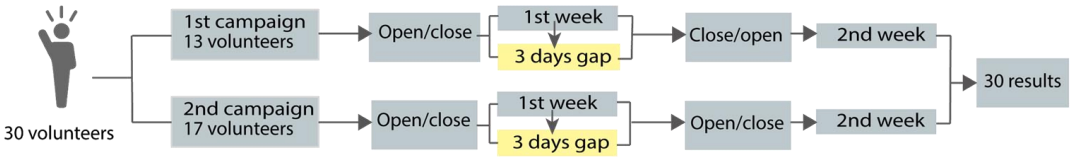
Case study

DTU

Bedroom ventilation by door opening

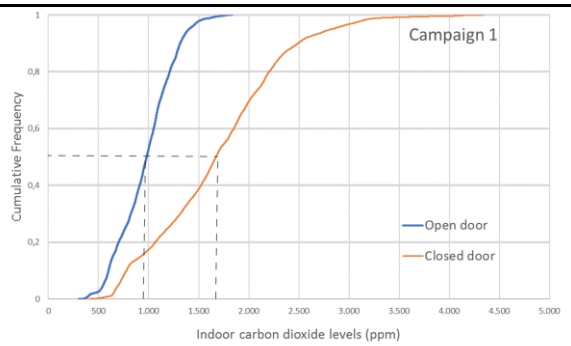


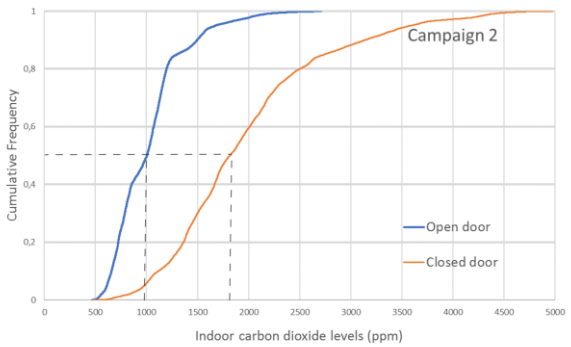


Results

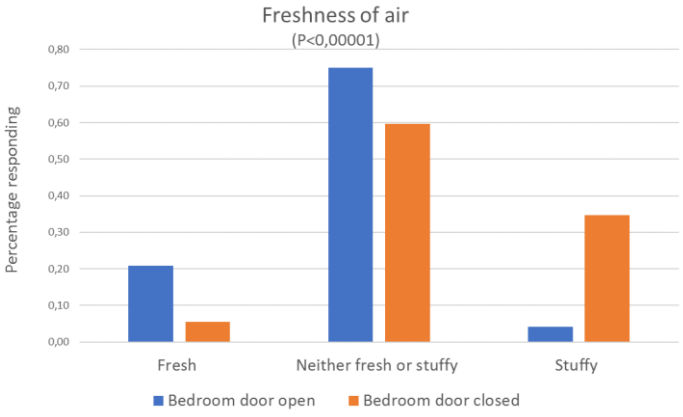
DTU

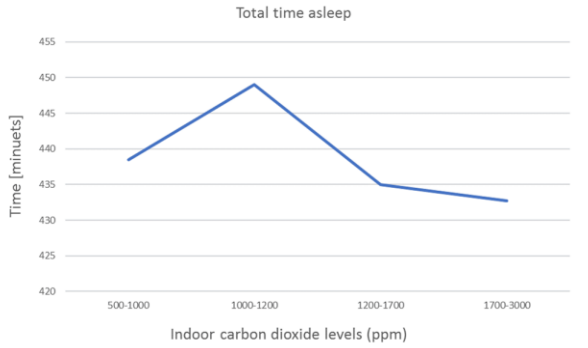
CO_2 concentration

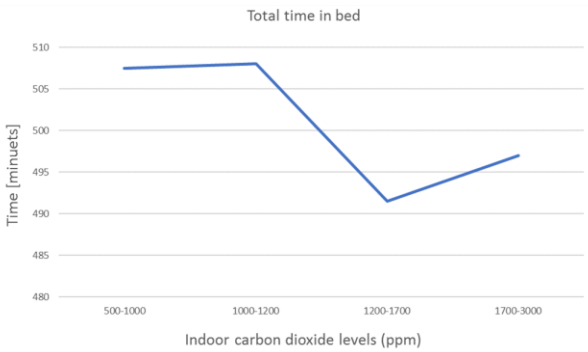




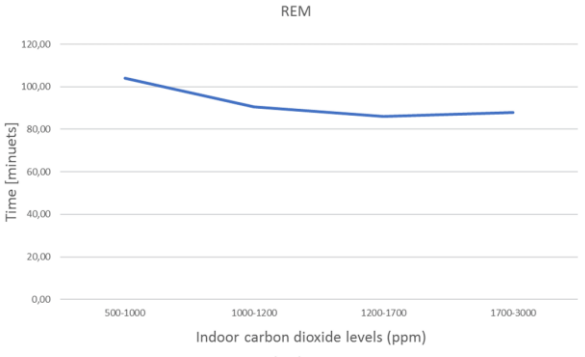
Subjectively reated IAQ

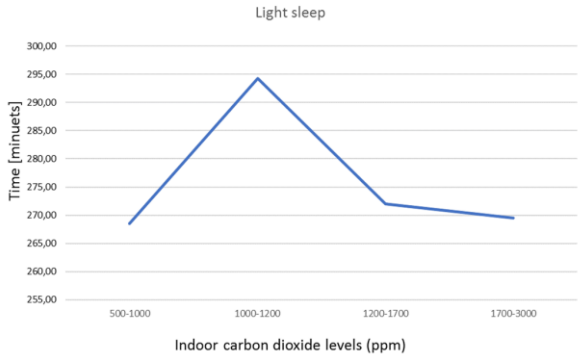






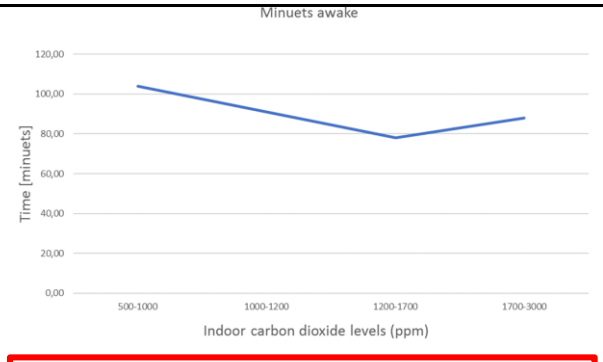
Fitbit results - 1

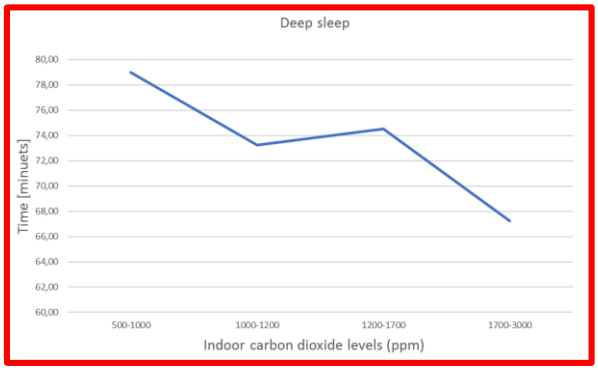




Fitbit results - 2

21





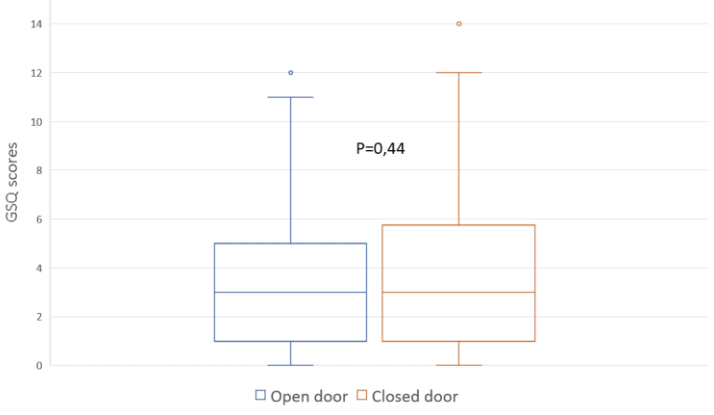
Fitbit results - 3

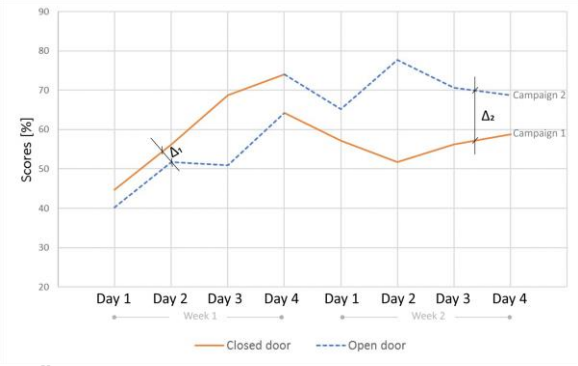
22

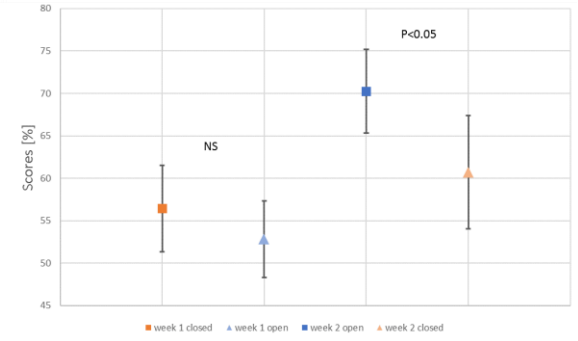
Comparison with the National Sleep Foundation benchmark

	Measured parameters				
	Min. Awake	Time in REM	Time in light	Time in Deep	Sleep efficiency
Open	31 min	18 %	54 %	16 %	87 %
Cosed	31 min	18 %	54 %	15 %	87 %
	Benchmark 'Good sleep quality'				
	<46 min	21-30 %	<81 %	16-20 %	>85 %

Groningen Sleep quality







Baddeley's Grammatical Reasoning Test

25



Conclusion

26

- Sleeping with door to bedroom closed or open significantly changes bedroom air quality
- There is an indication that slow-wave sleep (NREM) is affected by reducing IAQ
- Improved sleep quality seems to improve performance of logical test next morning



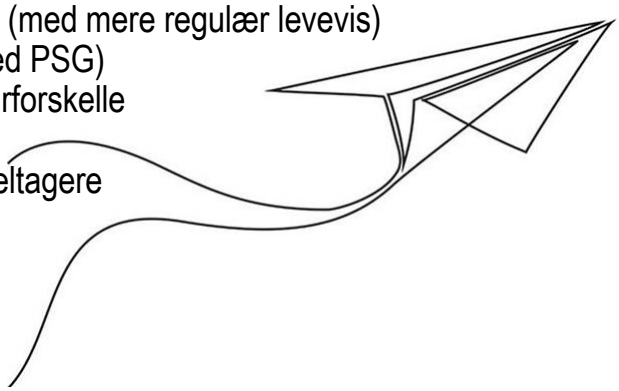
27



Fremtidige studier

28

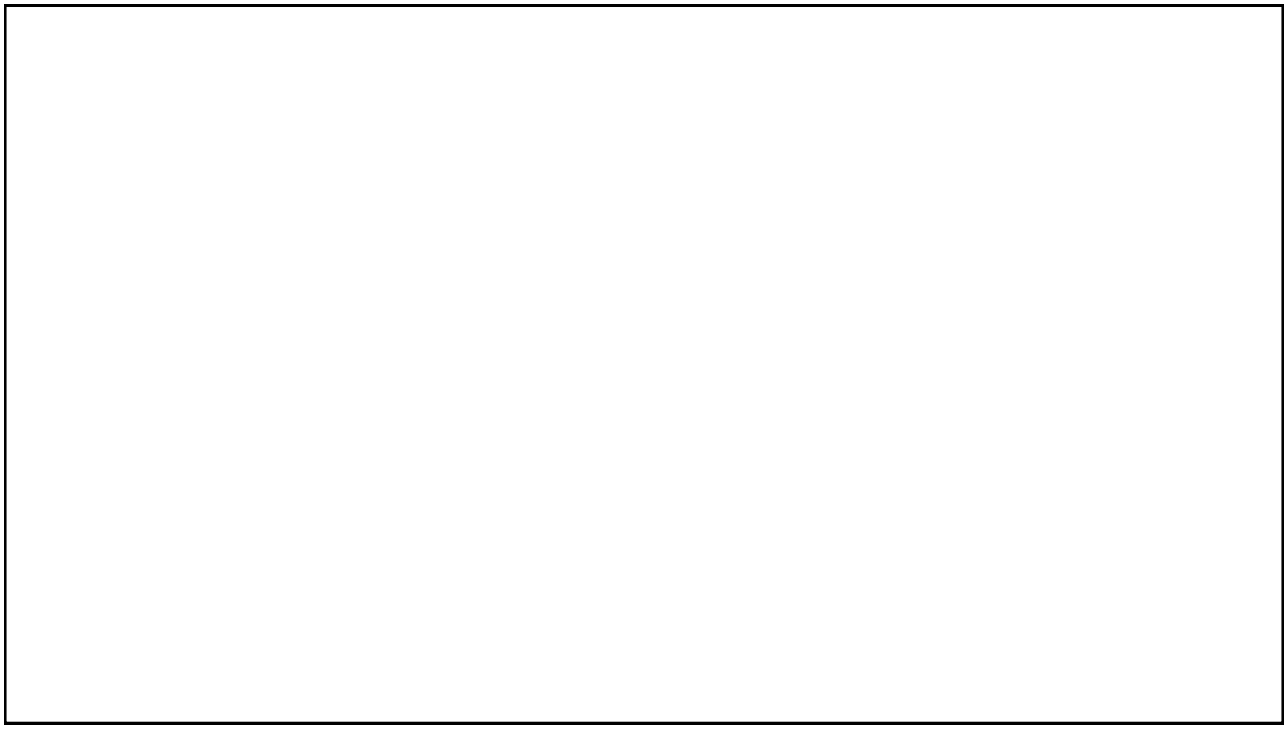
- "Blænde" forsøgspersonerne yderligere
- Undersøg forskellige aldersgrupper (med mere regulær levevis)
- Valg af måle-ur (sammenligning med PSG)
- Undersøge påvirkning af temperaturforskelle
- Ens værelsesstørrelser
- Længere forsøgsperiode og flere deltagere
- Fordeling af forsøgspersoner



Questions



Pawel Wargocki
Assoc. Prof.
Technical University of Denmark
(paw@byg.dtu.dk)



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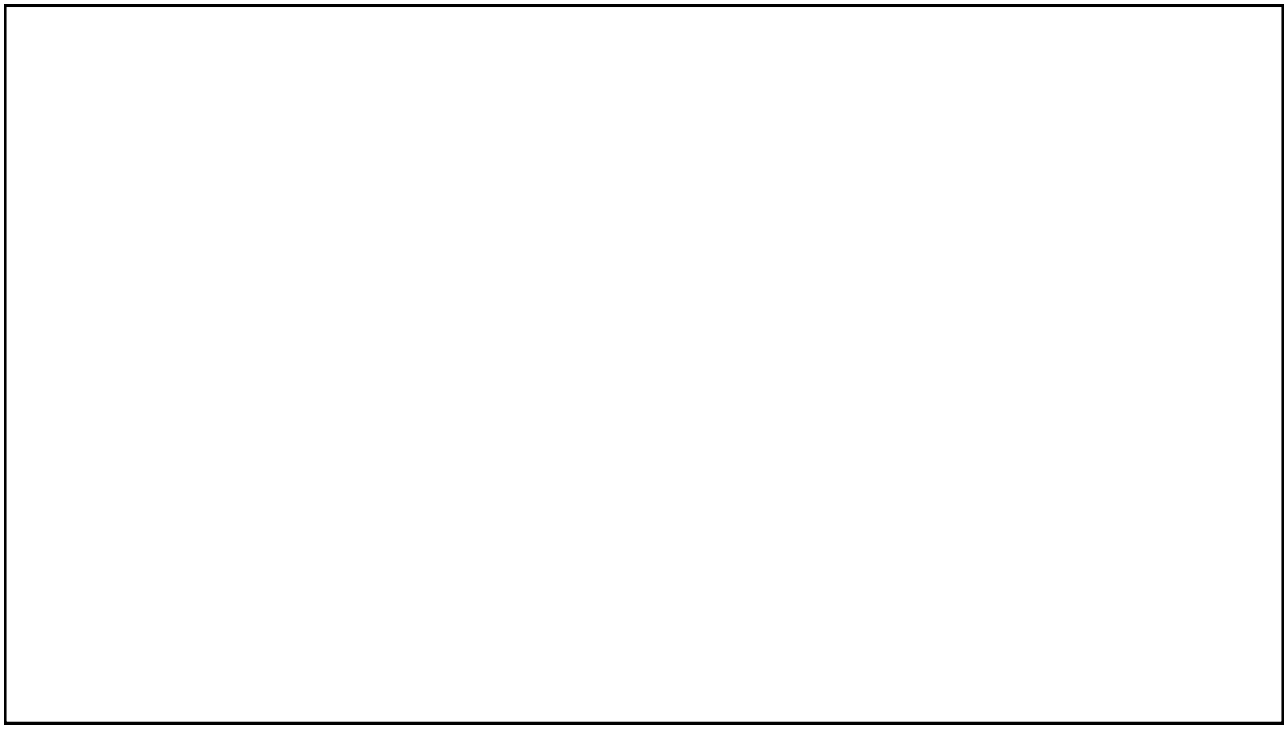


32

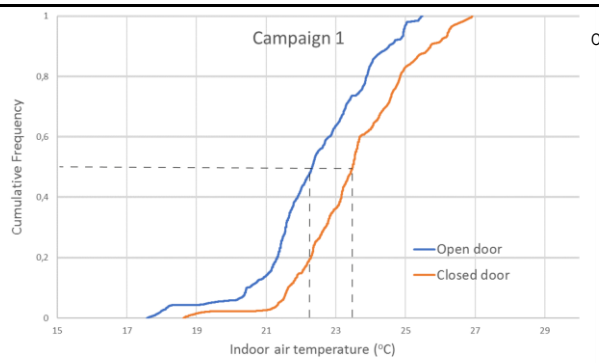
33

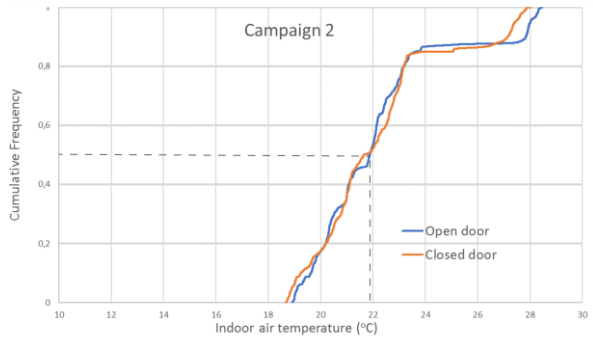


Subjektive resultater

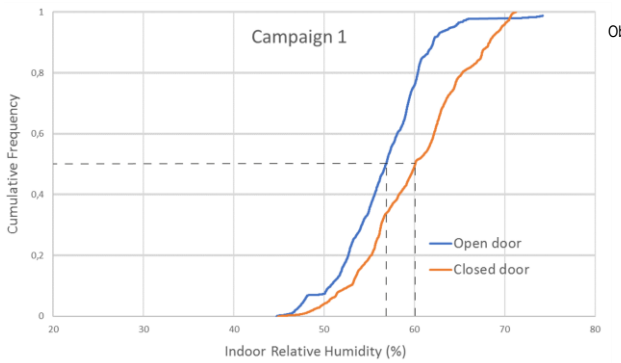
34

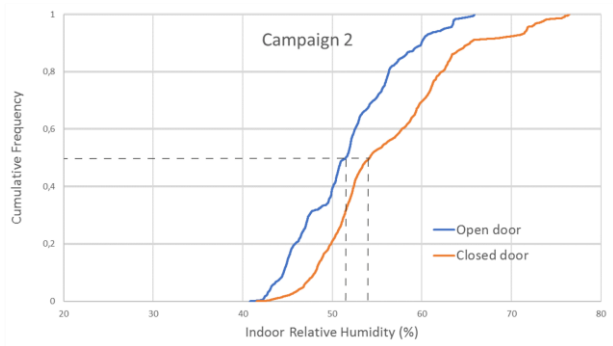
Måling af temperatur i soveværelse





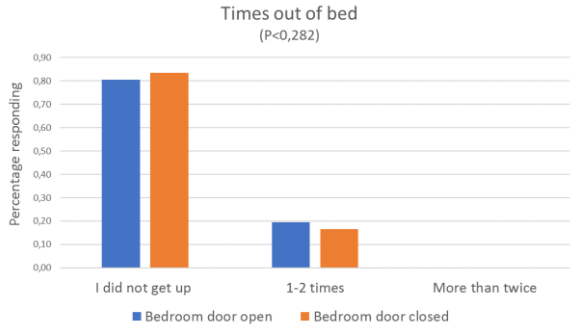
Måling af relativ luftfugtighed i soveværelse

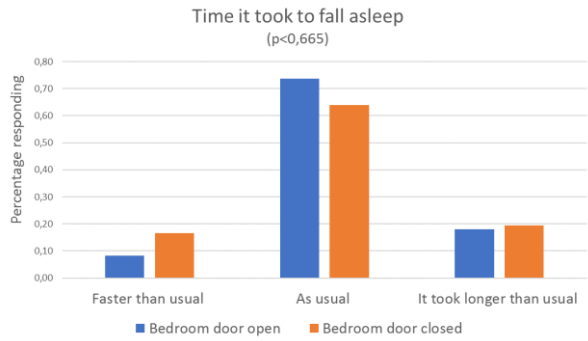




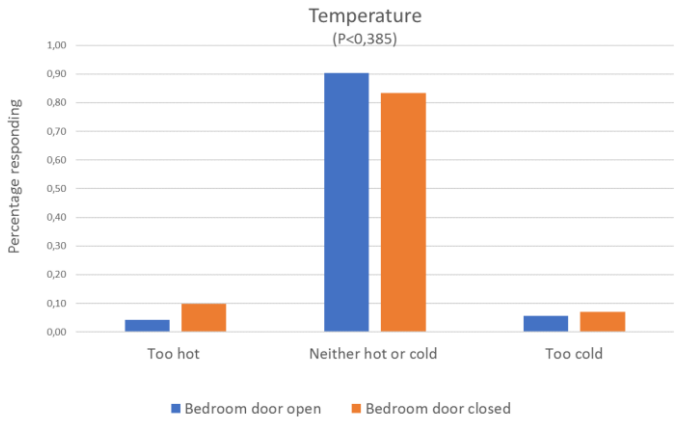
Evaluering

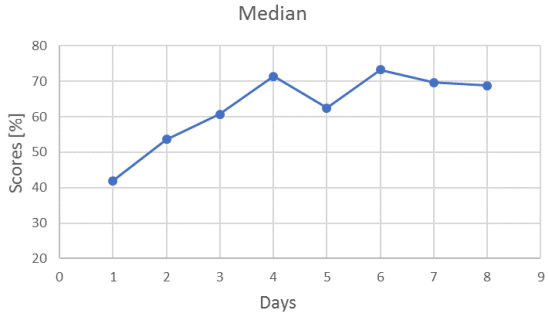
- Antal gange ude af sengen i løbet af natten
- Tid det tog at falde i søvn





Evaluering af IAQ i soveværelse





Baddeley's Grammatical Reasoning Test

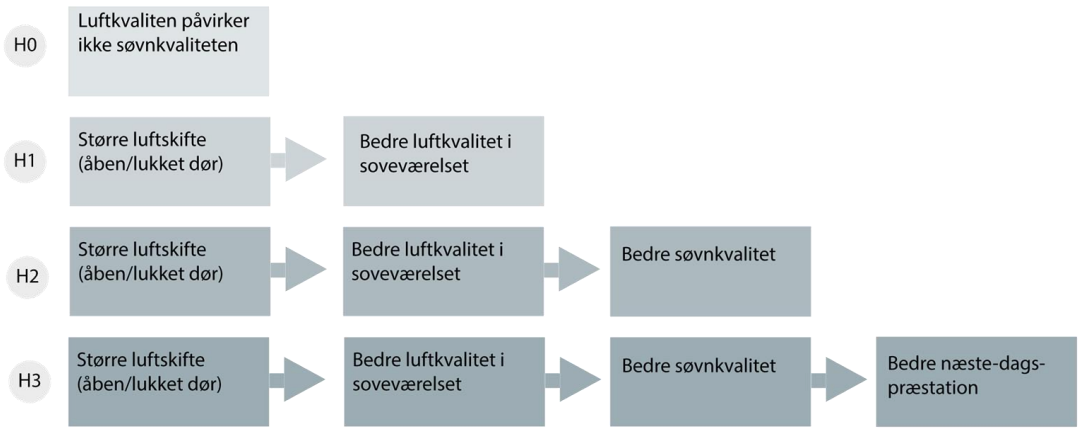


Diskussion

Er metoden robust nok?

- Luftkvalitet
- Næste-dags-præstation
- Søvnkvalitet





40th AIVC - 8th TightVent & 6th venticool Conference

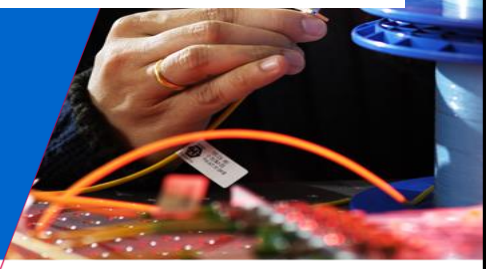
From energy crisis to sustainable indoor climate 40 years of AIVC

15-16 October 2019

Ghent, Belgium



CO_2-concentration of the surrounding air of sleeping infants inside a crib



Gert Jan Braun, **Wim Zeiler**

Faculty of the Built Environment

w.zeiler@bwk.tue.nl

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

0

Ventilation crucial for IAQ thus health

- **What about day care centers?**
- **Especially inside the baby cots!**



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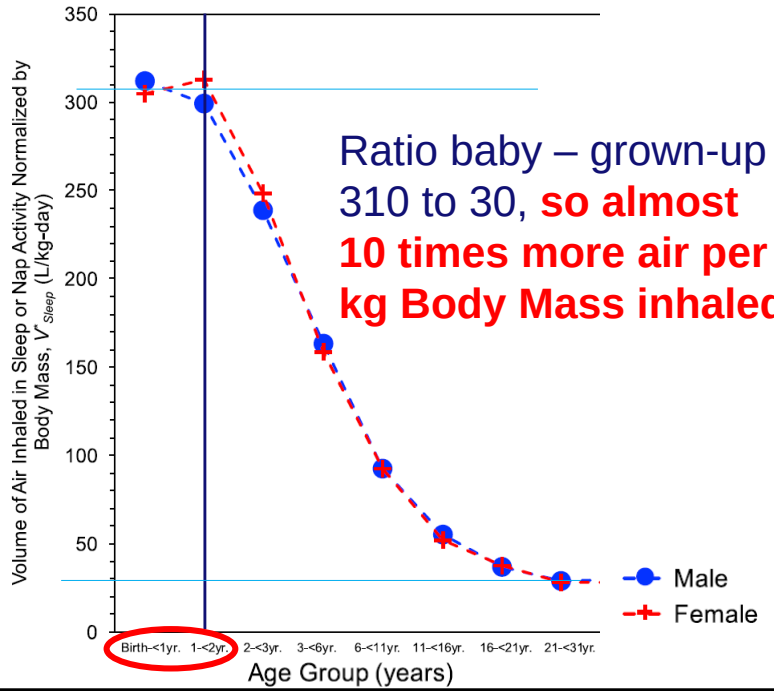
1



Ratio baby – grown-up 310 to 30, **so almost 10 times more air per kg Body Mass inhaled**



2

CO_2 concentrations at daycare centers in previous research

Year	Location	Number	Average CO_2 [ppm]	Reference
1982	Sweden	1	880	Berglund
1992	Canada	91	1505	Daneault et al.
1993	Finland	30	810	Routsalainen et al.
2002	Midwest USA	26	1142	Ferng and Lee
2005	Netherlands	51 62	920(bedrooms) 1297 (group room)	Haans and Boerstra
2009	Netherlands	60	1452	Versteeg
2011	Latvian	4	731	Stanvica and Lesinskis
2011	Paris	28	933	Roda et al.
2012	Montreal	21	1333	St-Jean et al.
2014	Portugal	52	1563	Mendes et al
2015	Italy	1	1100	Pagliano et al
2016	Europa	4	1128	Wargocki et.al



Normally measurements in the room, not within the baby cots

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3

Ventilation effectiveness baby bed depending on type and configuration



Crib



Bedstead



Bottom bunk bed



Top bunk bed

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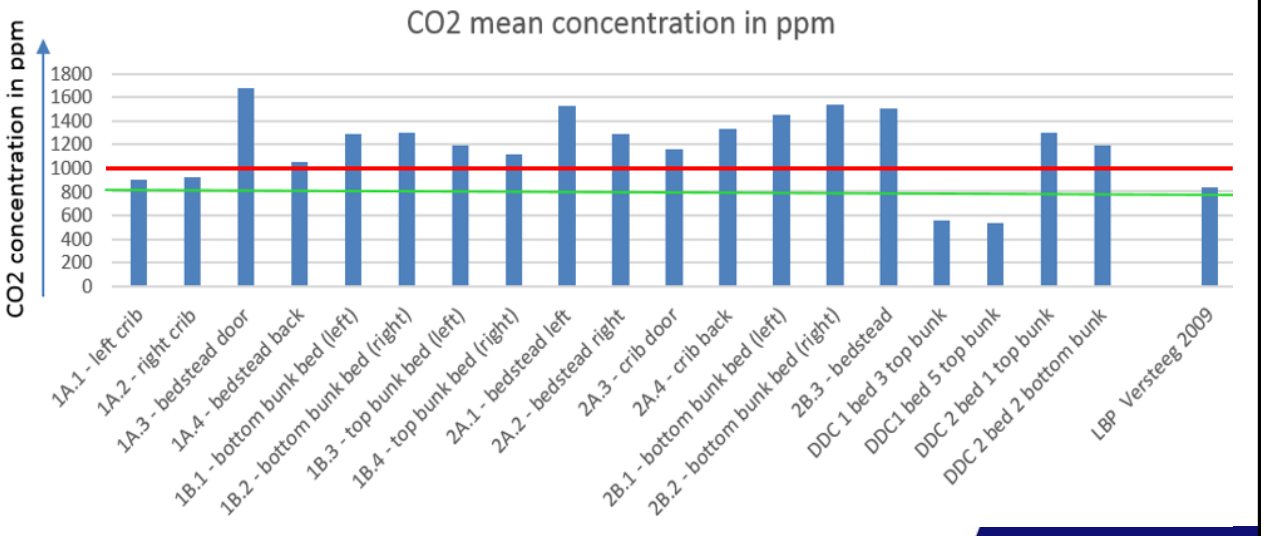
Overview research conducted by de Waard (2015) and Kruisselbrink (2017)

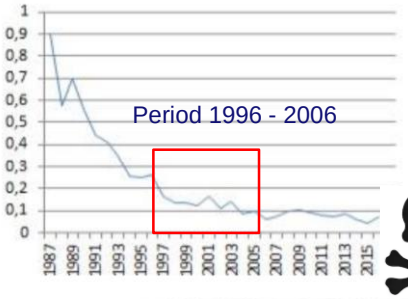


Risk Sudden Death Infant Syndrome 1996 – 2006 in Dutch Day care centers 8.8 times higher then at home

Conclusie.

In de periode september 1996-augustus 2006 was in Nederland het relatieve risico van wiegendood tijdens kinderopvang in de leeftijd 3-6 maanden 8,8 maal zo hoog (95-BI: 4,1-19,0) als tijdens dezelfde uren thuis.

Ned Tijdschr Geneeskd. 2008;152:1377-81

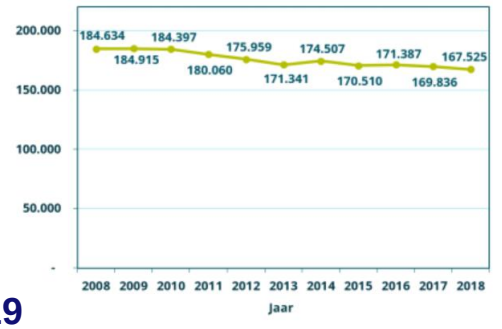


Period 1996 - 2006

Dying due to SIDS per 1000 babies

• SIDS = Sudden infant death syndrome (R 95)

Number of birth's



On average between 13 – 19 baby's a year death in the Netherlands

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6



How to ventilate this?

Double Bunk Bed

Around 90.000 in Dutch Day care centers

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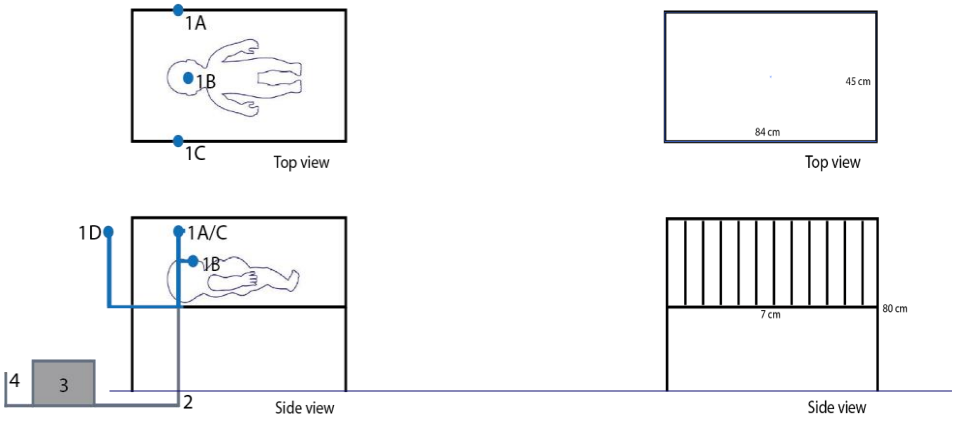
7

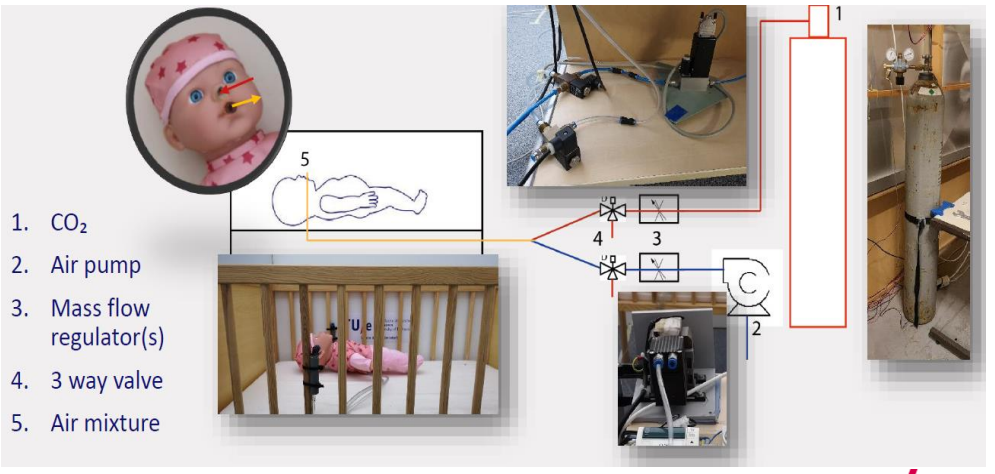
General measurement setup influence position on perceived IAQ



1.Four CO_2 sensors (1A/B/C/D)
2. Cable bundler
3. Central box and 4. Mains supply

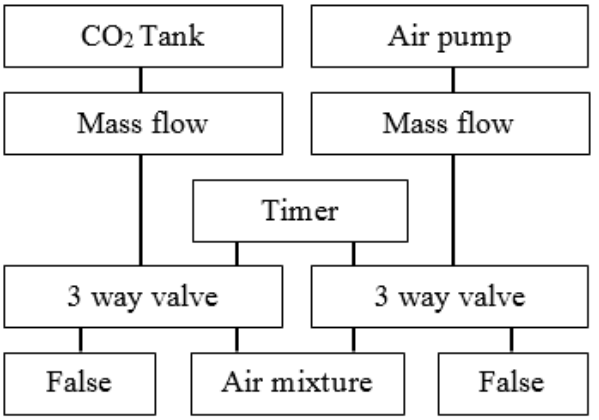
8

Breathing simulator, hose, CO_2 sensor (hose) and baby doll in test crib at TU/e



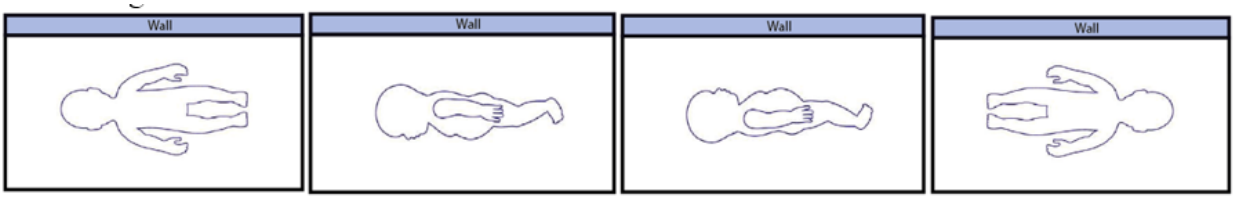
9

Schematically overview breathing



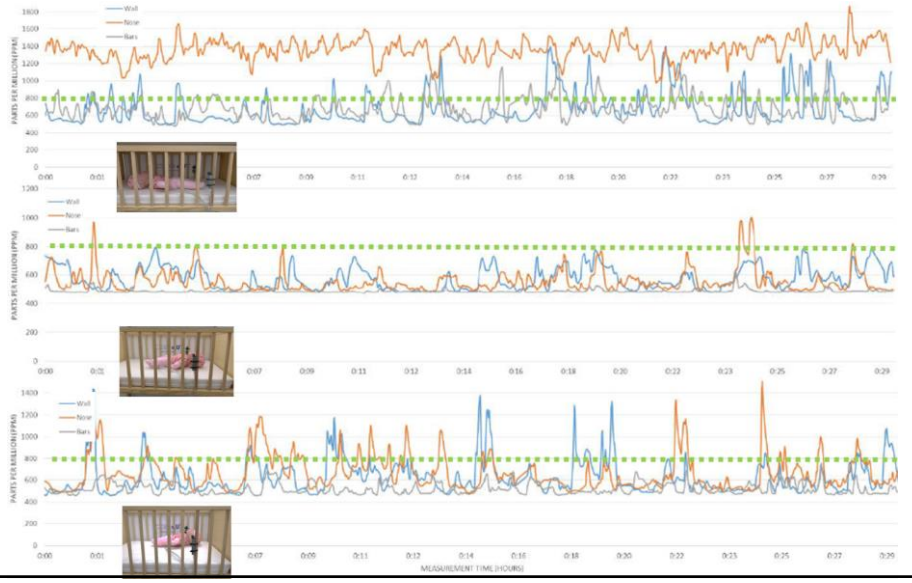
10

Measurement positions for the baby doll inside the cribs: supine, lateral facing room, lateral



11

Measurement data of 3 different prone orientation, limit of 800 ppm CO_2 marked



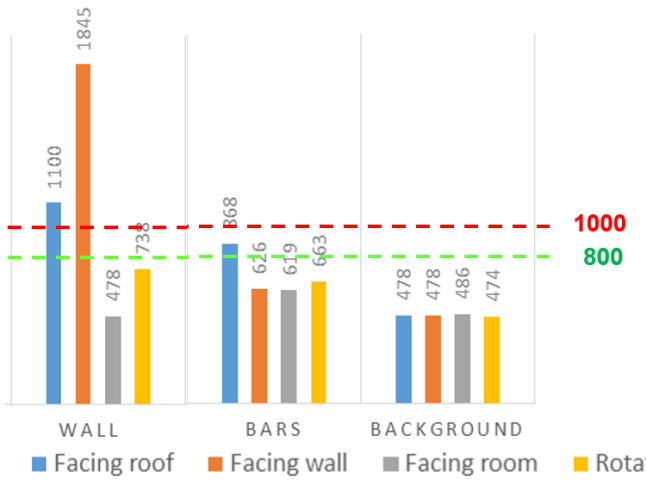
Dutch GGD health classes for CO_2 [ppm] concentrations and results

Class	A Very good	B Good	C Acceptable	D Insufficient	E Very poor
CO_2 [ppm]	< 650	650-800	800-1000	1000-1400	>1400

T

	Bottom bunk bed												Bedstead											
	Facing roof			Facing wall			Facing room			Rotated position			Facing roof			Facing wall			Facing room			Rotated position		
	Q1BBB1AM_190115	Q2BBB1AHWW_190109	Q3BBB1AHWB_190109	Q7BBB2M_190110	Q8BBB2HWW_190111	Q9BBB2HWB_190111	Q10BBB3M_190110	Q11BBB3HWW_190111	Q12BBB3HWB_190114	Q13BBB4M_190110	Q14BBB4HWW_190114	Q15BBB4HWB_190114	Q16BS1M_190110	Q17BS1HWW_190114	Q18BS1HWB_190114	Q22BS2M_190110	Q23BS2HWW_190114	Q24BS2HWB_190114	Q25BS3M_190110	Q26BS3HWW_190115	Q27BS3HWB_190115	Q28BS4M_190111	Q29BS4HWW_190115	Q30BS4HWB_190115
Wall	886	1157	1257	854	2992	1688	489	465	480	950	597	667	575	621	582	1086	530	1167	495	597	469	660	658	618
Middle	1376	1492	1417	1725	2271	1696	516	516	510	1263	1344	1361	556	660	730	1770	2452	1530	595	597	917	866	980	564
Bars	843	944	817	537	724	617	502	867	487	729	576	684	489	516	534	580	597	545	568	1282	573	561	515	481
Background	490	474	469	495	473	466	501	487	471	488	468	466	486	460	467	484	462	466	491	495	497	481	473	472

Average of the 3 sensor Baby Bunk Bed CO_2 concentrations



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Conclusions

- More attention is necessary for the assessment of the indoor environmental quality in (Dutch) day-care centres.
- **Especially the effect of the type of baby bed and its location within the sleeping room is far more important than generally known.**
- **The CO_2 concentration inside the baby beds can be more than 40% worst then the average room level.**

Questions?



Thank you for your attention!



Quality framework for residential ventilation systems in Flemish Region of Belgium

Feedback after three years of experience

M. De Strycker, L. Van Gelder, M. Andrzejewicz, V. Leprince

AIVC 2019 Ghent

BCCA

1

CONTEXT - MOTIVATION

- Examples of bad installations
  - Research project Optivent – IWT/Flanders – 2010-2014
- EPB – Flanders – Flemish Energy Agency
  - 80% of fines in EPB are related to the ventilation
- Ventilation system is an important investment
- Voluntary certification is not effective
- **… further actions needed to achieve better quality in ventilation installation**



Politie wordt ziek i
peperduur nieuw gebouw

Er hangt een reukje in de hoofdzetel van de federale politie. Door slechte ventilatie worden mensen ziek in het nieuwe gebouw, dat nog maar twee jaar wordt gebruikt.



2

CONTEXT - EPB-PROCESS IN FLANDERS REGION

- Building design (architect)
- Building permit
- EPB start declaration (before first brick is laid) by EPB reporter: estimation of energy performance and indoor climate
- Building process…
  - Foundations
  - Walls
  - …
  - Windows (with trickle vent)
  - …
  - Ducting
  - Fan / ventilation unit
  - …
  - Occupation
- Maximum 6 months after occupation: EPB registration by EPB reporter: as-built Energy Performance and indoor climate of the building



Building permits from 1/1/2016 !

BCCA

CONTEXT - REGULATION

- **Ministerial Decision 28 October 2015:**
  - **Ventilation predesign at declaration of start and ventilation performance report at EPB-registration**
  - **Quality framework**
  - Applies to building permits after 1/1/2016 in Flanders
  - Only for residential buildings
  - New building or major renovation
- **Government Decision 15 December 2017**
  - Supervision by independent quality organisation
  - ISO 17065 accredited certification body
  - 10% on site and desktop of measurements/reports audits
  - Control of reliability of inspection


Ventilatievoorontwerp

BCCA

ORGANISATION

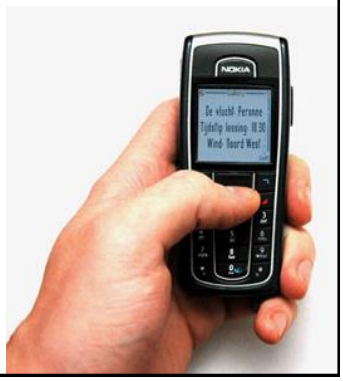
- Aiming at **transparent** and **reliable** data of ventilation system by integral approach
- Ventilation inspectors recognised by the quality framework
  - Theoretical and practical test
  - **Open system**: convince the market by engaging different people, motivate all parties to deliver quality
  - Different people can work together on same project: at first sight complex, but in the end more efficient
- Reporting only by recognised ventilation inspectors
  - Ventilation predesign
  - Ventilation design
  - Ventilation performance report: flows (MV), trickle vents, door undercuts, DCV, …
- Surveillance on the content of the documents in the database of the quality framework
  - Desktop audits
  - On site audits

BCCA

AUDITS BY BCCA

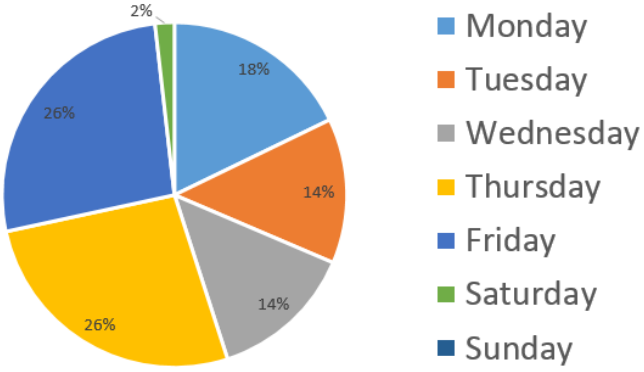
- Recognition – access to web application and database
- Desktop audits
  - Dossiers in database: correctness and completeness of data
- On site audits: correctness of measurements and **reliability of reporting**
  - During the measuring of flows
  - Planning in web application
    - SMS - start
    - SMS – end (with result)
    - auditor on site within 15 minutes
  - After installation: fixed components (e.g. on site airtightness audit)
- Non-conformities and sanctions
  - Modify report, extra audits, re-measuring, temporary of definite exclusion, …

Realtime monitoring of all measurements

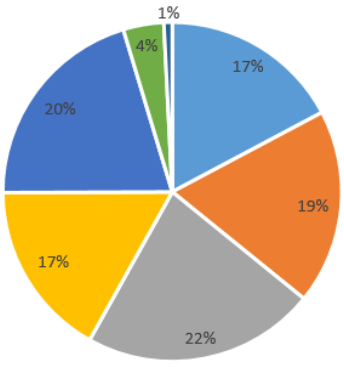


RESULTS – AUDIT DISTRIBUTION

Day of the week - audits



Day of the week - measurements

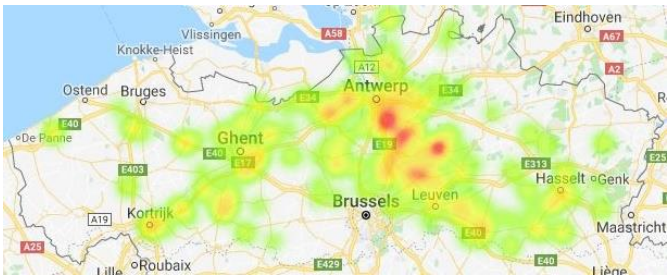


Results ventilation 2018

RESULTS – AUDIT DISTRIBUTION



measurements

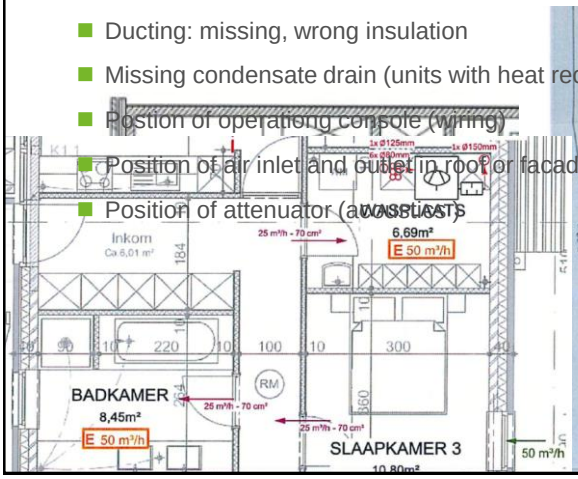


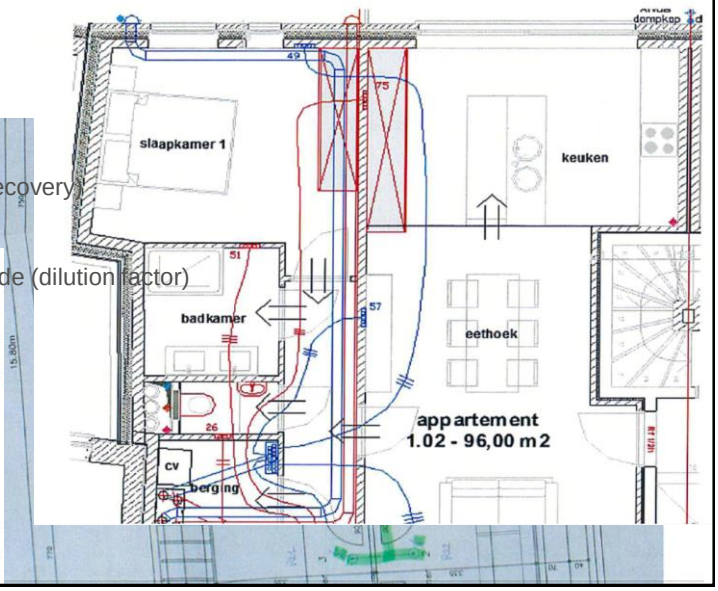
audits

BCCA

RESULTS – PREDESIGN

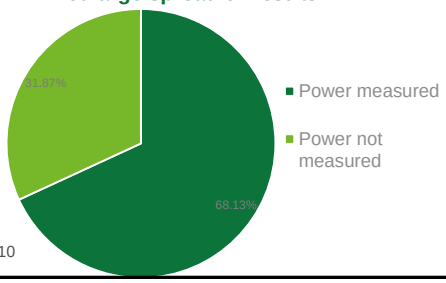
- Very limited interpretation
- Design not readable
- Ducting: missing, wrong insulation
- Missing condensate drain (units with heat recovery)
- Postion of operationg console (wiring)
- Position of air inlet and outlet in roof or facade (dilution factor)
- Position of attenuator (acoustics)





RESULTS – POWER CONSUMPTION

- Power measurement not mandatory (safety reasons)
- In 70% of the dwellings measured
- SFP
  - $SFP_{system} = \frac{P_{tot}}{\dot{V}_{max}}$ in W/(m³/h)
  - Mean value ok
  - But **large spread** on results



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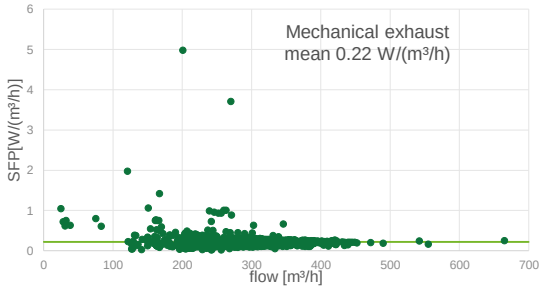
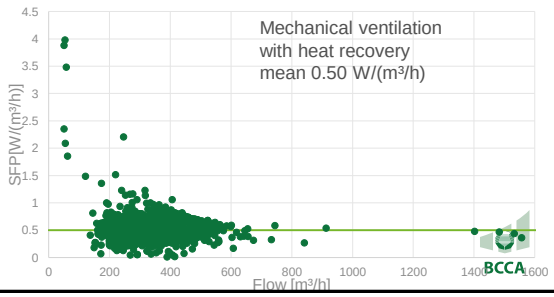
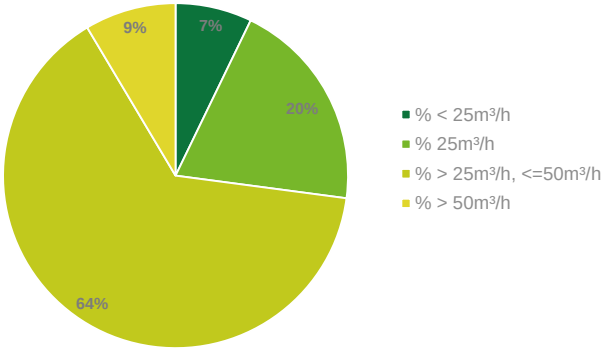




RESULTS – CONFORMITY WITH EPB-REGULATION

- Ventilation report = objective data about ventilation installation
  NOT conformity assessment
- Conformity assessment
  - By builder
  - By the authorities (i.c. VEA)
- Room with minimal flow: WC
  minimal flow: 25m³/h
- Conclusions
  - At least 7% of ventilation systems not compliant
  - Further analysis necessary
  - To some extent prove that inspectors report correctly



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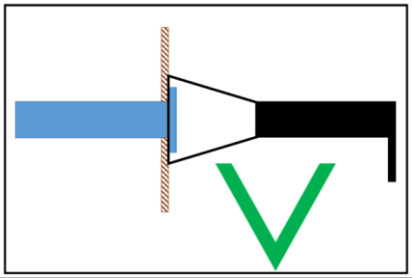
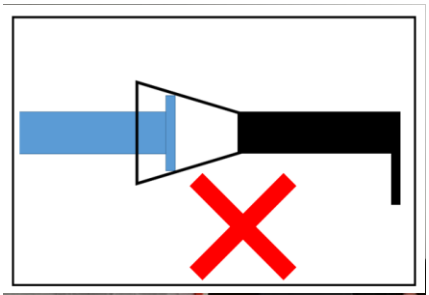
CHALLENGES IN MEASURING FLOW RATES ON-SITE

- Not possible to measure or no measurement = 0m³/h
- Some inspectors quite lazy, some very creative
- Need for clear instructions









CONCLUSION

- Concern about quality of ventilation systems in dwellings
- Mandatory inspection scheme in Flanders
  - Predesign: better information for builder, some additional guarantee for installer
  - Report of performance: clear and reliable information for builder and EPB-reporter
- Complexity of ventilation systems: long time between predesign and commissioning of the system
- Indications on
  - conformity with EPB-regulations
  - Quality of installations
- Guidance for inspectors and installers for practical situations

BCCA

CONTACT

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BCCA

For quality and confidence in the construction sector

BELGIAN CONSTRUCTION CERTIFICATION ASSOCIATION VZW

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COST

- Training (optional, 1 day): 355 EUR
- Theoretical exam/module (online): 51.07 EUR
  all (6) modules: 177.73EUR
- Practical exam (one hour, one on one): 178.75 EUR
- Company fee (yearly): 255.36 EUR
- Price per dwelling: 71.50 EUR
- Larger projects quantity reduction

BCCA

16

ADDED VALUE OF THE QUALITY FRAMEWORK

- For **builders**:
  - Better guarantee on the quality of the investment, more happy tenants, …
  - Before starting the works information on the ventilation system (→ VVO)
- For **inhabitants:**
  - Better IAQ – better indoor climate – better energy performance
- For **installers**:
  - Correct competitor conditions
- For **industry:**
  - Better condition for development and sale of performant components and systems
- For EPB **reporters**:
  - Lower risk on non-conformities
  - Lower risk on paying fees due to mistakes of other parties
- For **authorities**:
  - Evolution towards a broader support for minimal ventilation requirements
  - Public health – environmental goals

BCCA



1

TNO innovation for life

PROBLEMS IN VENTILATION PERFORMANCE: IT FAILS DUE TO EXECUTION & DESIGN



2

HOW IS THE PERFORMANCE IN THE NETHERLANDS?

- 80% dwellings flow rates fails for total dwelling and per ~~house &~~ individual rooms
- too much noise complaints
- People turn off ventilation system because of noise

(van Dijken, 2011)

New regulations 30 dBA

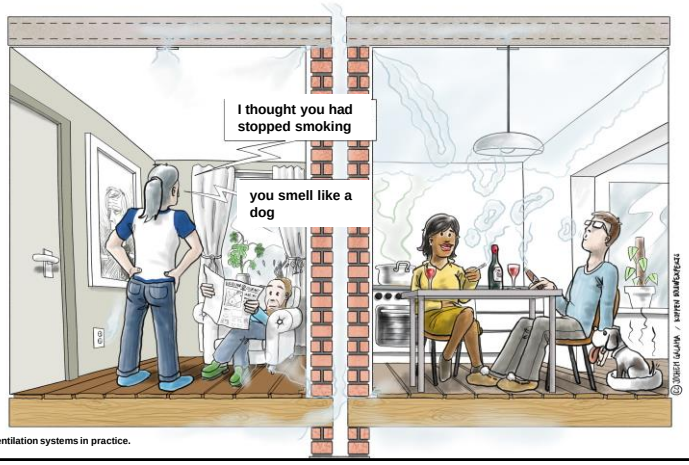
Recent study in 32 dwellings Netherlands (TNO):

- 62% to much noise
- 87% to much power consumption of the fans





DESIGNED VENTILATION FLOWS NOT ACHIEVED BECAUSE OF INSUFFICIANT AIRTIGHTNESS



Commission and performance contracting of ventilation systems in practice.

PERFORMANCE CONTRACTS IN THE NETHERLANDS

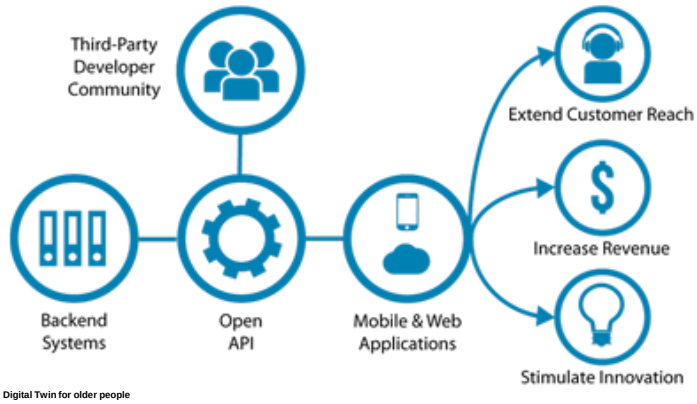
- Performance of ventilation system is checked incidentally
- New legislation “Private kwaliteitsborging” contractor must prove the performance
- Energy performance contract, initiative “Stroomversnelling” (Energiesprong)`. People pay a fix fee for electricity, heat and domestic hot water based on NZEB retrofitting
- Open source API to provide needed data of energy consumption



Commission and performance contracting of ventilation systems in practice.

OPEN SOURCE API MONITORING: STANDARDIZED ACCESS TO ENERGY AND IAQ DATA

Application Programming Interface





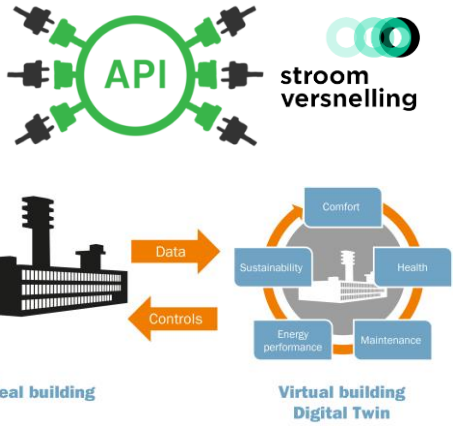
Digital Twin for older people

TNO innovation for life

WHAT DOES THIS OPEN SOURCE API OFFER:

- Simplified access to both energy, temperature and indoor air quality data
- Uniform data format (name, frequency etc)
- First step data quality (illogical values, etc)
- Reduction installation time
- This makes model based data analytics more easy (greybox, digital twin)

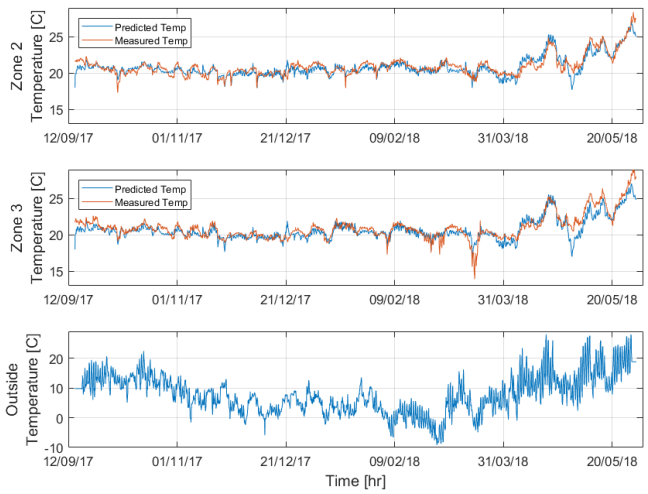
This approach is used to monitor dwellings in horizon2020 project Sphere



7

ANALYTICS OF INDOOR AIR QUALITY AND ENERGY USE BASED ON GREY BOX MODELS IN DWELLINGS

SPHERE BIM DIGITAL TWIN PLATFORM



- **SECOND FLOOR TEMPERATURE**
- **FIRST FLOOR TEMPERATURE**
- **AMBIANT TEMPERATURE**

This project has received funding from the European Union's H2020 programme under Grant Agreement No. 820805.

8

PERFORMANCE CONTRACT, QUALITY MANAGMENTS AND FIELD MEASUREMENTS

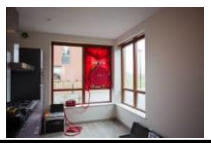
An analysis of 1,287 houses showed that 68% of single-family homes non-compliant. Many of these malfunctions could be avoided through the implementation of quality management tools. (Jobert, 2013)

If we want performance contracts we need simplified tools for determining:

1. Air flows
2. Airtightness
3. Noise of ventilation systems

"TKI Securevent project"







9

SIMPLIFIED NOISE MEASUREMENT OF VENTILATION SYSTEMS

1 A simplified approach to verify the possibility for too high noise levels based upon:

a. the pressure drop over the ventilation ducts,
b. the noise level nearby the ventilation unit (Class 2)
c. the electrical power consumption by the ventilator
d. visual inspection based on the number of bends, reducers, flexible hoses etc.



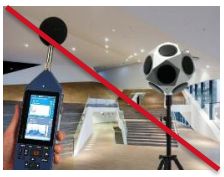






2 A simplified noise measurement based on BRL 8010
a. reverberation is not measured but determined according to tables
b. noise measurements in the critical reception areas





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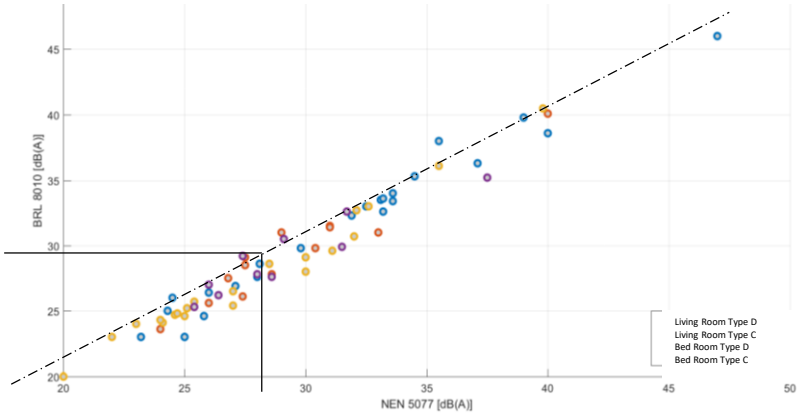
COMPARISON SIMPLIFIED MEASUREMENT BRL 8010 VS THE MEASUREMENT DUTCH STANDARD NEN 5077



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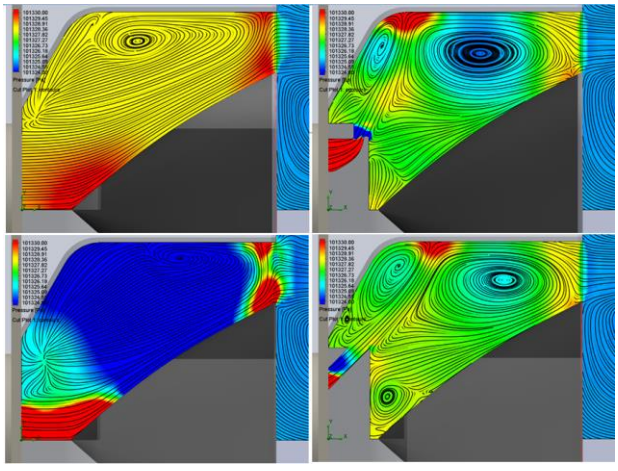
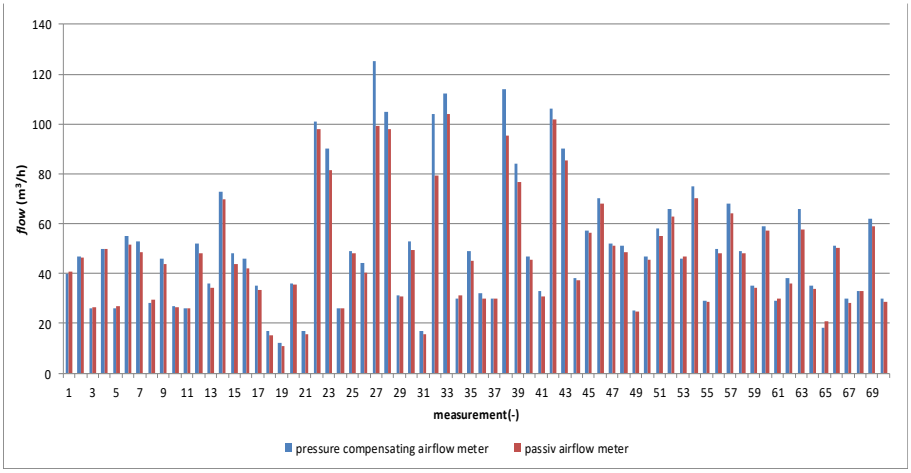
ROTATING VANE FLOW METER , SUPPLY COMPONENT IS MAIN CHALLENGE





COMPARISON PRESSURE COMPENSATING AND MODIFIED ROTATING VANE FLOW METER





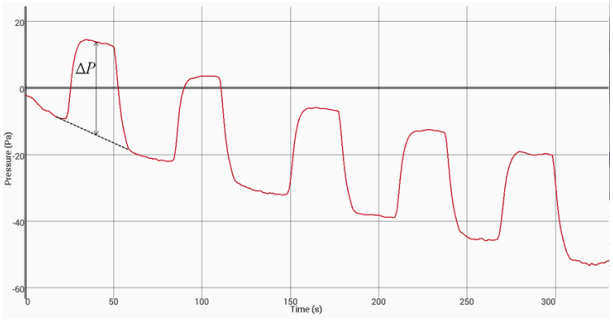
13

SIMPLIFIED MEASUREMENT OF AIRTIGHTNESS

- the ventilation system is used to maintain a pressure difference over the façade.
- By switching the ventilation system from on/off or high/low.
- The pressure difference is measured using a reference vessel



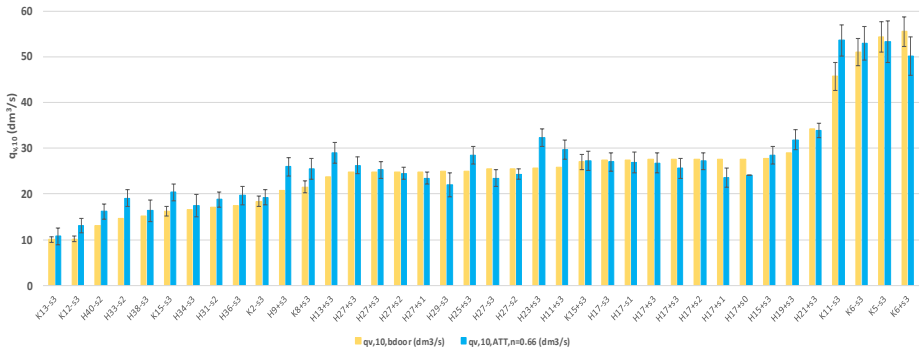
Commission and performance contracting of ventilation systems in practice.



Typical measured pressure difference

14

COMPARISING BLOWERDOOR WITH SIMPLIFIED MEASUREMENT



Comparison of blowerdoor measurement ($q_{v,10,bdoor}$) with the simplified airtightness measurement ($q_{v,10,ATT}$)

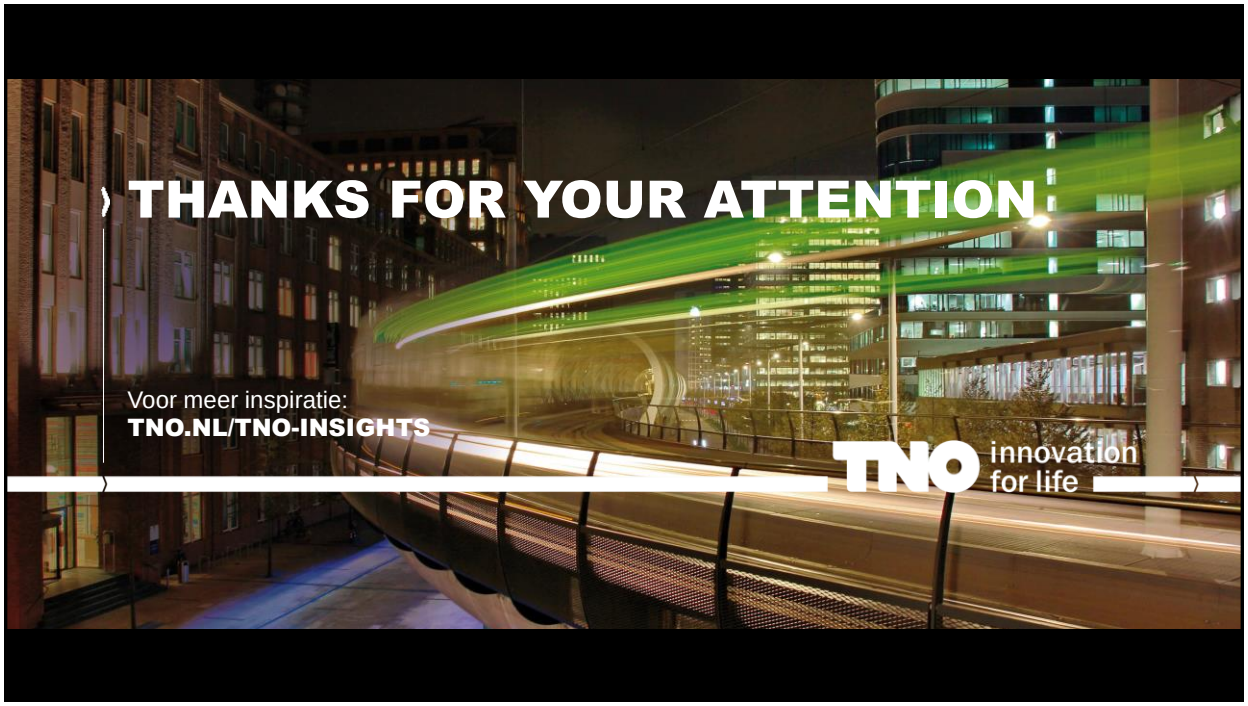
KEY POINT FOR PERFORMANCE CONTRACTING: TRAINING INSTALLATION FITTER

- Training ventilation fitters for Nearly Zero Energy Buildings and performance contracting (NZEB)
- Ventilation fitters will be trained with this new technologies
- Status: pilot trainings are being developed



NEWCOM New qualification schemes to build high quality

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 754148


THANKS FOR YOUR ATTENTION
Voor meer inspiratie:
TNO.NL/TNO-INSIGHTS
TNO innovation for life

Test of new analysis methodologies to assess dynamic airflow rate with the tracer gas decay method

G. Remion, B. Moujalled, M. El Mankibi

1

Introduction – Issues for assessing natural airflows

40th AIVC

- **Diversity of configurations**



- **Unstable flow path**
  - Low pressure mechanism
  - Variable airflows

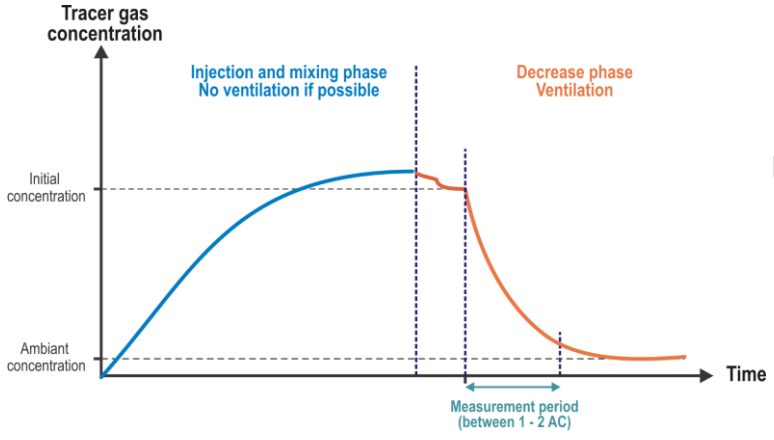


2

Introduction – ACH tracer gas measurement

40th AIVC

- **Concentration decay method**



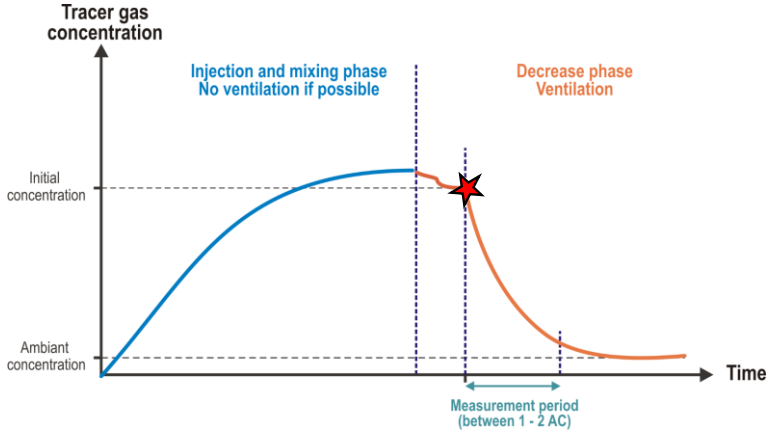
Provides the mean ACH

3

Introduction – ACH tracer gas measurement

40th AIVC

- **Concentration decay method**



Multipoints method

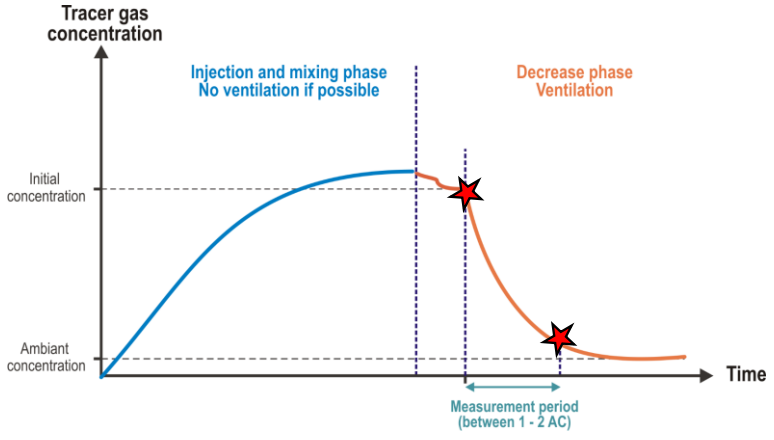
- Reduce measurement noise
- Does not tolerate variable airflows

4

Introduction – ACH tracer gas measurement

40th AIVC

- **Concentration decay method**



2 points method

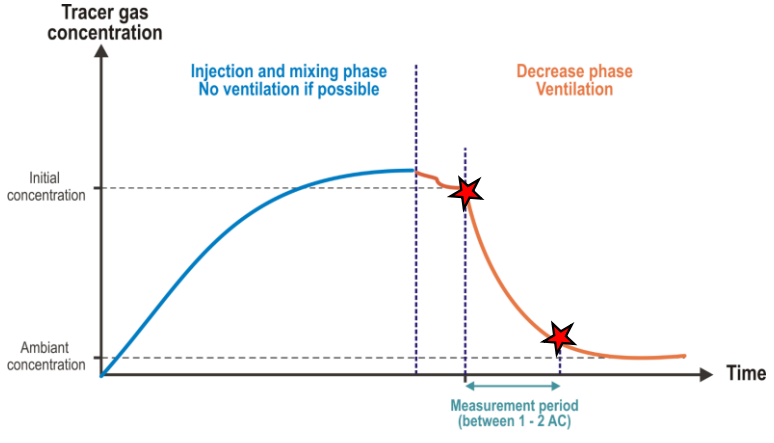
- Important uncertainties
- Tolerates variable airflows

5

Introduction – ACH tracer gas measurement

40th AIVC

- **Concentration decay method**



2 points method

Multipoints method

6

Objectives of the experiment

40th AIVC

- **Test a novel methodology to :**
  - Increase the accuracy of the method
  - Measure the dynamic airflow rate

→ **Kalman Filter**

  - Follow dynamic parameters
  - Reduce the measurement bias

Methods – Experimental setup

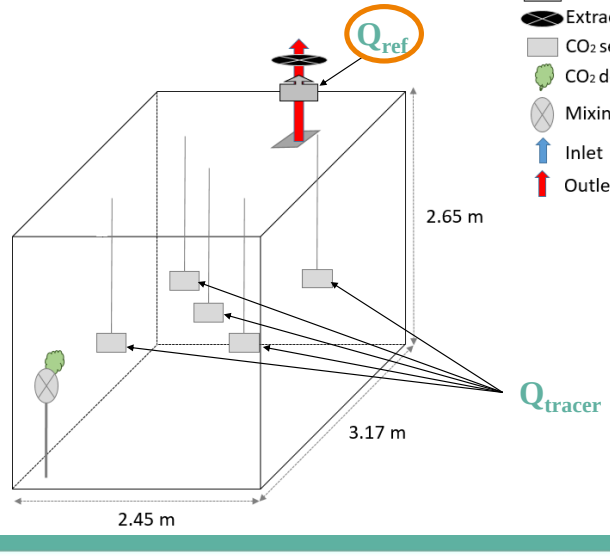
40th AIVC





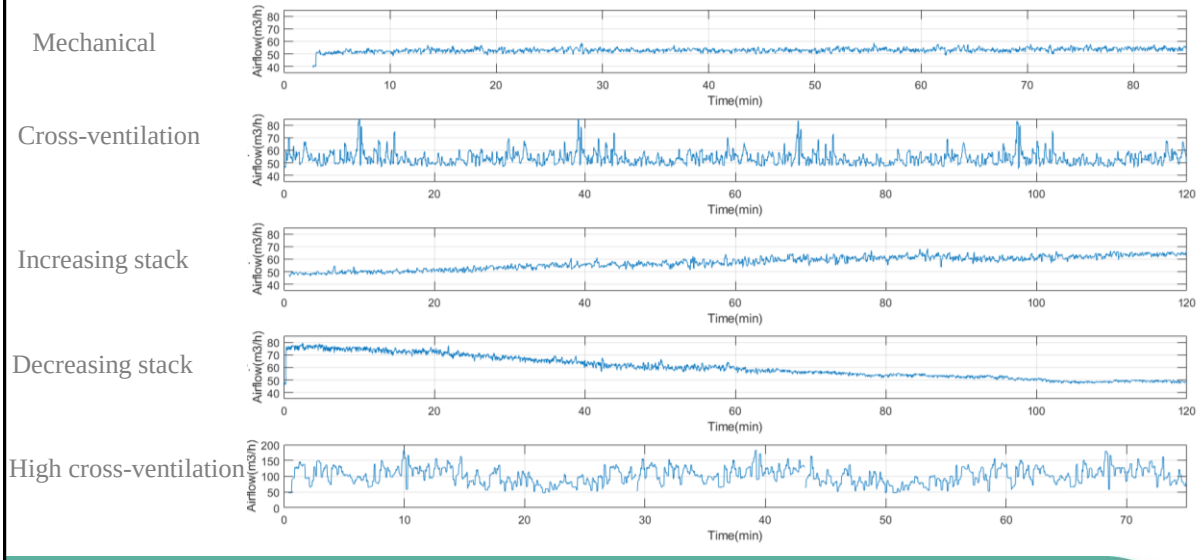
Methods – Experimental setup

- 5 wireless CO_2 sensors (accuracy 3% + 50 ppm)
- Controllable extract fan
- Airflow-meter that provides the reference value



9

Methods – Airflow variation profiles



10

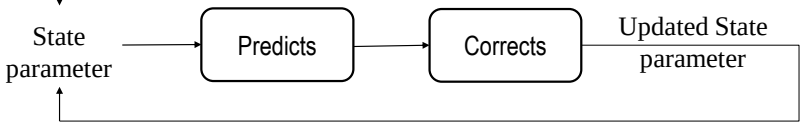
Methods - Kalman filter

$V = Measurement\ noise\ covariance\ matrix$

$W = Process\ noise\ covariance\ matrix$

$C_k^* = Noise\ corrupted\ measurement$

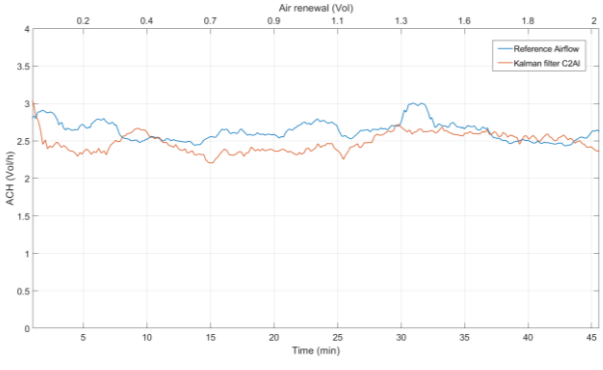
$$x_k = \begin{cases} Concentration \\ Airflow\ rate \end{cases}$$



11

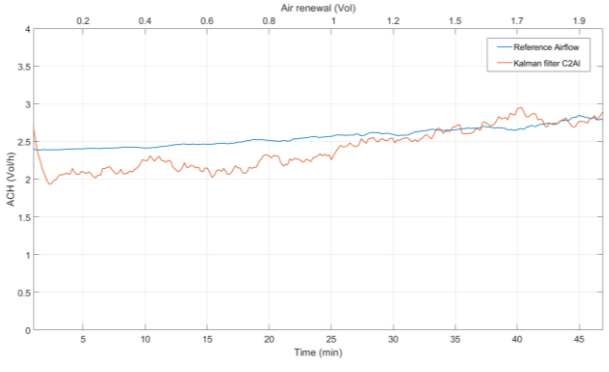
Results – Comparison Kalman filter with reference airflow

Cross ventilation



Mean deviation : 4,5% (0,12 Vol/h)

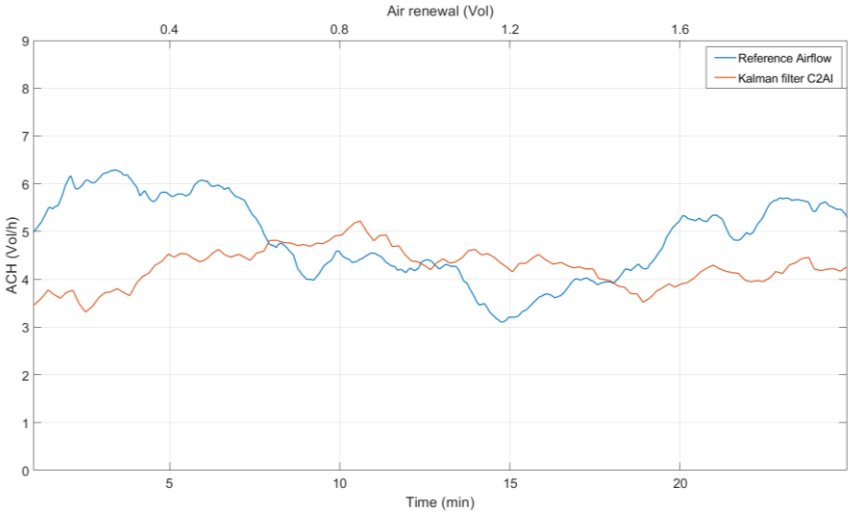
Stack increasing



Mean deviation : 5% (0,12 Vol/h)

12

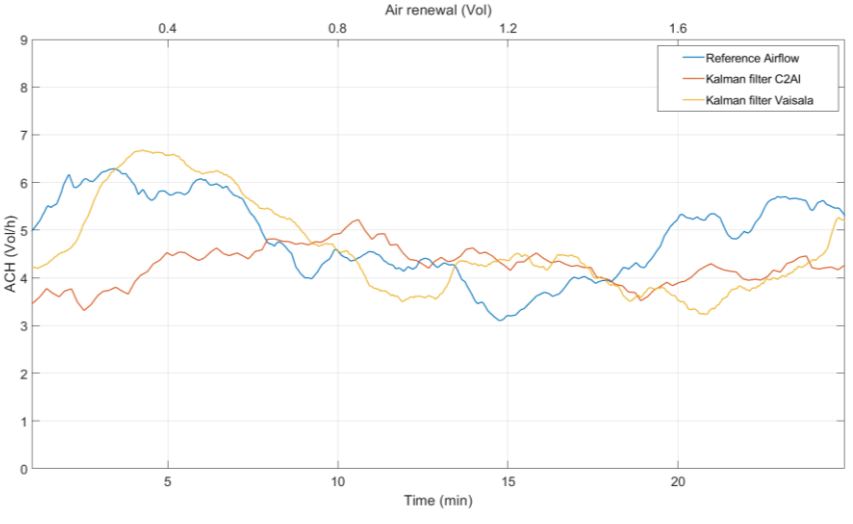
Results – Most critical airflow variation profile



- Mean deviation = 5,2%
- Poor ability to follow strong fluctuations

13

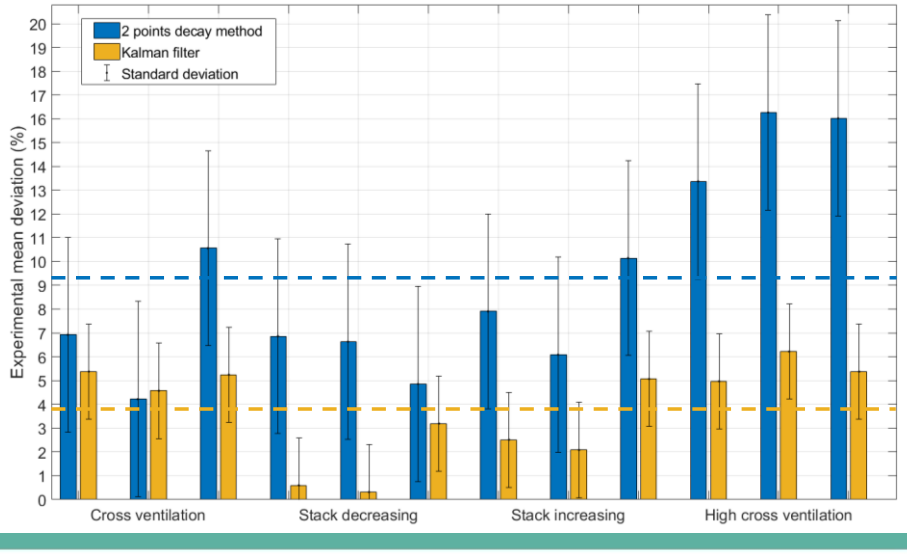
Results – Most critical airflow variation profile



- Increase of the measurement frequency improve the tracking ability

14

Results – Experimental mean deviations



9,2%
Std = 4,1%

3,8%
Std = 2%

15

Conclusions

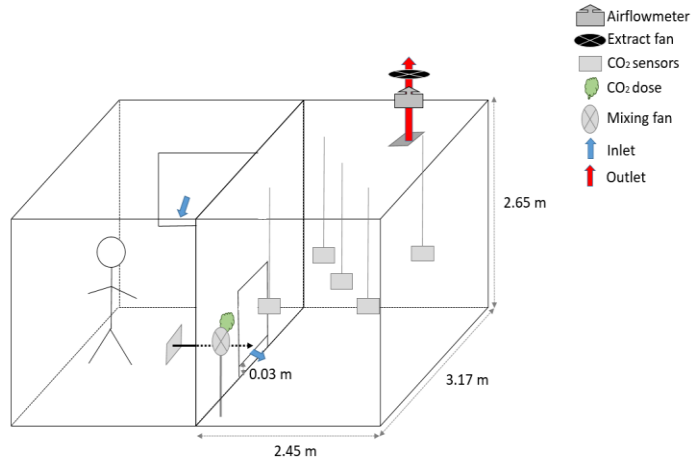
- Kalman filter allows reducing uncertainties
- Kalman filter allows measuring dynamic airflow rate
- Strong fluctuations of airflow rate require high measurement frequency

16

Perspectives

40th AIVC

- **Perform the test in a multizone building thanks to the Kalman filter**



17

Cerema

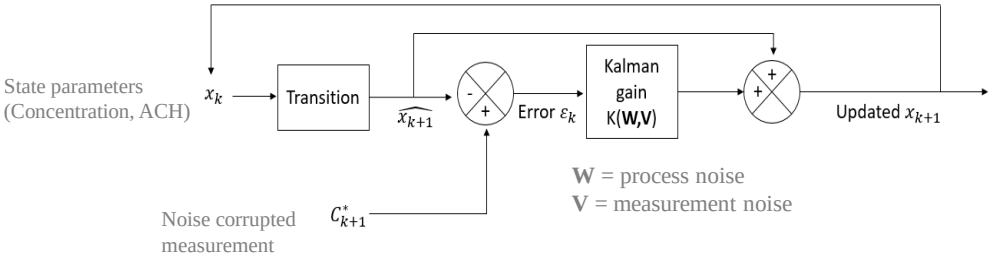
AIVC TightVent Europe BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM venticool the international platform for ventilative cooling

Thanks

gabriel.remion@cerema.fr

18

Kalman filter



W = process noise
V = measurement noise

Cerema

PLEIAQ



Reliability of ductwork airtightness measurement: impact of pressure drop and leakage repartition on the test result

Sylvain Berthault, Valérie Leprince

Cerema - Centre-Est & PLEIAQ, France

1

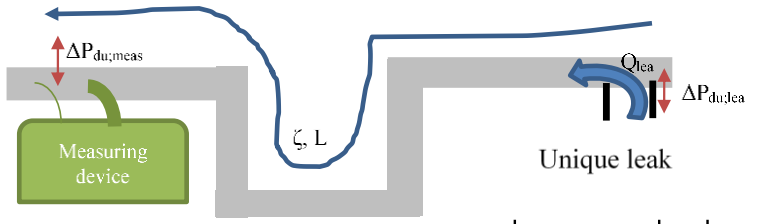
Reliability of ductwork airtightness measurement

- **Context :**
  - Ductwork airtightness test is mandatory in the context of the Effinergie label in France.
    - The reliability of the test becomes a key subject
  - Ductwork airtightness test assumes an homogeneous pressure difference between inside and outside along the measured section.
    - Pression drop due to friction and dynamic losses in the ductwork may induce a variation of this pressure difference.
- **Problematic :**
  - What is the impact of the pressure drop and of the leakage repartition on the test result?
- **Objectives :**
  - Test the impact on an experimental set-up
  - Developpe and validate a numerical model to estimate the impact of pressure drop on the result of the airtightness test according to the airtightness level

2

Numerical model

- **Pressure drop is due to friction losses (along ductwork) and dynamic losses (bends and junctions)**
  - Both proportional to V²
- **The objective of the numerical model is to estimate the <u>maximum</u> pressure losses during an airtightness test**
  - A **unique leak** at the end of ductwork with a measuring device at the opposite has been considered
  - A **constant Q_{lea} and the section** have been considered



$$Q_{lea} = K\Delta P_{du;leak}{}^{\frac{2}{3}}S$$

$$\left|\Delta P_{du;meas}\right| - \left|\Delta P_{du;leak}\right| = \frac{\zeta\rho}{2} * \left(\frac{4Q_{lea}}{\pi D^2}\right)^2$$

$\zeta = pressure\ loss\ coefficent$

3

Numerical model

- **To avoid using with an iterative method the maximum is calculated with the pressure at the measurement device as**
  - $\left|\Delta P_{du;leak}\right| \leq \left|\Delta P_{du;meas}\right|$
- **The error on the measured flowrate is**
  - $E = \frac{\left|Q_{\Delta P\,du;meas}\right| - \left|Q_{\Delta P\,du;lea}\right|}{\left|Q_{\Delta P\,du;meas}\right|} = \frac{K\left|\Delta P_{du;meas}\right|^{\frac{2}{3}} - K\left|\Delta P_{du;leak}\right|^{\frac{2}{3}}}{K\left|\Delta P_{du;meas}\right|^{\frac{2}{3}}}$
- **And therefore**
  - $\boldsymbol{E \leq 1 - \left(1 - \frac{8\zeta\rho K^2 L^2}{D^2} * \left|\Delta P_{du;meas}\right|^{\frac{1}{3}}\right)^{\frac{2}{3}}}$

$\zeta = pressure\ loss\ coefficent$
K = airtightness class of the ductwork
$\Delta P_{du;meas}$ = pressure difference at the measurement device

4

The experimental set-up

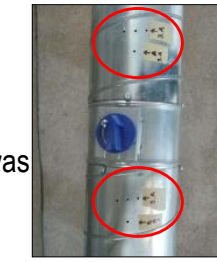
- **Presentation**
  - The experimental set-up was a laboratory replication of a multi-family dwelling's ductwork: two main columns with two dwellings connected on each column.



Replication of a multi-family dwelling's ductwork

Circular GALVA duct Diameter (mm)	Length (m)
315	2.60
200	15.08
125	10.4

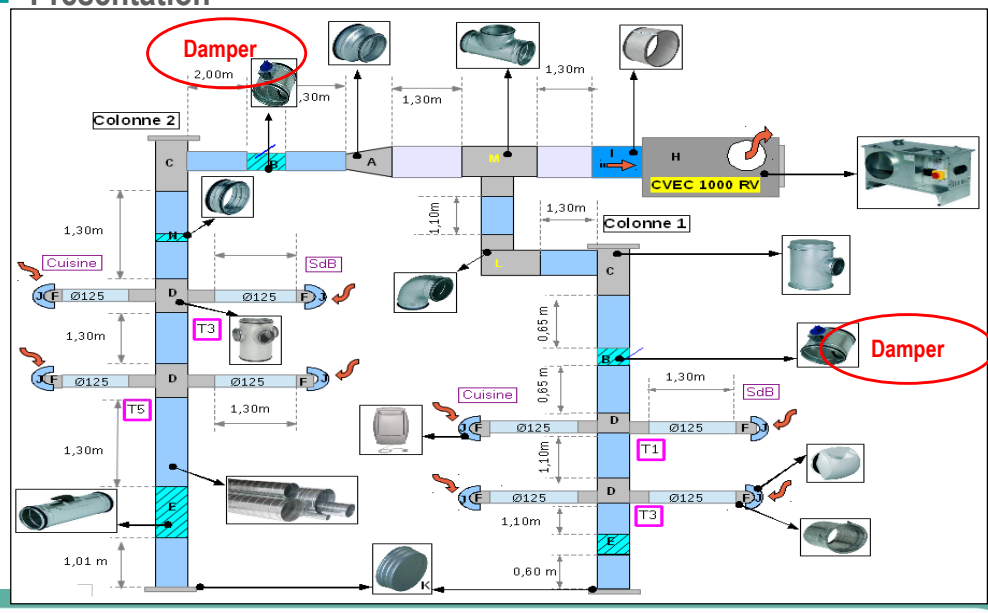
First, ductwork built class C,
then the ductwork was drilled to
reach 1,5 * class A.



5

The experimental set-up

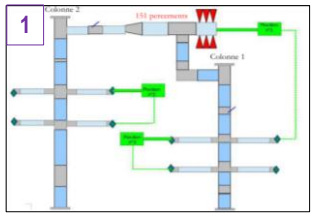
- **Presentation**



6

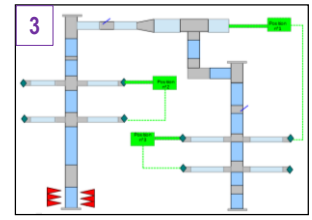
The experimental set-up

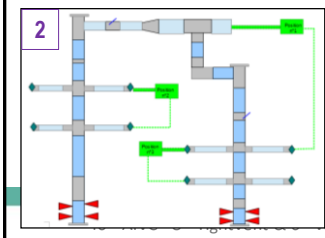
- **Impact of the measuring device location according to leakage distribution**
  - 4 different leakage distributions inducing approximately the same airtightness level
  - 3 different locations for the measuring device



The 4 different leakage distributions:

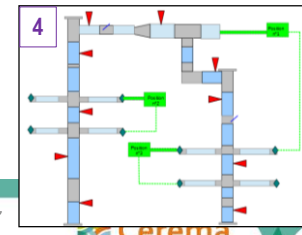
1. Leaks gathered close the fan
2. Leaks gathered at the bottom of columns 1 and 2
3. Leaks gathered at the bottom of column 2
4. Equally distributed leaks all along the ductwork





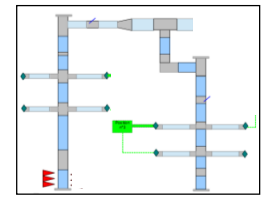
Locations of the measuring device (x3) for the 4 different leakage distributions:

A. By the fan
B. On column 1
C. On column 2



7

Results: Theoretical impact



- **The maximum theoretical impact is calculated with**
  - Only one large leakage at the bottom of column 1
  - The measuring device at the bottom of column 2.
- **According to the French standard DTU68.3, the average pressure losses coefficient is ζ ≈6.9**
- **For a measurement performed at 120 Pa, the error on the measurement flowrate is < 3% up to a ductwork 3*Class A :**

$$\frac{|\Delta P_{du;meas}| - |\Delta P_{du;leak}|}{|\Delta P_{du;meas}|} \leq \frac{8\zeta\rho K^2 L^2}{D^2} * |\Delta P_{du;meas}|^{\frac{1}{3}} \leq 0.045 \Rightarrow K \leq 0.00008 \approx 3 * Class\ A$$

⇒ **Provided the ductwork is at most 1,5 * class A, the ductwork airtightness measured shall not vary with:**

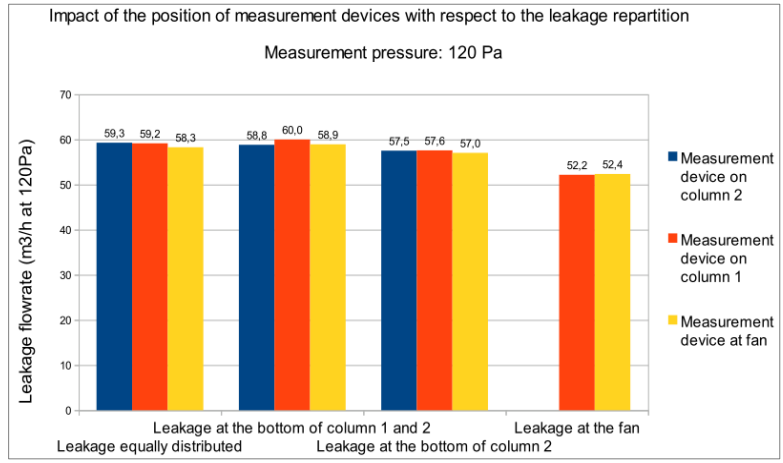
- **the position of the measurement device**
- **the location of leakages**

8

Results: impact of leakage distribution and measuring device location

- **Experimental studies**

Confirmed by the performed measurements !



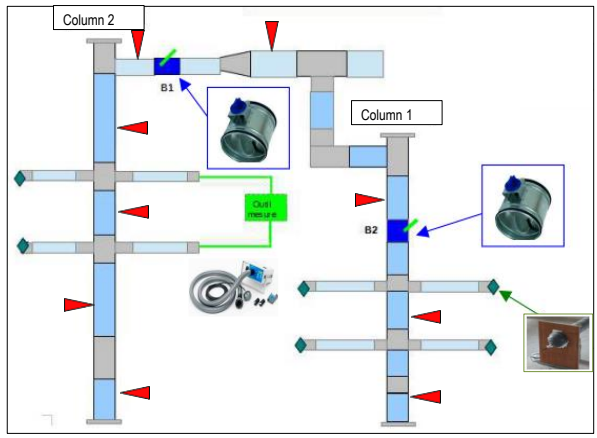
Leakage flowrate as a function of leakage distribution and location of the measuring device at 1.5*class A

9

The experimental set-up

- **Impact of the pressure drop on the result of the airtightness test**

To increase the pressure drop in the ductwork, 2 dampers have been included (one on each column).



Leaks are equally distributed all along the ductwork.

10

The experimental set-up

Impact of the pressure drop on the result of the airtightness test

Each damper has 7 different positions from “0” 0pen to “6-F” Closed. The position of the 2 dampers were modified simultaneously from “0pen” to “Closed” through 7 positions.

Position damper	« 0 » = Open	« 3 » = three quarter closed	« F » = Fermé
Top view of the damper control			
Interior view of the shutter			

- The pressure loss coefficient of the damper has been calculated according to its position
  - $0 \leq \zeta \leq 128$
- 42 tests performe
  - 7 positions
  - 3 tests pressures (90 Pa, 120 Pa et 160 Pa)
  - 2 levels of ductwork airtightness (class C, 1.5*class A)

$\zeta = pressure\ loss\ coefficent$

Results: impact of the pressure drop

Maximum theoretical impact

	Dampers position	Open	1	2	3	4	5	Closed
	Total pressure drop (Pa)	6.9	8.7	10.5	17.5	62.6	163.2	216.5
1.5* class A	K (1.5*Class A)	3.88E-05						
	Max. variation at 90 Pa	1%	1%	1%	1%	5%	14%	19%
	Max. variation at 120 Pa	1%	1%	1%	2%	6%	16%	21%
	Max. variation at 160 Pa	1%	1%	1%	2%	7%	18%	24%
class C	K (class C)	2.12E-06						
	Maxi. variation at 90 Pa	0.00%	0.00%	0.00%	0.01%	0.02%	0.06%	0.08%
	Max.variation at 120 Pa	0.00%	0.00%	0.00%	0.01%	0.03%	0.07%	0.09%
	Max. variation at 160 Pa	0.00%	0.00%	0.00%	0.01%	0.03%	0.08%	0.10%

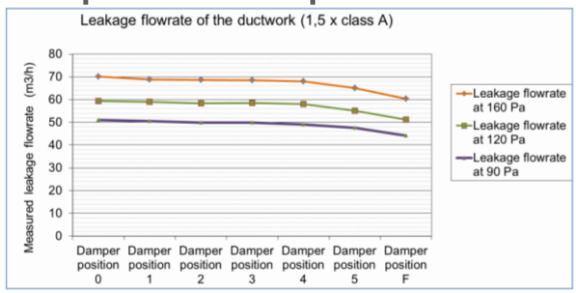
Variation for 1,5*class A over 10% when the damper is in position 5 or closed.

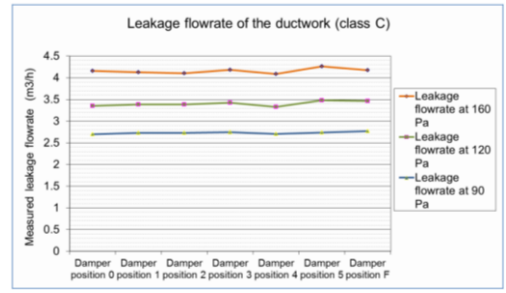
Negligible variation for class C

Maximal variation of measured flowrates at 90 Pa, 120 Pa and 160 Pa according to the damper positions

Results: impact of the pressure drop

- **Experimental impact**





Leakage flowrate of the ductwork as a function of the damper's position with an airtight ductwork at 1,5*class A and class C

- As predicted with the theoretical approach, the position of the damper has **no impact** on the measured flowrate for a **class C** ductwork.
- For the ductwork 1,5*class A, the measured flowrate decreases from position 4 up to -14% at 160 Pa.

Conclusion

- **A mathematical model has been developed to estimate the maximal error on the measurement flowrate according to:**
  - the airtightness of the ductwork
  - the ductwork configuration (pressure drop due to friction and dynamic losses)

The model has been checked by measurement on an experimental set-up and it has shown that :

- The impact of pressure losses on the measured flowrate is expected to be very small for airtight ductwork (class C)
- For very leaky ductworks it would be advisable to define a maximal length to be tested (distance between the measuring device and the farthest end of the ductwork) **or** to check the homogeneity of the pressure at various locations.



Thanks

Valérie Leprince - PLEIAQ
Sylvain Berthault - CEREMA

Techniques to Estimate Commercial Building Infiltration Rates

Andrew Persily, Lisa Ng, W. Stuart Dols, Steven Emmerich
National Institute of Standards and Technology
Gaithersburg, Maryland USA



40th AIVC - 8th TightVent & 6th venticool Conference, 2019
Ghent BELGIUM, 15-16 October 2019

Why infiltration?

IAQ, Energy, Moisture

First AIC Conference in 1980: Infiltration Instrumentation and Measurement





Why commercial?

Early focus - low-rise residential

Commercial: Bigger, multizone, more complex ventilation systems, less airtightness data, fewer infiltration measurements



Earliest commercial building infiltration estimation method - 1977

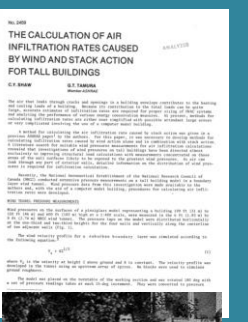
Shaw and Tamura, 1977

Wind & stack equations

Inputs: Height, airtightness, wind speed, in-out temperature, wind & thermal coefficients,

Another equation to combine wind and stack to total infiltration

34 Gscholar citations; 1 comparison to measurements not in GS


THE CALCULATION OF AIR INFILTRATION RATES CAUSED BY WIND AND STACK ACTION FOR TALL BUILDINGS

C.Y. SHAW G.T. TAMURA



3

Infiltration Estimation in Commercial Energy Analysis

Infiltration impacts energy

Infiltration > 0 (Hunt 1979; Grot 1986**)**

Many (US) energy calculations assume no infiltration

Myth of pressurized buildings





EnergyPlus uses empirical equation

$I = I_{design} * F_{schedule} (A + B\Delta T + Du^2)$

Low-rise residential coefficients

$F_{schedule}$ = 0.25 when ventilation on

4

More Recent Advances: Large Building Infiltration Correlations

1-year CONTAM simulations of reference buildings

Fit data to empirical equations, system on and off

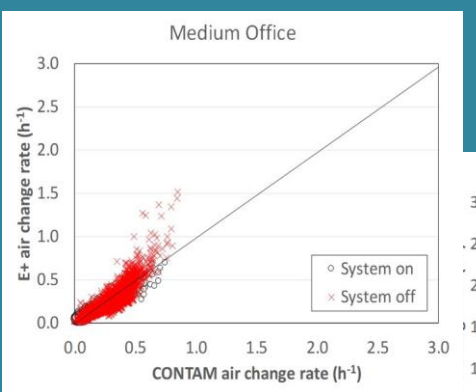
$I = I_{design} * \cancel{F_{schedule}} (A + B\Delta T + Du^2)$

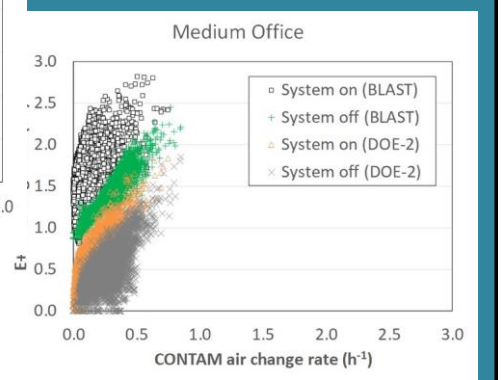
Correlated A, B and D with building height, surface-to-volume ratio, ratio of supply airflow to exhaust

Open Studio Measure called "Adding infiltration correlated for weather and building characteristics" (https://bcl.nrel.gov/node/83101).

5

Infiltration correlations vs. CONTAM predictions

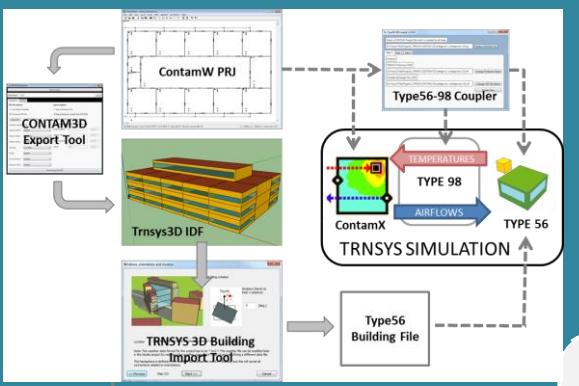




EnergyPlus estimates vs. CONTAM predictions

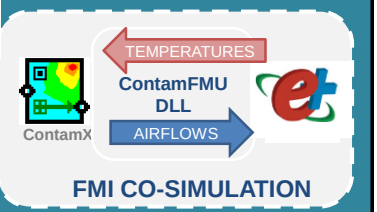
6

More Recent Advances: Couple Energy-Airflow Models



CONTAM/TRNSYS Workflow

CONTAM/EnergyPlus



FMI CO-SIMULATION

7

SUMMARY

Less work on infiltration estimation in larger, commercial buildings than low-rise residential

Bigger, multizone, more complex systems, fewer airtightness and infiltration measurements

3 options: Multizone modeling, Empirical formulas (using technically sound, non-zero coefficients), and Coupled energy-airflow modeling

Unclear how simple methods can be, but infiltration needed for energy and IAQ analyses

8

Alternative solution proposal to improve the air change in light shafts based on flaps

Dr. MIGUEL ÁNGEL PADILLA-MARCOS
UNIVERSITY OF VALLADOLID

1

INTRODUCTION

- The concept of “light shaft” has been developed in South European cities due to the regulations on building depth. It is defined as the confined outdoor space formed in and between the buildings whose principal function is lighting and ventilating indoor spaces in a natural way.

- Light shafts are designed to provide light to those indoor spaces that cannot take the light directly from outdoor spaces due to its location into the building.

- They are also very important in terms of ventilation but usually are not designed for that purpose, hiding the air access.

- The quality of that air is also lower than the indoor air. Outdoor air flows freely through the city even though emissions of combustion gases and other pollutant sources contaminate it.

-The impact of several outdoor space geometries on the air quality have been analysed using the age of the air and efficiency concepts defined by Sandberg (1981)

-It has been demonstrated that the air quality and its renovation is affected by the architectonical configuration of the models and the aero-dynamical phenomena of the environment

2

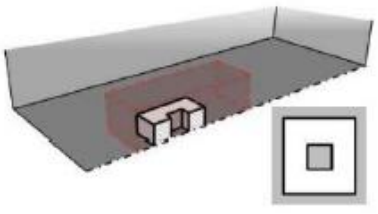
METODOLOGY

- Study of 3D cases considering its two-dimensions.
- Simplification from 3D to 2D dimensions to minimize the computing costs.
- Elimination of the transversal dimension or “y” axe.
- Study of the 2D cases in the symmetry plane.
- Transversal direction is only conditionate by the walls of the light shaft.

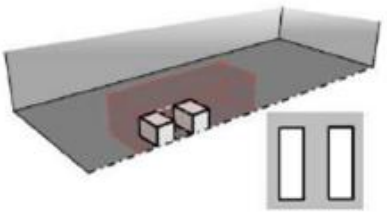
2D ANALYSIS → 3D MODEL
developed infinitely along the normal direction to the simulation plane

STUDY OF TWO CASES.

- Study of the usual formal configuration in the Spanish architecture tradition
- Election of two cases due to its similarities regarding the cut in the symmetry plane of a 3D model
- Efficiency difference of ± 1.4%
- Better results were obtained in Case 2.



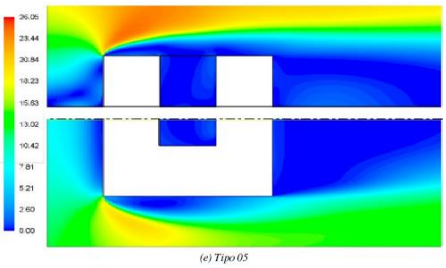
Case 1. Isolated light shaft surrounded by a ring-shaped building



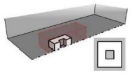
Case 2. Two parallel and transversal blocks

STUDY OF TWO CASES. EFFICIENCY.

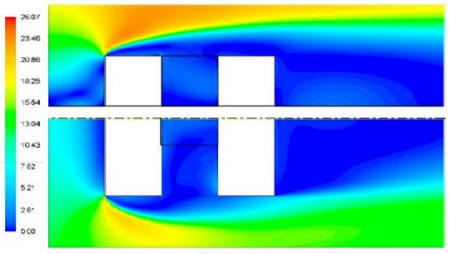
- The outside space is resembled as a continuous outside space or corridor.
- The moving air undergoes acceleration when it approximates the solid built.
- The air has no other lateral escape routes to distribute pressures
- Age of the air and outside space efficiency change in comparison with 3D studies however the behaviour pattern take approximated 3D guidelines.



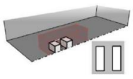
(e) Tipo 05



Case 1. Isolated light shaft surrounded by a ring-shaped building



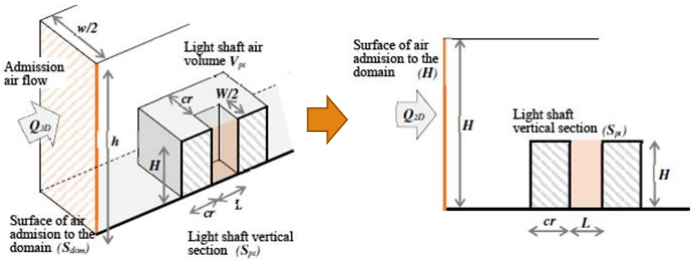
(h) Tipo 08



Case 2. Two parallel and transversal blocks

3D MODEL TO 2D MODEL

- Adjustment of the variables due to the elimination of one dimension.
- The physical variables like volume become dependent of the dimension omitted and is the product of it two-dimensions obtained from the built surface.
- The height of the domain and vertical section of the light shaft will be conducted
- Air flow in the computational domain admission is the result of multiplying the average velocity of wind profiler in the domain per its height.



$$Q_{3D} = \bar{u} \cdot h \cdot w \ \ldots \Rightarrow Q_{2D} = u \cdot h \cdot (1\ m)$$

$$V_{pt_{3D}} = H \cdot L \cdot W \ \ldots \Rightarrow V_{pt_{2D}} = H \cdot L \cdot (1\ m)$$

3D MODEL TO 2D MODEL

- It is demonstrated that the simplification to the 2D simulation model is adequate.

- The 2D models are accurate enough to analyse the efficiency of the air renovation of the light shaft.

Compared results between relatives efficiencies in the reference air renovation.

6x42 (2D)	6x2x42	6x3x42	6x4x42	6x5x42	6x6x42
1.70 %	1.06 %	1.40 %	1.72 %	2.00 %	2.24 %

Results obtained from the 2D simulation of the base case, dimensions 6m x 42m.

	Unitary volume	Unitary air flow	Average age of the volume	Control efficiency
patio 6x42	252 m^3	0.04857 m^3/s	152658.810 s	1.636 %

IMPROVEMENT OF THE RENOVATION EFFICIENCY

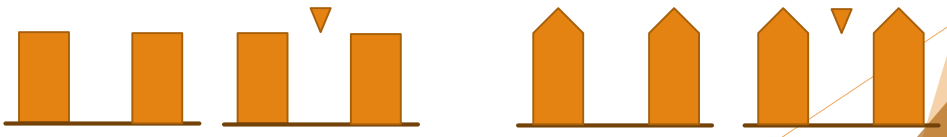
- After the study of the influence of the light shaft dimensions in its air renovation it was decided to analyse it behaviour including a flap.

- The modification of the air behavior can be achieved by the modification of the parameters that determine its movement.

- This kind of modification have the aim to improve the health and comfort conditions of the ventilation inside the light shaft.

- To study that four 2D cases have been proposed. Two of them with flap and two of them without it.

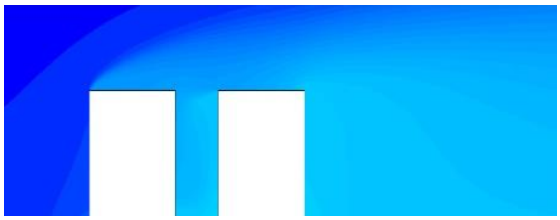
- The cases represent a central cut of 6x425 where wind moves at 6m/s in a height of 100m over the building



IMPROVEMENT OF THE RENOVATION EFFICIENCY

CASE A.1

Renovation efficiency in a light shaft of 6x18m shaped by a flat roof building of 12m wide



CASE A.1	Unitary volume	Unitary air flow	Average age of the volume	Control efficiency	Relative efficiency
Control domain	1908 m³	60369 m³/s	563.1 s	2.81 %	-
Light shaft	108 m³	0.176 m³/s	783.4 s	2.02 %	39.16 %
Upper third	36 m³	0.176 m³/s	759.3 s	2.08 %	13.47 %
Central third	36 m³	0.176 m³/s	767.1 s	2.06 %	13.33 %
Lower third	36 m³	0.176 m³/s	823.8 s	1.92 %	12.41 %

CASE A.2

Renovation efficiency in a light shaft of 6x18m shaped by a flat roof building of 12m wide with a flap



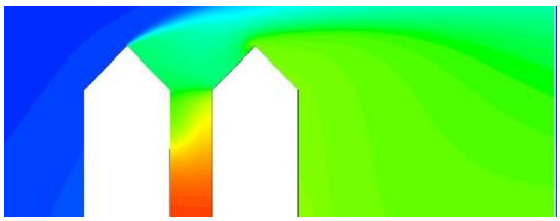
CASE A.2	Unitary volume	Unitary air flow	Average age of the volume	Control efficiency	Relative efficiency
Control domain	1908 m³	61490 m³/s	572.5 s	2.71 %	-
Light shaft	108 m³	1827 m³/s	834.4 s	1.86 %	3.54 %
Upper third	36 m³	1827 m³/s	678.5 s	2.28 %	1.45 %
Central third	36 m³	1827 m³/s	763.9 s	2.03 %	4.29 %
Lower third	36 m³	1827 m³/s	1060.8 s	1.46 %	0.93 %

9

IMPROVEMENT OF THE RENOVATION EFFICIENCY

CASE A.1

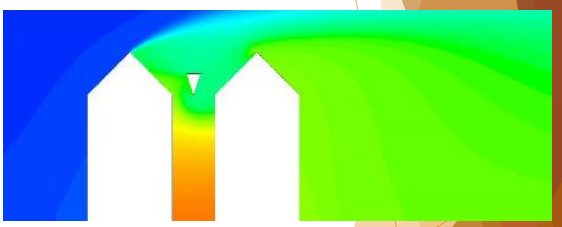
Renovation efficiency in a light shaft of 6x18m shaped by a flat roof building of 12m wide



CASE B.1	Unitary volume	Unitary air flow	Average age of the volume	Control efficiency	Relative efficiency
Control domain	1833 m³	55928 m³/s	1378.1 s	1.19 %	-
Light shaft	108 m³	0.09 m³/s	3230.6 s	0.51 %	18.57 %
Upper third	36 m³	0.08 m³/s	2133.3 s	0.67 %	8.22 %
Central third	36 m³	0.09 m³/s	3331.6 s	0.49 %	6 %
Lower third	36 m³	0.09 m³/s	3928 s	0.42 %	5.09 %

CASE A.2

Renovation efficiency in a light shaft of 6x18m shaped by a flat roof building of 12m wide with a flap



CASE B.2	Unitary volume	Unitary air flow	Unitary air flow	Control efficiency	Relative efficiency
Control domain	1833 m³	55935 m³/s	1685.1 s	0.97 %	-
Light shaft	108 m³	0.413 m³/s	3175.7 s	0.52 %	4.12 %
Upper third	36 m³	0.413 m³/s	2391.5 s	0.69 %	1.82 %
Central third	36 m³	0.413 m³/s	3397.9 s	0.48 %	1.28 %
Lower third	36 m³	0.413 m³/s	3131.7 s	0.44 %	1.17 %

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IMPROVEMENT OF THE RENOVATION EFFICIENCY

CASE A.1



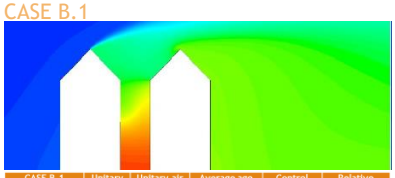
CASE A.1	Unitary volume	Unitary air flow	Average age of the volume	Control efficiency	Relative efficiency
Control domain	1908 m³	60369 m³/s	563.1 s	2.81 %	-
Light shaft	108 m³	0.176 m³/s	783.4 s	2.02 %	39.16 %
Upper third	36 m³	0.176 m³/s	759.3 s	2.08 %	13.47 %
Central third	36 m³	0.176 m³/s	767.1 s	2.06 %	13.33 %
Lower third	36 m³	0.176 m³/s	823.8 s	1.92 %	12.41 %

CASE A.2



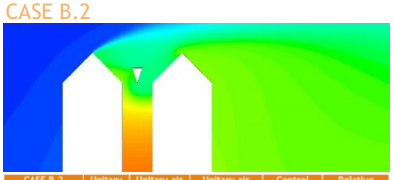
CASE A.2	Unitary volume	Unitary air flow	Average age of the volume	Control efficiency	Relative efficiency
Control domain	1908 m³	61490 m³/s	572.5 s	2.71 %	-
Light shaft	108 m³	1827 m³/s	834.4 s	1.86 %	3.54 %
Upper third	36 m³	1827 m³/s	678.5 s	2.28 %	1.45 %
Central third	36 m³	1827 m³/s	763.9 s	2.03 %	4.29 %
Lower third	36 m³	1827 m³/s	1060.8 s	1.46 %	0.93 %

CASE B.1



CASE B.1	Unitary volume	Unitary air flow	Average age of the volume	Control efficiency	Relative efficiency
Control domain	1833 m³	55928 m³/s	1378.1 s	1.19 %	-
Light shaft	108 m³	0.09 m³/s	3230.6 s	0.51 %	18.57 %
Upper third	36 m³	0.08 m³/s	2133.3 s	0.67 %	8.22 %
Central third	36 m³	0.09 m³/s	3331.6 s	0.49 %	6 %
Lower third	36 m³	0.09 m³/s	3928 s	0.42 %	5.09 %

CASE B.2



CASE B.2	Unitary volume	Unitary air flow	Unitary air flow	Control efficiency	Relative efficiency
Control domain	1833 m³	55935 m³/s	1685.1 s	0.97 %	-
Light shaft	108 m³	0.413 m³/s	3175.7 s	0.52 %	4.12 %
Upper third	36 m³	0.413 m³/s	2391.5 s	0.69 %	1.82 %
Central third	36 m³	0.413 m³/s	3397.9 s	0.48 %	1.28 %
Lower third	36 m³	0.413 m³/s	3131.7 s	0.44 %	1.17 %

- Case A.1 has achieved the best efficiency close to the 3%

-B.2 suffers a decrease of 30% in its domain efficiency in comparison with Case A.1 due to the blockage of the air.

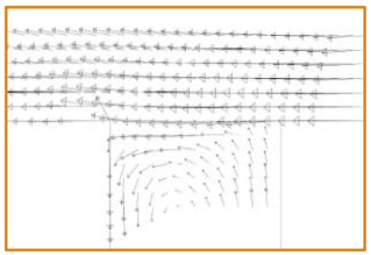
- Case A.1 has a lower air flow admission.

- Case A.2 has a descend of 50% in the efficiency in comparison with A.1

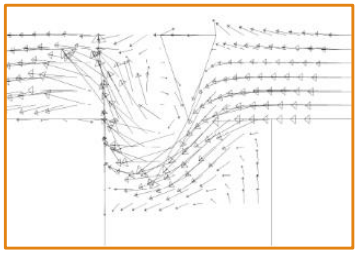
- It is demonstrated that a increase of the velocity does not necessarily imply an improvement in the efficiency.

IMPROVEMENT OF THE RENOVATION EFFICIENCY

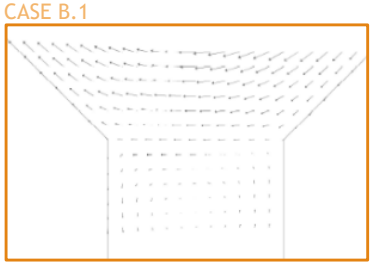
CASE A.1



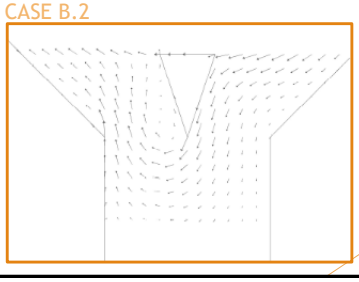
CASE A.2



CASE B.1



CASE B.2



- The flap creates a change of direction in the air movement in the top of the light flat.

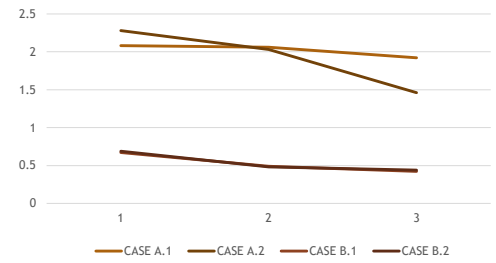
-B.2 suffers an increase of it reflow phenomenon.

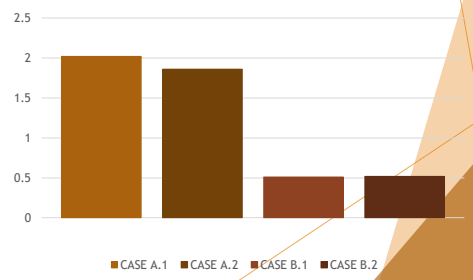
-The air, change the direction and enters the light shaft as admission flow, so even though the renovation flow has been increased, this air has already passed the exchange process.

This phenomenon causes a cyclic return of the air, witch implies a decrease in efficiency.

CONTROL EFFICIENCY

- The control efficiency is higher in the flat roof cases.
- It implies an improvement in the upper third because at the same time it caused an effect or standstill in the lower third.
- In the central third, the values are very similar in all cases.
- In model B, the control efficiency values do not change significantly in any of the light shaft thirds or in the totality of the light shaft





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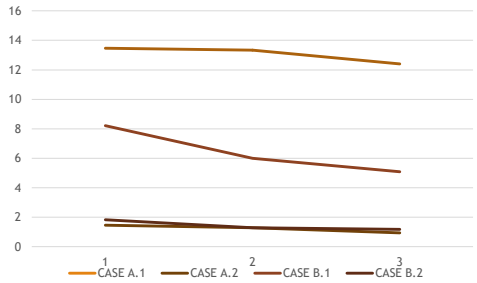
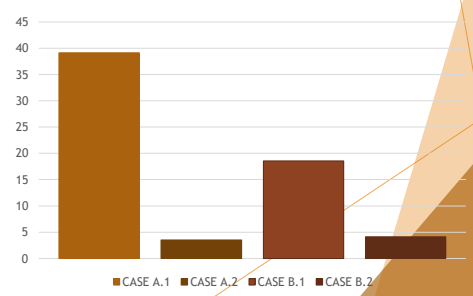
RELATIVE EFFICIENCY

- Every case has a different behaviour in it relative efficiency.
- The best results were obtained in Case A.1
- Values obtained in model B.1 are higher than those obtained in the case B.2
- In the two flap cases, very similar results are obtained, not only in each third of the light shaft but also in the totality of the light shaft.





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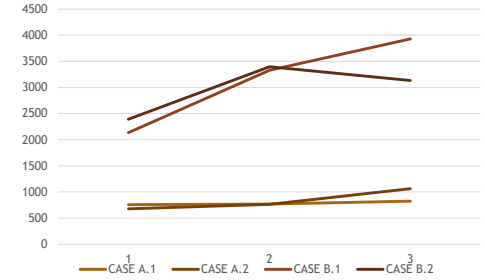
IMPROVEMENT OF THE RENOVATION EFFICIENCY

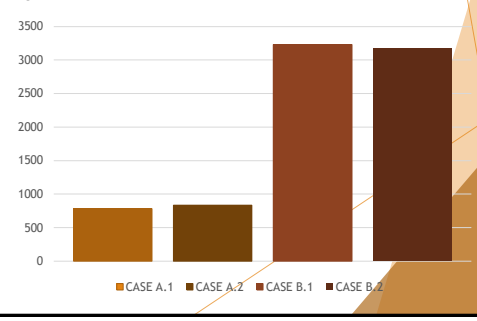
- The age of the air is lower when there is an obstacle in the middle of the top of the light shaft than when the building has a flat roof, and higher in the case of the sloped roof.

- The central third presents similar values in the different cases without significant variation when there is or not a flap.

- Case A.1 represents the greatest ageing in the upper third, but not in the lower third.

- In B cases the disposition the flap causes an increase of the age of the air in the upper third, but also implies a significant improvement in the lower third.





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CONCLUSIONS

- The efficiency of light shaft air renovation determines the quality in which the air provided to the buildings has health conditions. The concept of the age of the air is used to evaluate the average time that a group of air particles stay inside a computational model.

- It has been demonstrated that the 2D simplification of the models proposed for the CFD simulations makes the analysis easier, which implies reducing the computational times and cost. This model obtains a precision of ±1.4% in comparison with the equivalent 3D models previously studied.

- The study of the renovation efficiency in the four Cases (A.1, A.2, B.1, B.2) shows that it is higher when the light shaft is directly open to the exterior than when there is an obstacle located in the middle of it, trying to change the movement patron of the air masses. As a result, it is possible to observe that Cases A.1 and B.1 have values between 39.21% and 18.6% of efficiency. Meanwhile, Cases A.2 and B.2 only get an efficiency between 4.1% and 3.5%.

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Probabilistic modelling of wind induced air exchange in buildings

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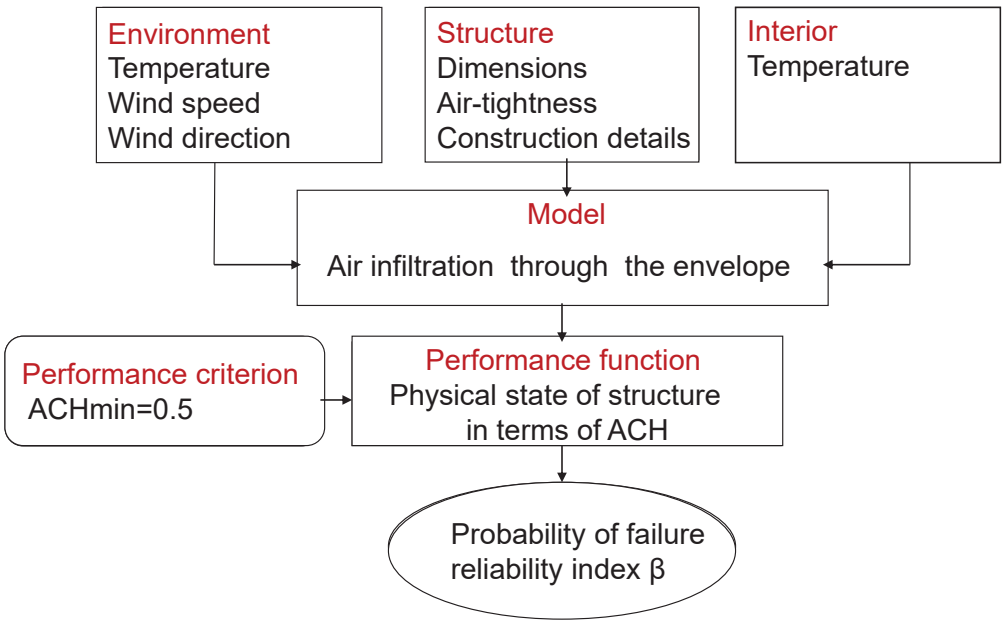
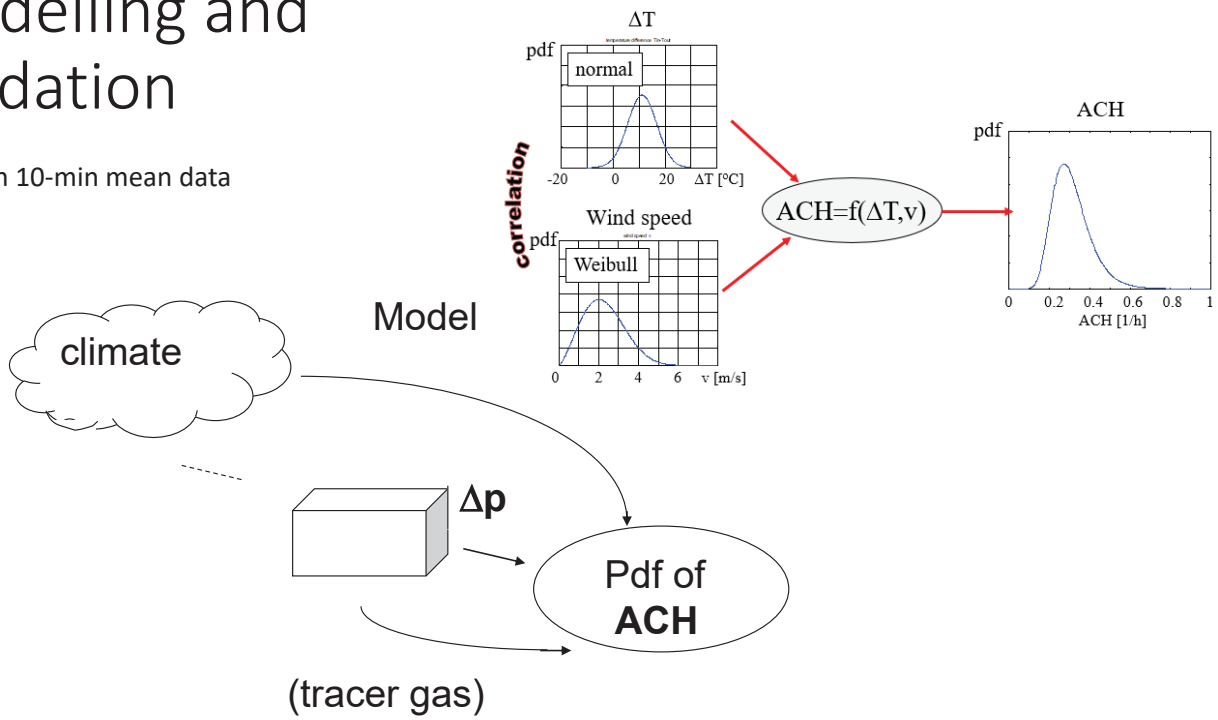
Chalmers University of Technology
Department of Architecture and Civil Engineering

Probabilistic modelling of ACH for reliability analysis



Modelling and validation

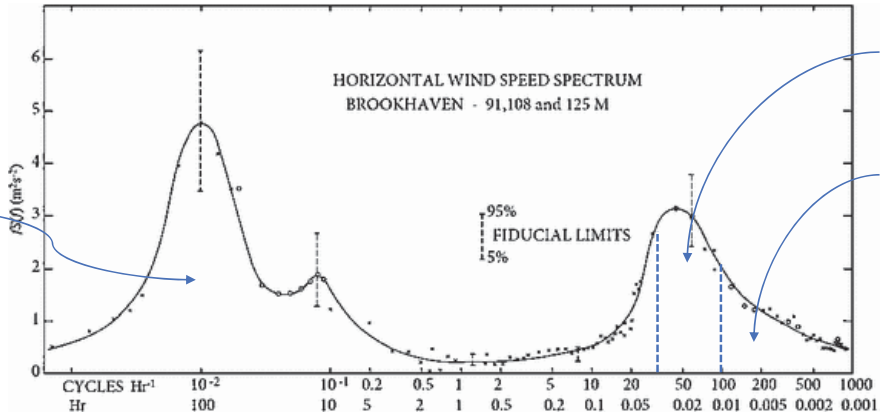
Based on 10-min mean data



(Pietrzyk 2000, Pietrzyk et al. 2008)

Wind speed turbulence

Wind speed Spectrum



Large scale turbulence

Topography-generated turbulence

Structure-generated turbulence

4 days 1hour 10 min 3 sec

(Van der Hoven, 1957 modified by Gusten 1989)

Variability of air change rate

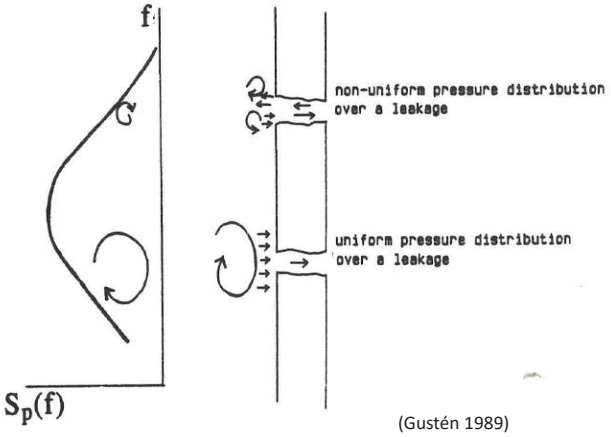
$$ACH_d(t) = 3600/V \sum_{j=1}^{n} \left(K_{d,j}(v_q)\right) A_j \left[0.5\rho\left(Cp_{d,j}^{ext} - Cp_{d,j}^{int}\right) {v_d}^2(t) + 0.04 z_j \Delta T(t)\right]^{0.5}$$

In time domain:

$v(t) = v_m + \delta_v(t)$

In frequency domain:
power spectrum
reduced power spectrum:

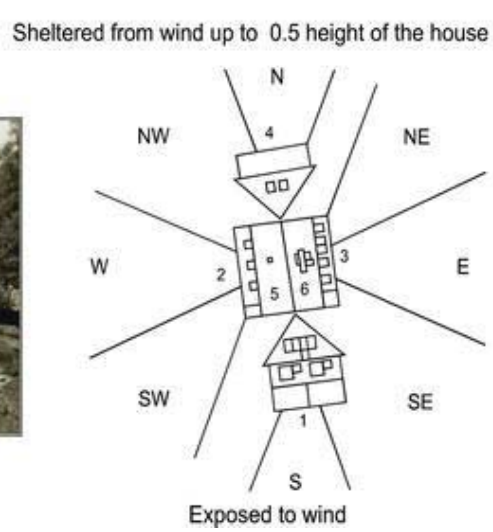
$$\frac{fS_v(f)}{\sigma_v^2} \quad \frac{fS_p(f)}{\sigma_p^2} \longrightarrow S_{ACH}(f) = |H(f)|^2 S_v(f)$$

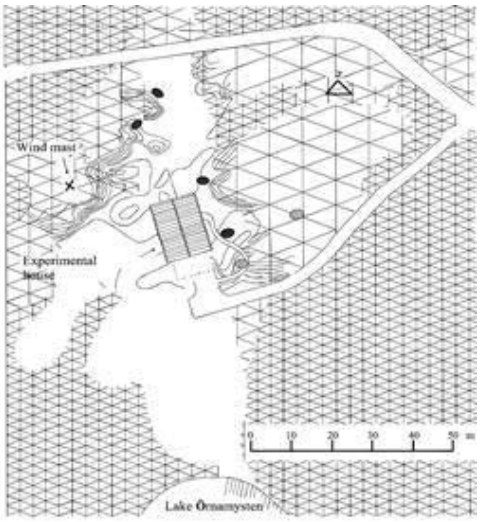


(Gustén 1989)

Experimental building – exposure to wind

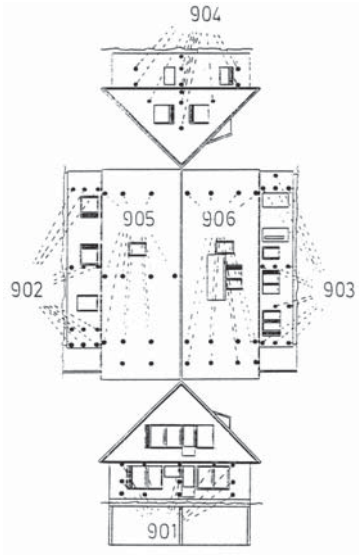




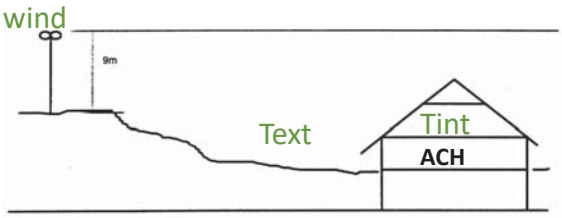


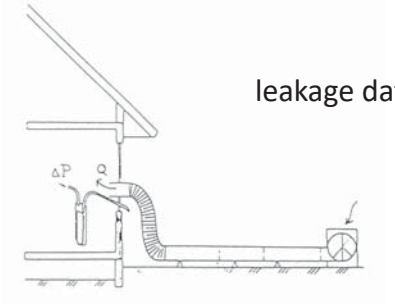
Measurement program

8 months - each hour for 10 minutes



Δp - pressure difference

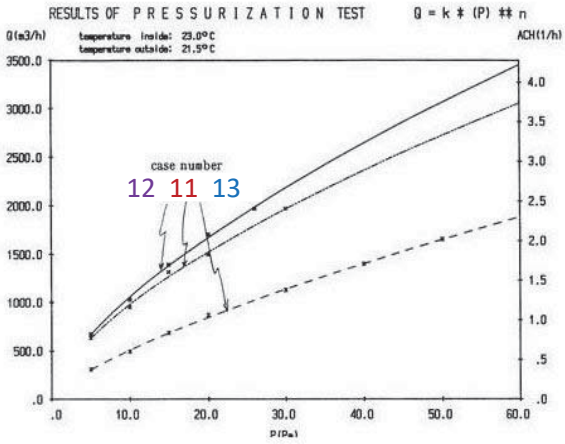


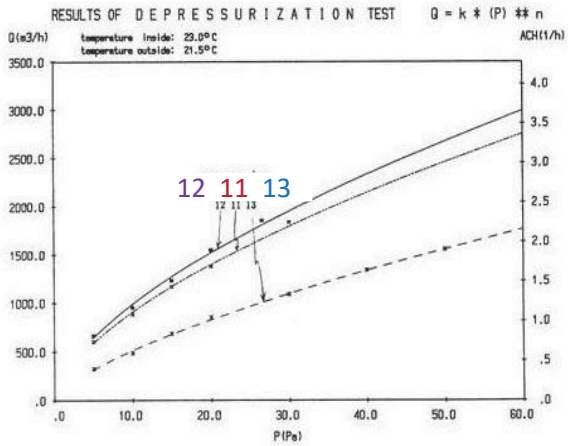


leakage data

air tightness (courtesy of J.Gustén)

Blower door tests using reductive sealing method

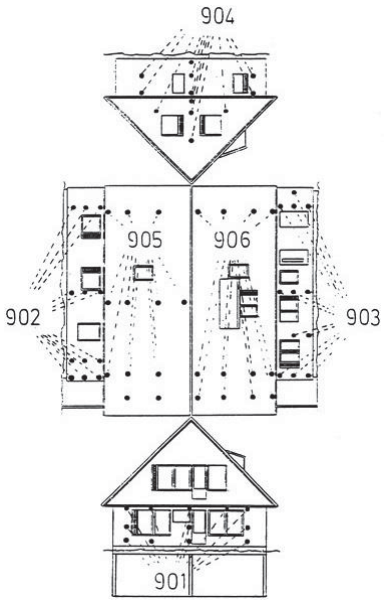


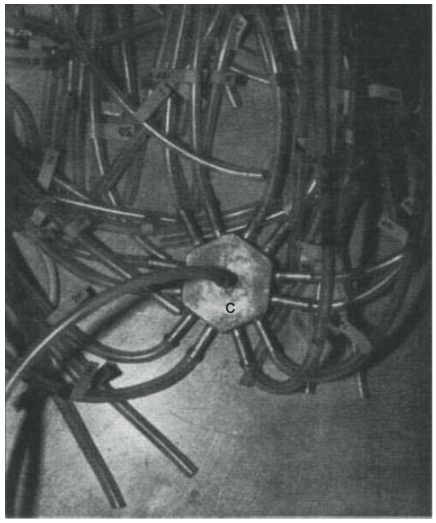


	Case no.	Ventilation duct	Attic	Ventilation window	Cat door	Garage door
Garage	11	The floor between the cellar			sealed	Not sealed
Cellar	12	and the living part of the			Not sealed	Not sealed
Cat door	13	house is sealed			Not sealed	sealed

(Pietrzyk 2014)

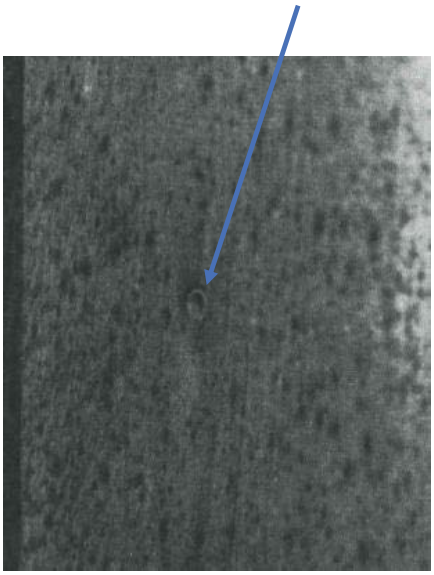
Wind pressure measurements





12-to-1 tube connector

Inlet to the pressure sensor

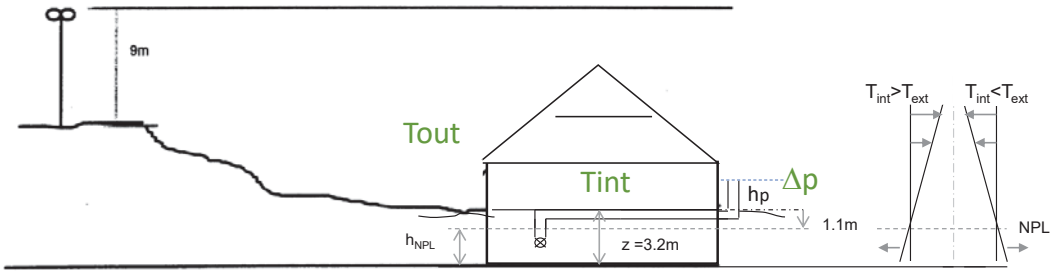


(Schechinger 1993)

Analysis of the results

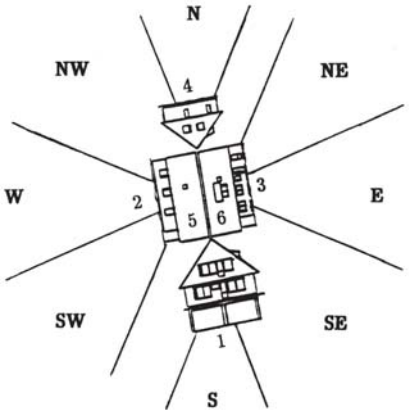
Wind dir.	μ_v 10-min	σ_v 10-min	$\frac{\sigma_v}{\mu_v}$	μ_{v3s}	σ_{v3s}	$\mu_{\Delta p3s}$ windward	$\sigma_{\Delta p3s}$ windward	$\frac{\sigma_{\Delta p3s}}{\mu_{\Delta p3s}}$
N	2.27	0.97	0.43	0.91	0.47	1.45	1.24	0.86
E	2.89	1.09	0.38	0.96	0.45			
S	2.23	1.01	0.45	0.90	0.41	1.09	1.06	0.97
W	2.19	1.13	0.52	1.00	0.59			

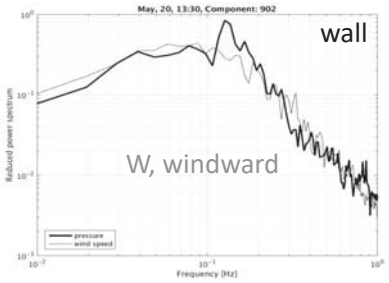
Wind speed, wind direction



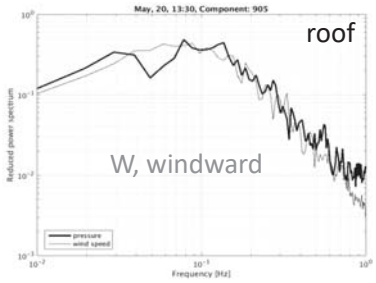
Spectral analysis of 3-s wind speed and 3-s Δp

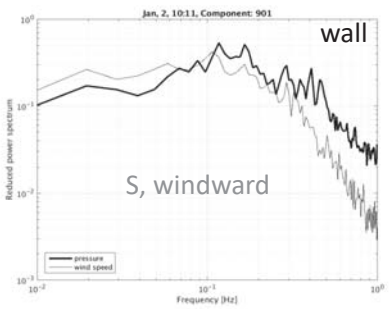
$fS_v(f)/\sigma_v^2$ $\quad \boldsymbol{fS_p(f)/\sigma_p^2}$



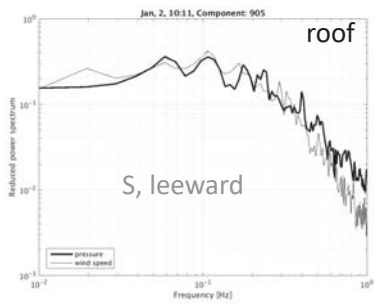


wind 4.8m/s





wind 6.8m/s



Conclusions

- The extension of the probabilistic model of air infiltration in buildings to include rapid pressure fluctuations on the air change rate based on the spectral data is proposed.
- The analysed spectra of the windward wall pressure differences together with the relevant upwind speed spectra show similar forms. The degree of coherence between fluctuating wind speeds and pressure differences between outside and inside of the building will be further examined.
- High coefficients of variations of the rapid fluctuations of the pressure differentials across the facades might be important in the process of the air exchange.
- The examples show the differences between the shapes of the individual pressure spectra. The mean values of the reduced power spectra for the specified wind speed and direction across each component will be further studied.


Measurement room in the experimental house
Thank you for your attention

FACULTY OF ENGINEERING AND ARCHITECTURE

DEPARTMENT OF ARCHITECTURE AND URBAN PLANNING
RESEARCH GROUP BUILDING PHYSICS

Impact of an occupancy and activity based window use model

on the prediction of the residential energy use and thermal comfort

Silke Verbruggen, *Jelle Laverge, Marc Delghust, Arnold Janssens*

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fwo Opening new horizons

NEPBC

1

INTRODUCTION

WINDOW USE has an impact on
- Energy use
- Thermal comfort

WINDOW USE MODELS
- Weather based
- Offices
- Not related to the day to day life of the occupants

→ Occupancy and activity based window use model

2

OCCUPANCY & ACTIVITY BASED WINDOW USE MODEL



Based on the work of Dorien Aerts

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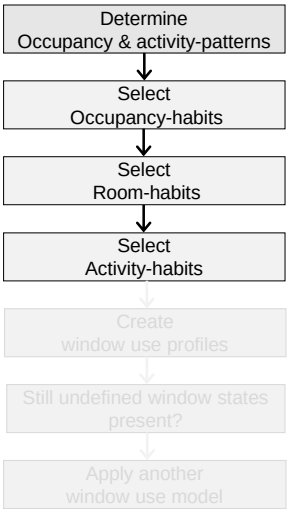
OCCUPANCY & ACTIVITY BASED WINDOW USE MODEL



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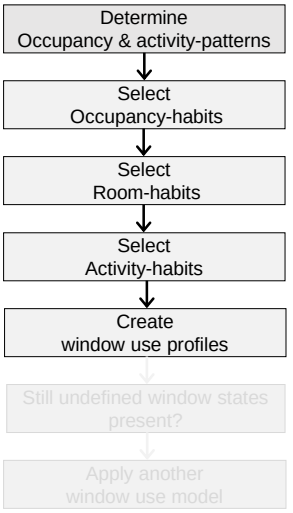
OCCUPANCY & ACTIVITY BASED WINDOW USE MODEL



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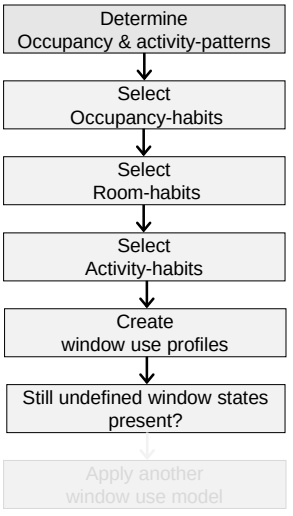
OCCUPANCY & ACTIVITY BASED WINDOW USE MODEL



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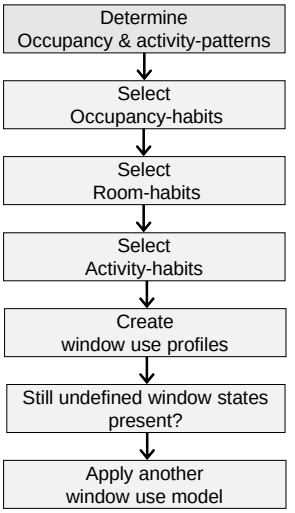
OCCUPANCY & ACTIVITY BASED WINDOW USE MODEL



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METHODOLOGY

Impact of window use models on energy use and thermal comfort

1) Windows always closed
2) Flemish EPBD model
3) Weather-based model
4) Occupancy & activity based model (Habits)

SETTINGS	
Heating setpoint	18°C
Ventilation rate	183 m³/h (building)
Internal heat gains	1057 kWh/year
Domestic hot water use	1380 kWh/year

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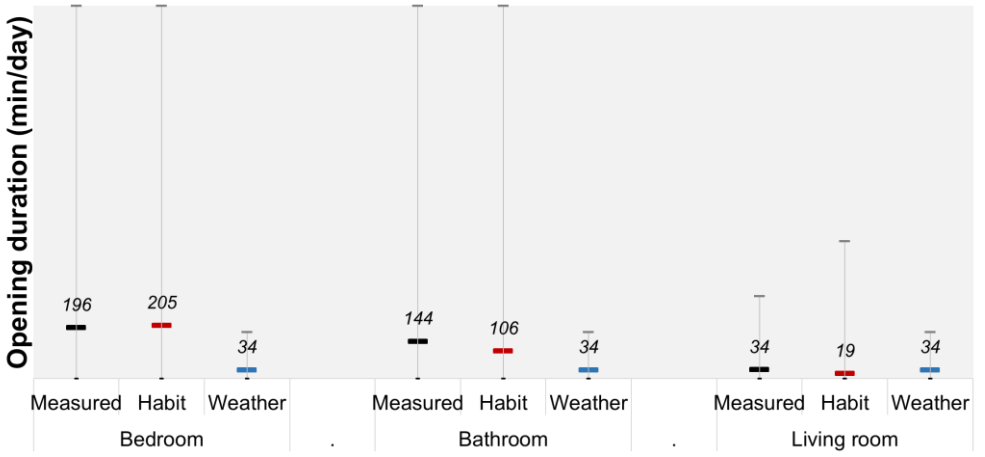
8

WINDOW OPENING DURATION

Winter



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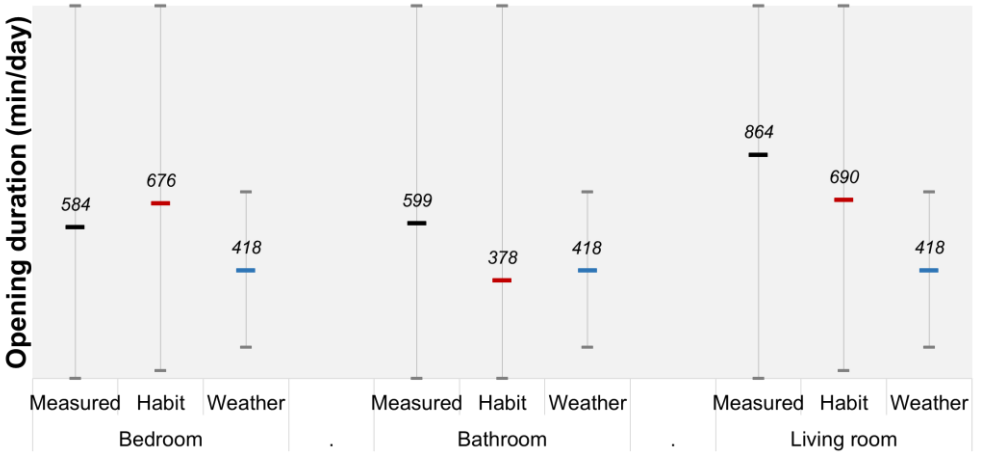
WINDOW OPENING DURATION

Summer



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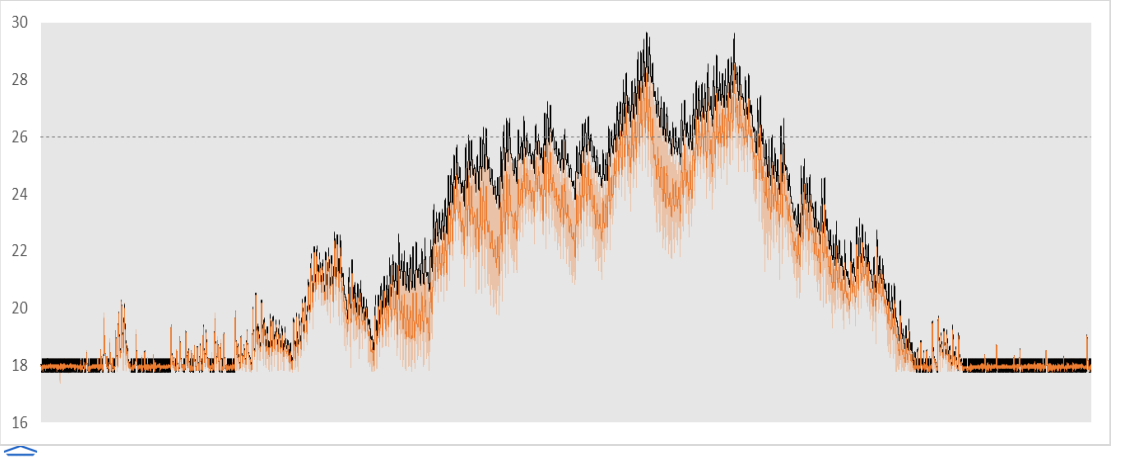
IMPACT ON THERMAL COMFORT

Living room



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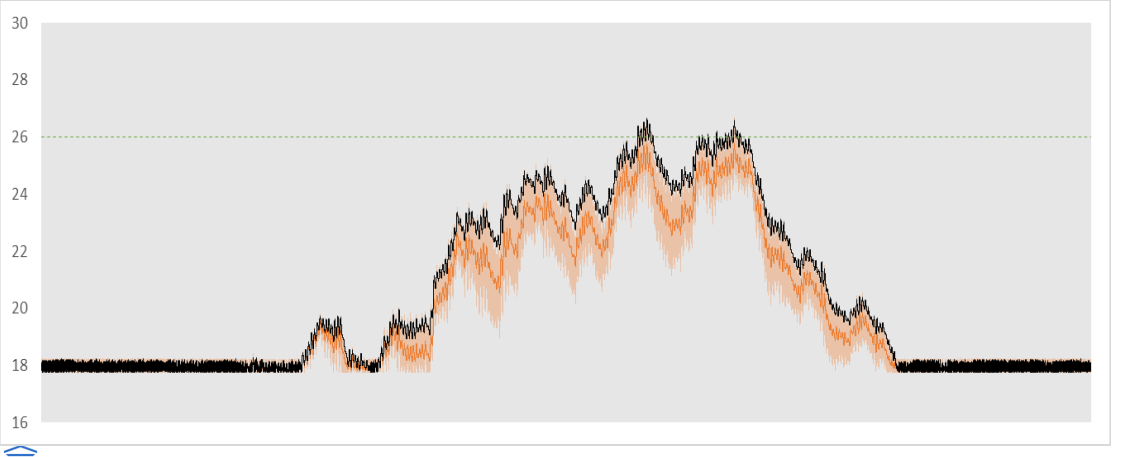
IMPACT ON THERMAL COMFORT

Bedroom



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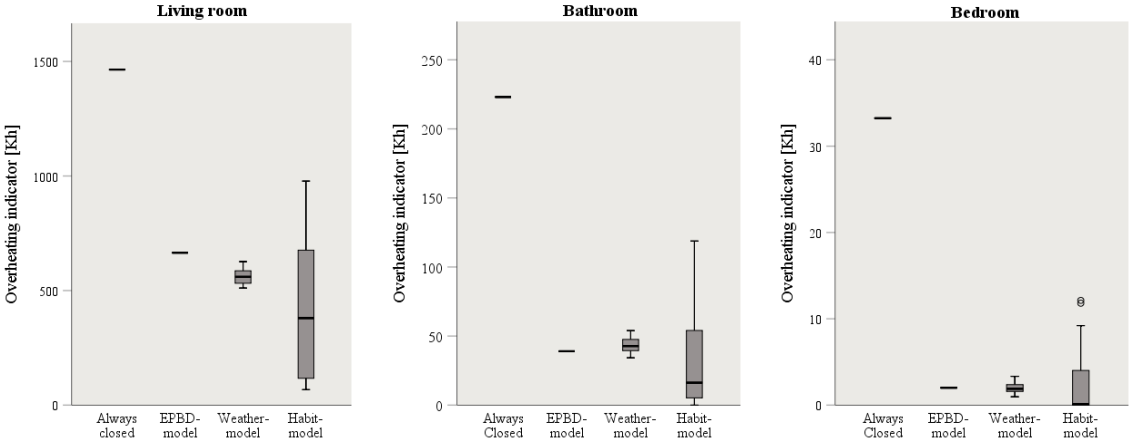
IMPACT ON THERMAL COMFORT



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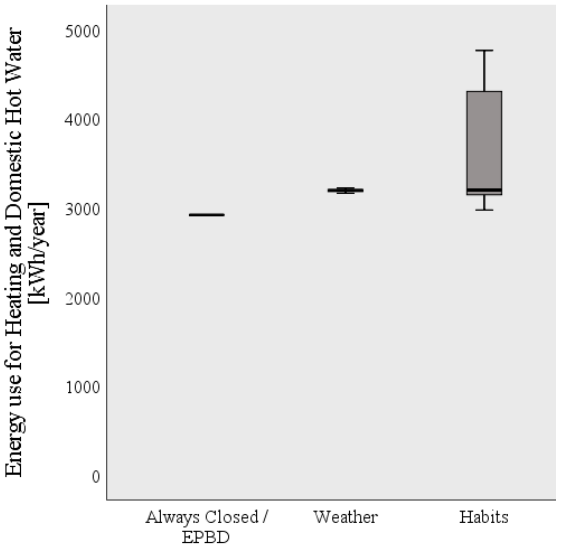
IMPACT ON ENERGY USE



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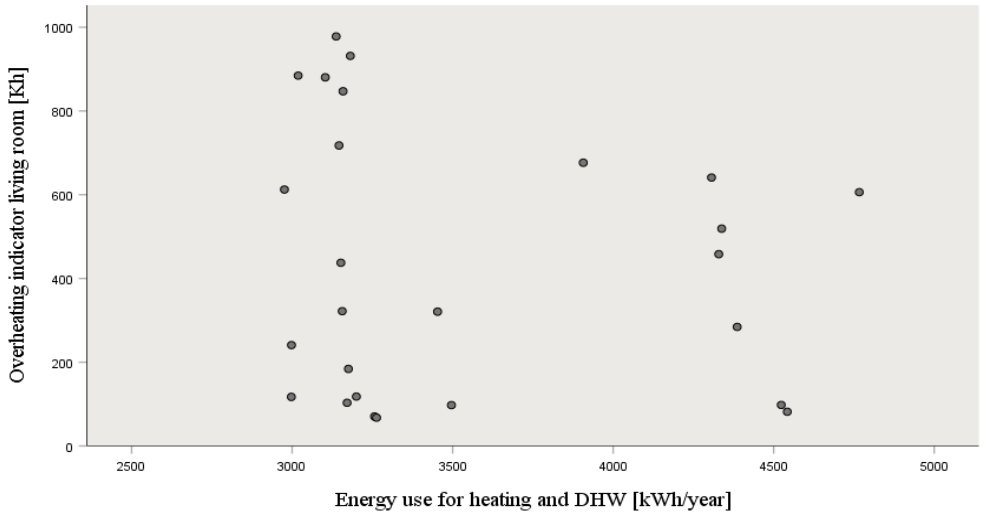
IMPACT OF DIFFERENT HABITS



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CONCLUSIONS

- Occupancy & activity based model
  → better estimate the real window opening behaviour
  → variability between households

→ An optimal window opening strategy could prevent overheating, while limiting the energy use at the same time

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Thank you for your attention!

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Arbeitsbereich für Energieeffizientes Bauen

Ambient air filter efficiency in airtight, highly energy efficient dwellings – A simulation study to evaluate benefits and associated energy costs

Performed in the framework of IEA EBC Annex 68

Gabriel Rojas, University of Innsbruck, Austria
Unit for Energy Efficient Buildings
October 16th, AIVC 2019

EBC | Bundesministerium Verkehr, Innovation und Technologie | IEA FORSCHUNGS KOOPERATION | FFG Forschung wirkt.

1

Motivation

In very airthight residential housing with MVHR (Passive Houses)…

What is the exposure contribution from outdoor originated and from indoor originated particulate matter?

What filter quality is recommendable?

What impact has the use of a recirculating vs. extracting cooker hood?

Simulation study (CONTAM) accounting…

- filter efficiency
- envelope penetration
- particle deposition
- outdoor air concentration
- indoor sources

$= f\ (particle\ size)$
21 size bins

2

Model assumption – Reference apartment

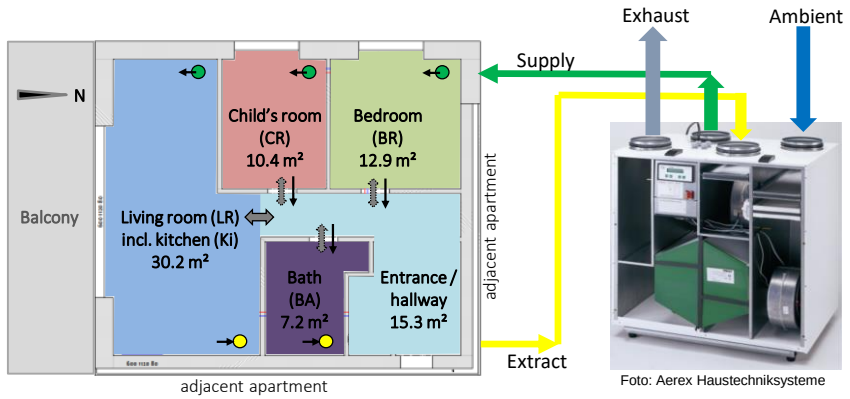


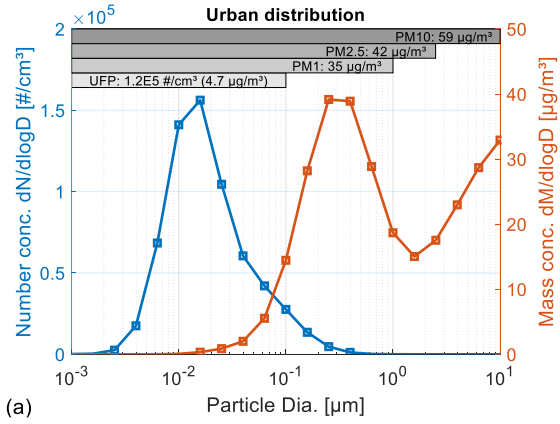
Foto: Aerex Haustechniksysteme

Ventilation air flows in m³/h (l/s)

	BR	CR	LR/Ki	BA	Total
Supply	40 (11.1)	20 (5.6)	30 (8.3)		90 (25)
Extract			60 (16.7)	30 (8.3)	90 (25)

3

Model assumption – Ambient air PM concentration

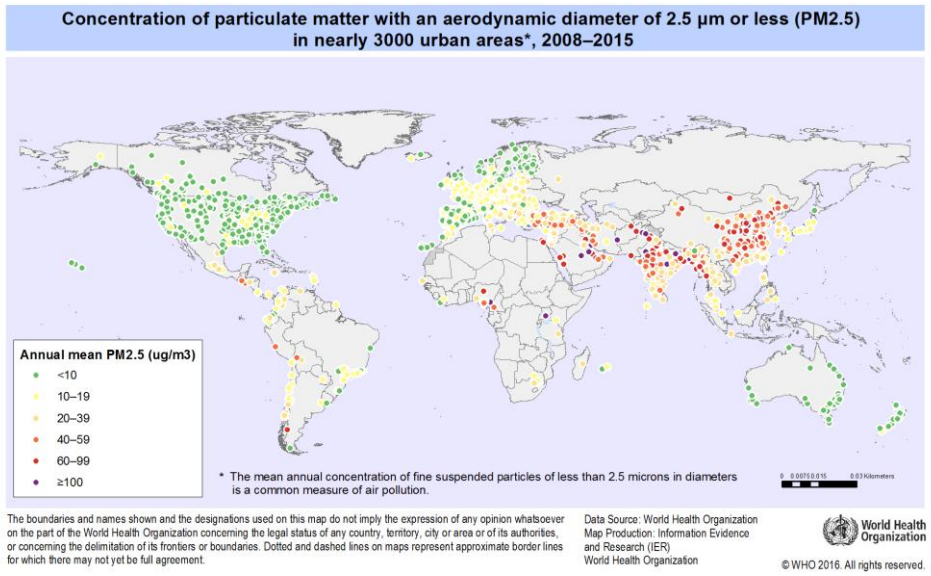


Derived from:Ruprecht, Jaenicke. 1993. "Tropospheric Aerosols." Pp. 1–31 in *Aerosol-Cloud-Climate Interactions*, edited by P. Hobbs. Academic Press

	PM2.5
Low	8.4 µg/m³
Ref	**42 µg/m³**
High	84 µg/m³

4

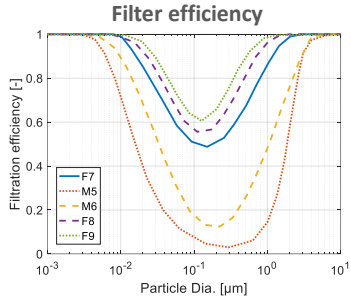
Model assumption – Ambient air PM concentration



Source: https://www.who.int/gho/phe/air_pollution_pm25_concentrations/en/

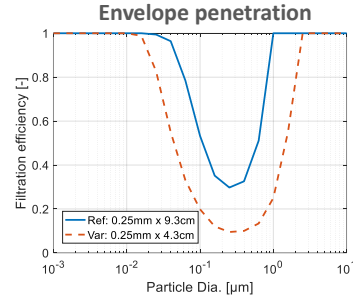
Model assumptions: filter, penetration, deposition

Filter efficiency



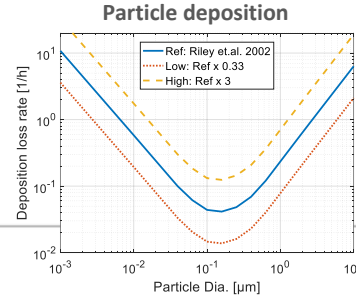
Derived from: Shi, Bingbing. 2012. "Removal of Ultrafine Particles by Intermediate Air Filters in Ventilation Systems - Evaluation of Performance and Analysis of Applications Ventilation Systems." Chalmers University of Technology, Göteborg, Sweden.

Envelope penetration



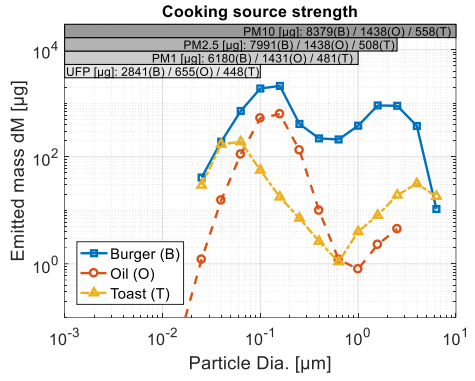
Derived from: Liu, De Ling and William W. Nazaroff. 2003. "Particle Penetration through Building Cracks." *Aerosol Science and Technology* 37(7):565–73.

Particle deposition



Derived from: Riley et.al. (2002). "Indoor Particulate Matter of Outdoor Origin: Importance of Size-Dependent Removal Mechanisms." *Environmental Science and Technology* 36(2):200–207.

Model assumptions: Cooking source strength

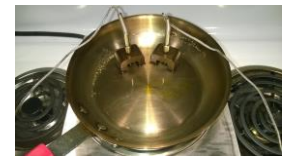




breakfast



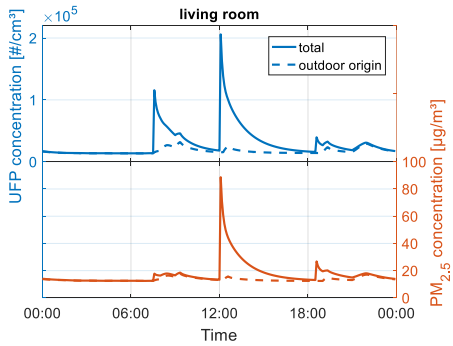
lunch



dinner

7

Results: Daily evolution



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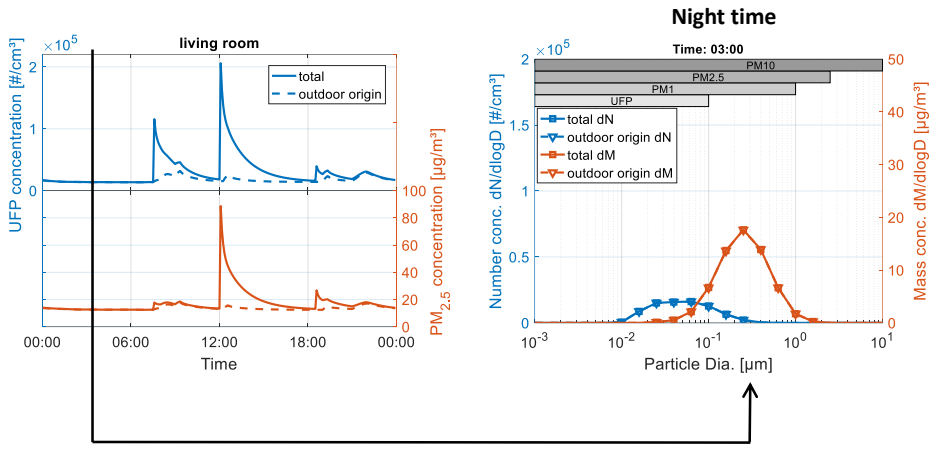
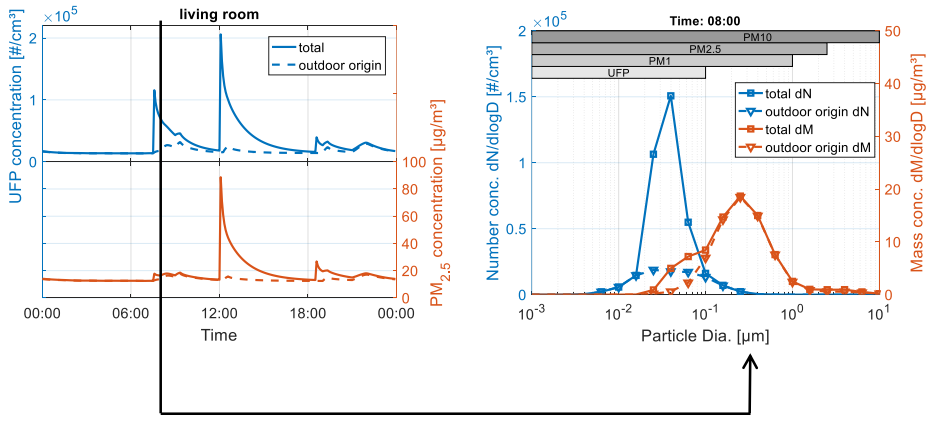
Results: Daily evolution



9

Results: Daily evolution



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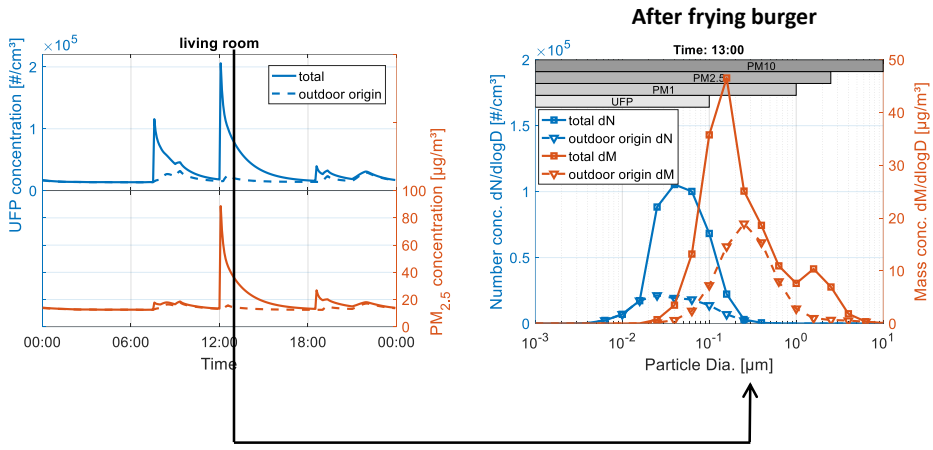
Results: Daily evolution



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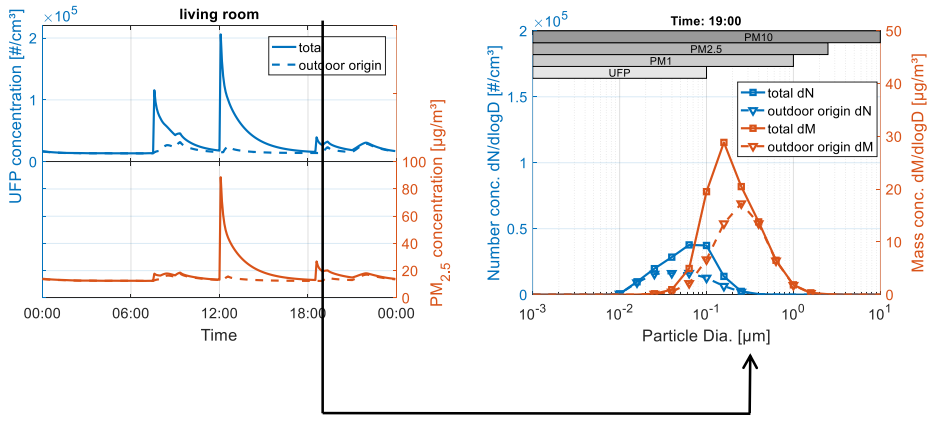
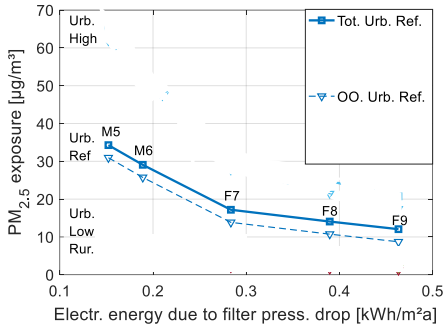
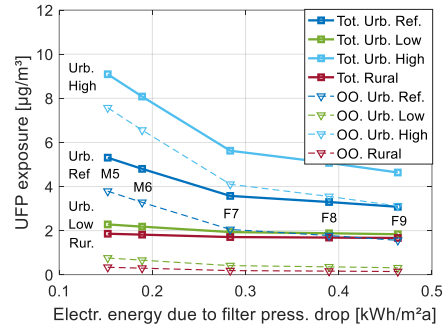
Results: Daily evolution



12

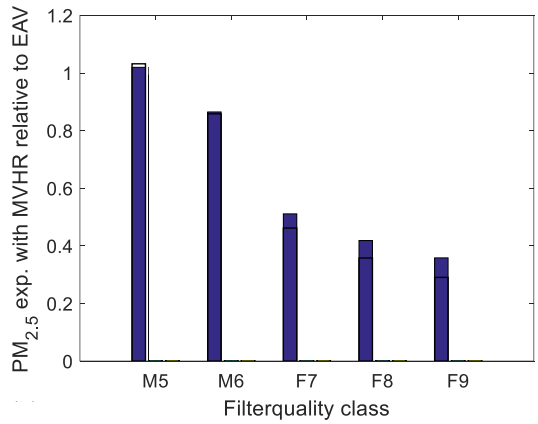
Results: Exposure reduction vs. electr. fan power



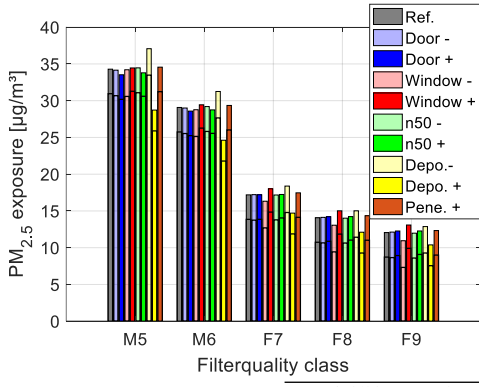


M5	M6	F7	F8	F9
MERV9/10	MERV11/12	MERV13	MERV14	MERV15

Results: Relative to extract air ventilation



Sensitivity on model assumptions



	Reference	Low	High
Bed- / child's room door opening	8am – 10pm	4 x 10 min	0-24 hrs
Window opening (tilted): all	3.6 h/day	0 h/day	6.3 h/day
Kitchen area	3 x 20 min	-	3 x 35 min
Living room area	3 x 10 min	-	3 x 18 min
Bedroom	2 x 56 min	-	2 x 98 min
Childs room	2 x 6 min	-	2 x 11 min
Airtightness / n50	0.6 1/h	0.3 1/h	1.5 1/h
Deposition rate multiplier	1	0.33	3.0
Penetration factor for crack with dimensions	W 0.25 mm x L 9.4 cm	-	W 0.25 mm x L 4.3 cm

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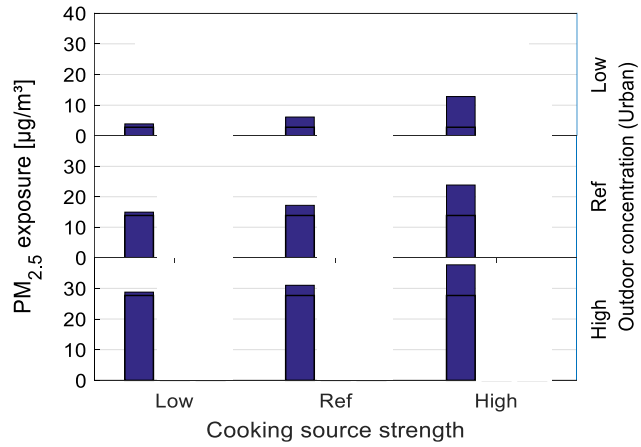
Results: Outdoor vs indoor source strength



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Recommendations for airtight residential housing with MVHR / Passive Houses

- F7 (ePM1-50% / MERV 13) can be considered a good general recommendation. However, higher quality (F9) are recommended for moderate or high polluted areas.
- Extracting cooker hoods are advisable for household where high cooking induced particle generation (e.g. frying) can be expected. However, in areas with high outdoor pollution, PM introduced with make-up air will be a (more) relevant source.
  -> Further product development is encouraged.
- Recirculating cooker hoods will not notably reduce total PM exposure.
  -> Further product development is encouraged.

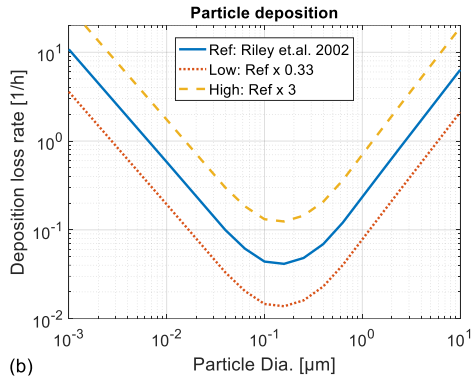
Outlook / Further research

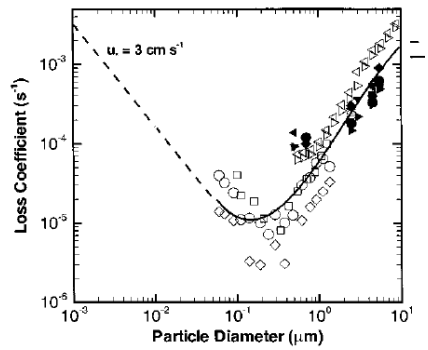
- Apply time-resolved recent ambient air data for simulation
- Apply more diverse indoor generation models
- Apply resuspension models
- Eperimental validation
- Measure / apply (fractional) filter efficiency for filter class acc. to ISO 16890
- **Account for potentially different health effects from outdoor originated vs indoor generated particles.**

Thank you!

EBC
Bundesministerium Verkehr, Innovation und Technologie
IEA FORSCHUNGS KOOPERATION
FFG Forschung wirkt.

Model assumptions: PM deposition

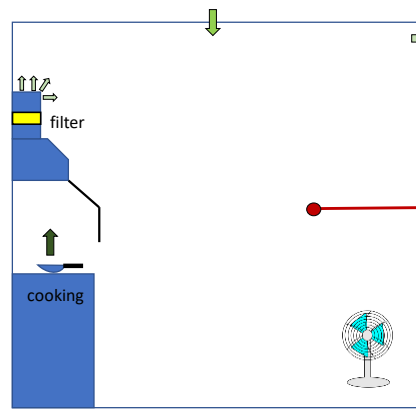




Source: Riley et.al. (2002). "Indoor Particulate Matter of Outdoor Origin: Importance of Size-Dependent Removal Mechanisms." *Environmental Science and Technology* 36(2):200–207.

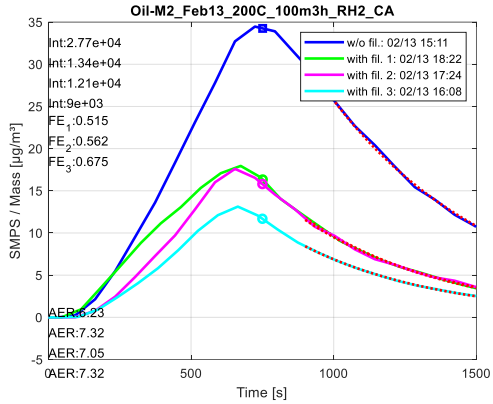
Measurement method: cooking source strength





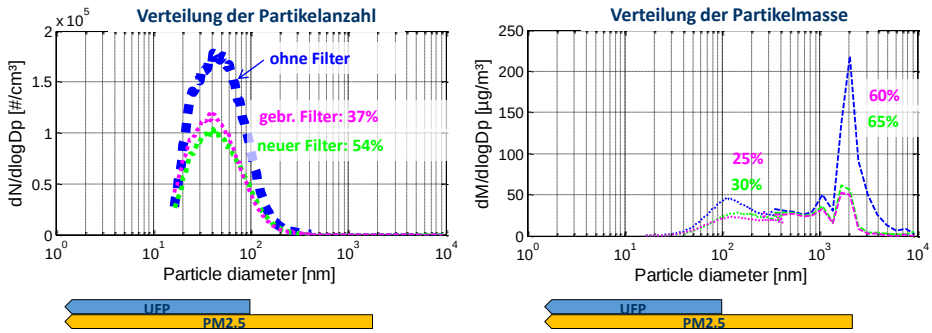
$RE = 1 - \frac{\Delta C_{withFilter}}{\Delta C_{without}}$

Deriving cooking source strength

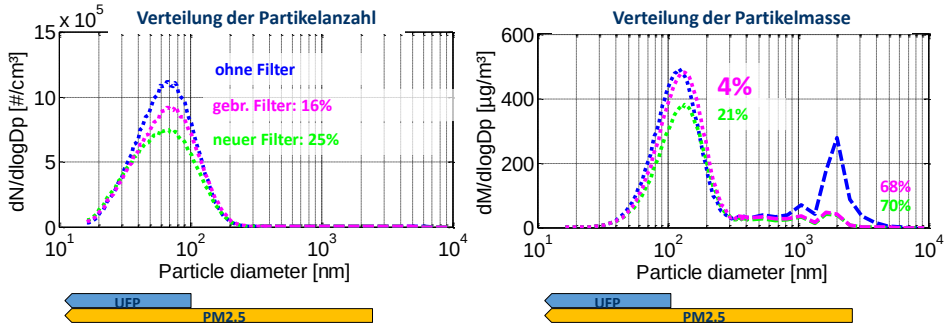


$$m = \int_0^{peak} AER\ V\ c\ dt + V\ c$$

Größenverteilung der Partikel: Zwiebel @ 200 C



Filter Br1-2, gemessen mit SMPS 3936 (10-400nm) und OPS 3330 (0,3 -10µm), 3 Wiederholungen



Filter Br1-2, gemessen mit SMPS 3936 (10-400nm) und OPS 3330 (0,3 -10µm), 2-3 Wiederholungen

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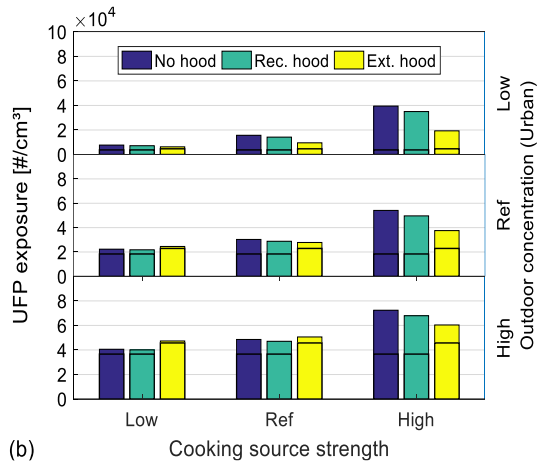
Results: Outdoor vs indoor source strength



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Competence Pool Indoor Air Quality & Health
Laboratory for: Microbiology & Microparticles| Building Chemistry| HVAC



OUT2IN

Impact of filtration- and air purification techniques on the penetration of outdoor air pollutants into the indoor environment by ventilation

Dr. Ing. Joris Van Herreweghe
Belgian Building Research Institute

With the support of:
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Laboratory Air Quality
& Department Technical Stimulation of Sustainable Buildings

With the financial support of:
innoviris.brussels empowering research
Anticipate Prospective Research Programme

1

OUTLINE

- **The project in brief**
  Context | Research questions | Approach | Added value
- **First results: highlights**
  Test setup | *In Laboratory*
- **Conclusions and further research**

2

OUTLINE

- **The project in brief**
  Context | Research questions | Approach | Added value
- **First results: highlights**
  Test setup | *In Laboratory*
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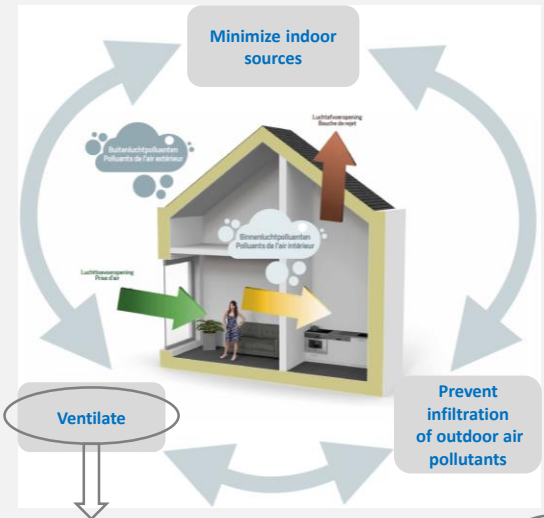
3

CONTEXT: ROAD TO A GOOD INDOOR AIR QUALITY



Basic principle: replace the polluted indoor air by outdoor air

= source of fresh and clean air?

4

CONTEXT: OUTDOOR AIR QUALITY (IN BCR)

Artsen roepen Brussel op om luchtvervuiling aan te pakken: "Uw bevolking leeft in gevaarlijke lucht"

20/11/2017 om 06:02 door gjs | Bron: BELGA - Print - Corrigeer

Luchtkwaliteit is 'uitermate slecht' in Brussel

MILIEU BRUSSEL 09/4/2019 TDN © BRUZZ DELEN:

LE SOIR.be

Mis en ligne le 18/12/2016 à 15:25
Michel De Muelenaere

Pollution: seuil d'information dépassé à Bruxelles

La qualité de l'air à Bruxelles: un problème de santé publique largement sous-estimé

Rtbf 26/04/2019





Brusselse lage-emissiezone van kracht

01/01/2018 om 07:03 door rdc | Bron: BELGA

5

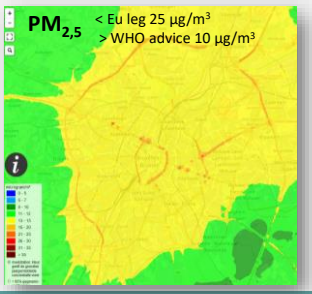
CONTEXT: OUTDOOR AIR QUALITY (IN BCR)

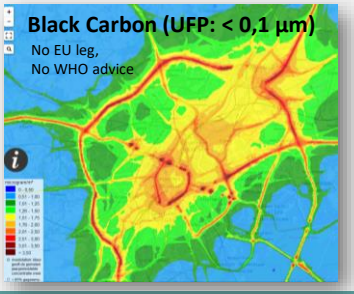
Already improved

BUT: some pollutants remain problematic

1. **Ozone** (O_3) and precursors (NO_2 & VOC's)
   → Peak pollutions in summer time

2. **Particulate Matter** (PM)
   → continuous problem and peak pollutions (winter time, smog)





6

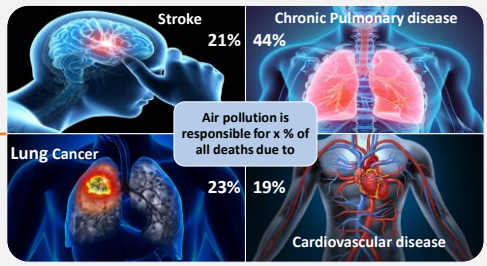
CONTEXT: OUTDOOR AIR QUALITY (IN BCR)

Health impact

Worldwide: 6.410.000 deaths = 9.100.000.000 years of life
Belgium: 8340 deaths = 86.000 years of life
↔ *Traffic in Belgium: 597 deaths = 40.800 years of life*

2.800.000
Due to
Indoor Air Quality

4.200.000
Due to
Outdoor Air Quality



Social cost for Belgium: 8 billion €/year

PROJECT: RESEARCH QUESTIONS

Given: magnitude and impact outdoor air quality problems (in BCR)
buildings become more airtight (= less uncontrolled infiltrations)

? Which role do ventilation systems play in the penetration of outdoor air pollutants?

? **Is classic filtration sufficient** or need for **more intensive filtration/purification**?

? How does filtration **efficiency evolves in time,** when to **replace filters?**

? Performance of **electrostatic precipitation**, relation to classic filtration, risks (O_3 production)

? Can the combination of filtration and smart ventilation strategies contribute to a better IAQ

APPROACH: FOCUS PM (10nm-10µm), O_3, NO_X, VOC



In lab

on component level

Filter efficiency ifo time



In situ

On system level

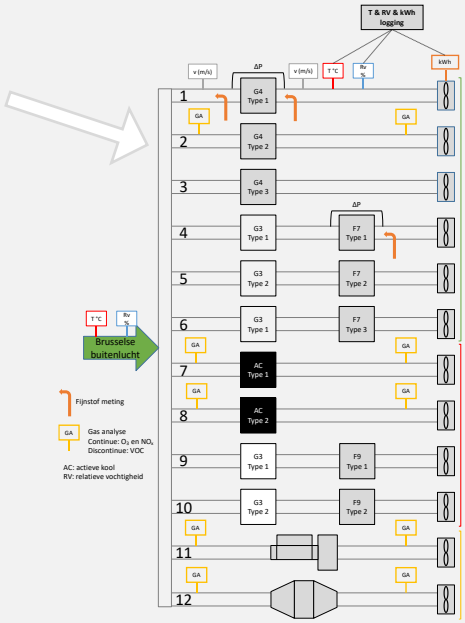
Measurement of pollutants: IN-RETAINED-OUT



Computer simulation

On building level

pollutant balance



@ greenbizz .brussels



Klassieke Filtratie

Doorgedreven Filtratie

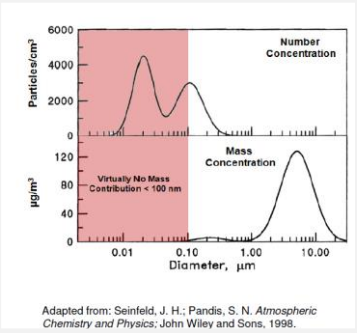
Innovatief



9

APPROACH ADDED VALUE COMPARED TO STOA

1. **Real life measurements with Brussels outdoor air**
   (↔ standardized filter testing = synthetic dust/particles)
2. **From component, over system to building level**
   (↔ indoor/outdoor ratio)
3. Measurement range of **10nm-10µm** => *PM_{10}, $PM_{2,5}$, PM_1 & $PM_{0,1}$*
   (↔ standardized filter tests do not include UFP)
4. Measurements in **number concentrations**
   (↔ many use mass concentration = underestimation of the smallest particles)
5. **Efficiency in function of time**
   (↔ standardized filter testing = snapshot)
6. Also **chemical pollutants** *(Ozone, NOx and VOC)*
   (↔ many studies are limited to PM)



Adapted from: Seinfeld, J. H.; Pandis, S. N. *Atmospheric Chemistry and Physics;* John Wiley and Sons, 1998.

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OUTLINE

- **The project in brief**
  Context | Research questions | Approach | Added value
- **First results: highlights**
  Test setup | *In Laboratory*
- **Conclusions and further research**

11

RESULTS: CONSTRUCTION IN LABORATORY TEST SETUP

Principal components

- 12 parallel testlines (metal ducts, 160mm)
- 1 or 2 filterboxes/devices per testline (A)
- diaphragm (B) (air flow measurement and adjustment)
- Constant flow ventilator set @ 150 m³/h (C)

Measuring parameters

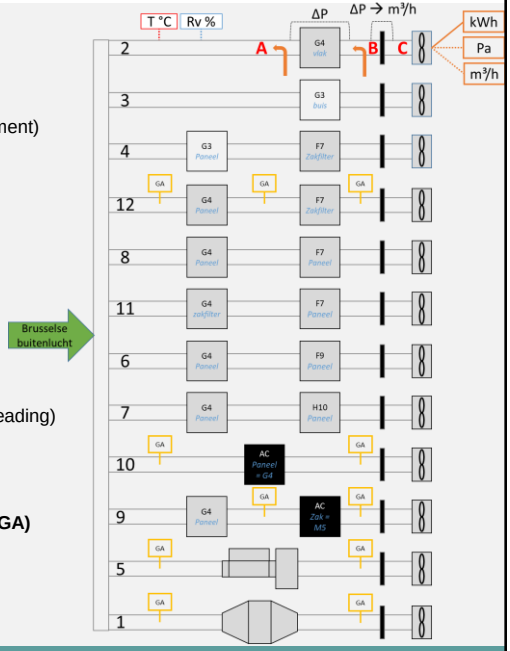
- **Continuous (——)**
  energy consumption each ventilator (kWh)
- **Discontinuous (·····)**

1) Physical parameters (all testlines)

- temperature (°C)
- relative humidity (%)
- pressure drop (Pa) over box and line (vent reading)
- flow (diaphragm) and vent. reading
- **filterperformance** (PM-measurement)

2) Chemical parameters (specific testlines = GA)

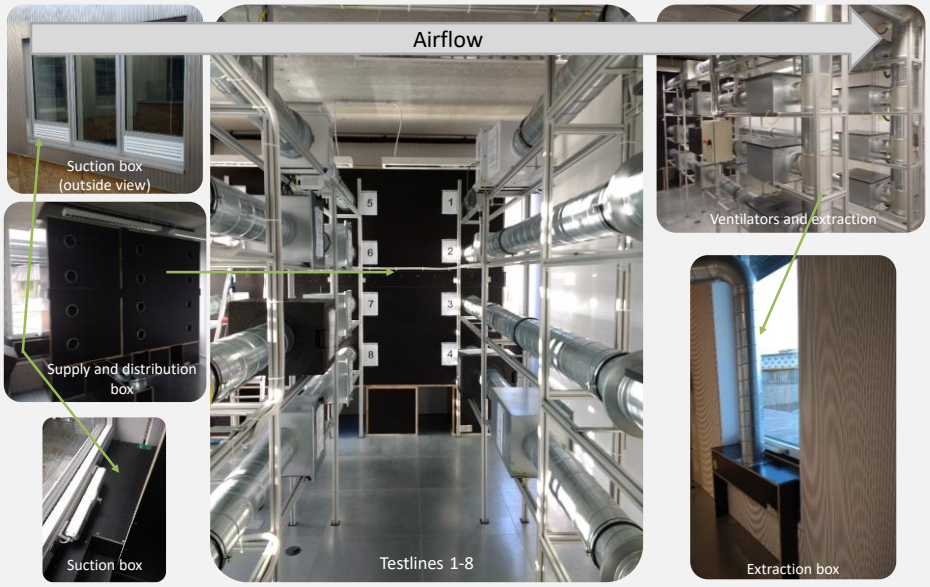
- NOx, O_3 & VOC



12

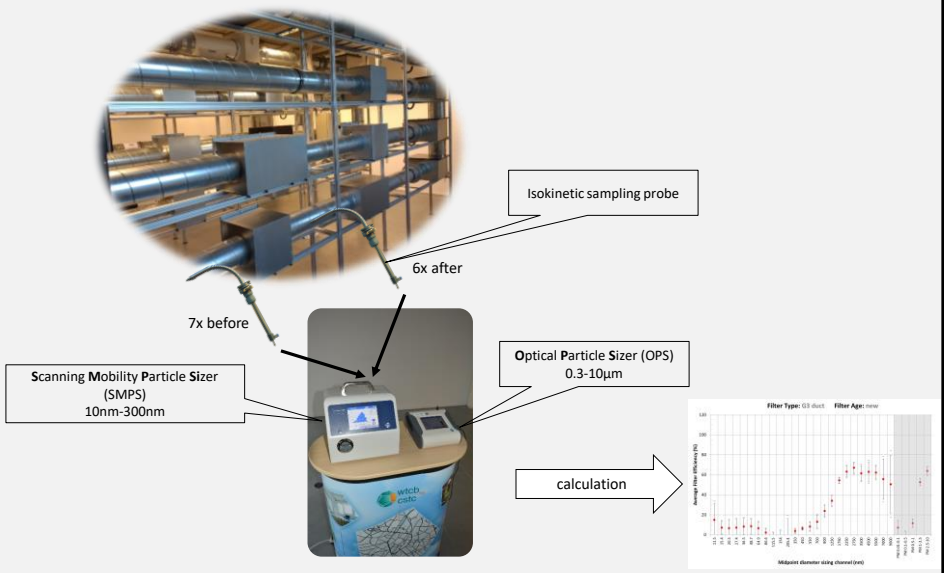
RESULTS: CONSTRUCTION IN LABORATORY TEST SETUP

As built



RESULTS: IN LABORATORY PERFORMANCE MEASUREMENTS

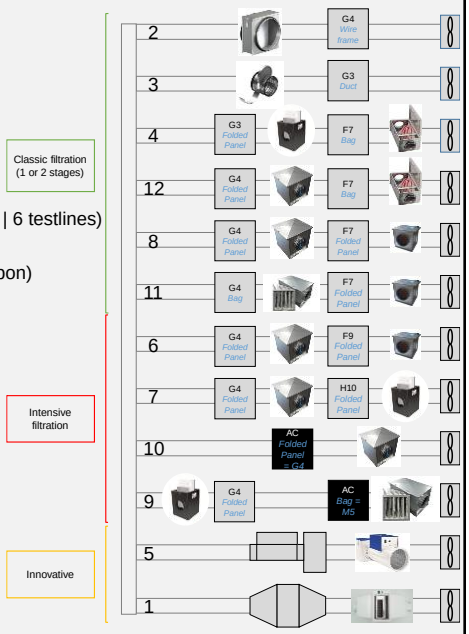
Eurovent 4.10: *in situ* filterperformance



RESULTS: CONSTRUCTION IN LABORATORY TEST SETUP

Selected filterboxes and devices

- **Classic filtration** setups (1 (G3/G4) or 2 stages (+F7) | 6 testlines)
- **Intensive filtration** (4 testlines | F9 & H10 | active carbon)
- **Innovative**: electrostatic precipitation (2 devices)



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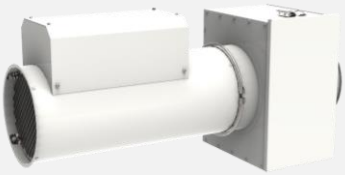
RESULTS: CONSTRUCTION IN LABORATORY TEST SETUP

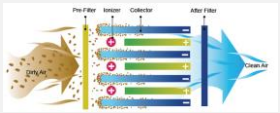
Electrostatic precipitators





- **Type 1**
  - Separate ionisation and collector part
  - Positive ionisation
  - **Throw away PP honeycomb collector** (2X)
  - Version coated with active carbon available (odors and gasses)





- **Type 2**
  - Ionisation (horizontal wires) and collector in one **unit**
  - Positive ionisation
  - **cleanable metal collector**
  - Additional active carbon filtration in option



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OUTLINE

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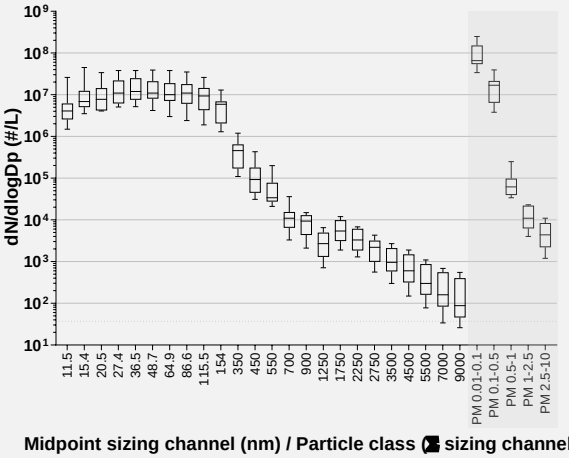
RESULTS: OUTDOOR AIR

Particle distribution outdoor air @ Brussels



Midpoint sizing channel (nm) / Particle class (Σ sizing channels)



SMPS
10nm-0.3µm

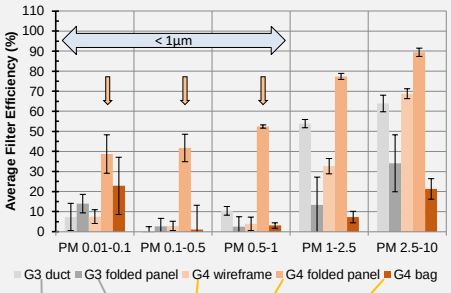
OPS
0.3µm-10µm

- dominated by the smaller particles (99% < 0.5 µm)
- "natural" particle load is sufficient to perform filter performance measurements (….. 37 #/L)

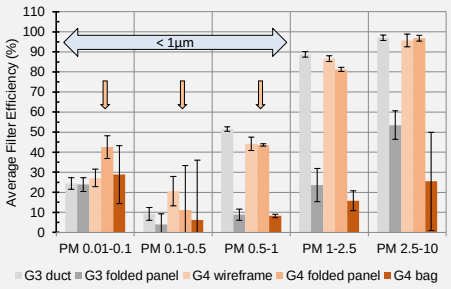
19

Coarse filters: Filter Efficiency

G3 vs G4: new



G3 vs G4: 6 months





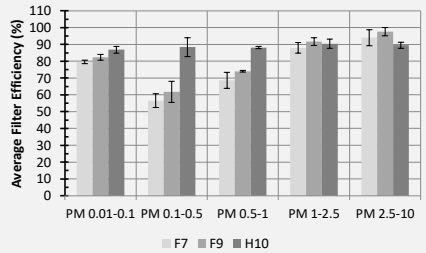
General for coarse filters:
- Low and variable efficiency for particles < 1µm
- Except for G4 FP at new state (electrostatic charge?)

G3 vs G4
- For **same filter type** (folded panel) → much higher efficiency for G4 filter
- Differences in efficiency between different types of the **same filter class** (e.g. G4)

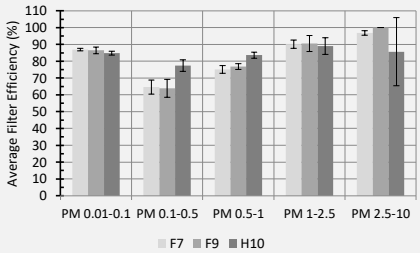
In function of time
- For filters with small surface area
  → increase in performance in time (filter cake)

Fine filters: Efficiency

F7 - F9 - H10: new



F7 - F9 - H10: 6 months



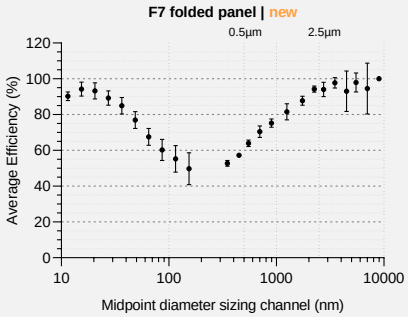


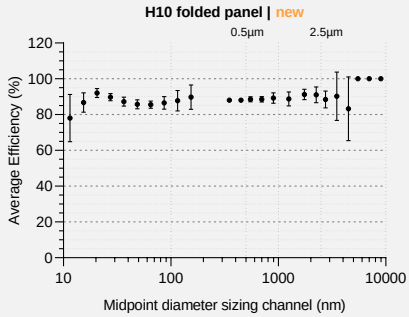
General
- Much more efficient than coarse filters

F7 vs F9 vs H10 (@ new state)
- Slight increase in efficiency between F7&F9
- Significant higher efficiency for H10, especially for PM0.1-0.5 & PM0.5-1
  => most penetrating particle size (MPPS)

In function of time
- No significant differences for F7 & F9
- H10 significant reduction for MPPS

Fine filters: Efficiency (new)





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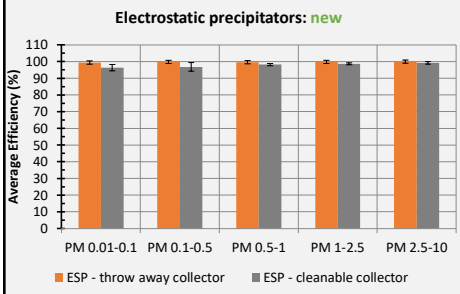
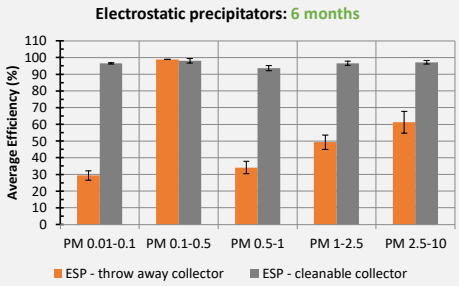
Electrostatic Precipitators (ESP)





New: ESP versus other fine filters: Very high, consistent efficiency in the complete measure range

New: throw away collector versus cleanable: Small difference in performance (difference in design)
Bit higher for throw away initially

In function of time:
cleanable: small decrease (but still ≥ 90%)
throw away: significant decrease except for class PM0.1-0.5

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Conclusions

Outdoor particulate load in Brussels

→ dominated by very small particles (number concentrations)

→ gaining research attention → deeper in respiratory system = potential greater health risks

Coarse filters = protection of the system

→ efficiency for particles < 1µm rather limited

→ large variability in efficiency between different filter types of the same class!

→ ! Small filter surface

Fine filters = improvement of the supplied air quality

→ dip in efficiency for particles between 56-800nm for F7 & F9, not for H10 @ new state

→ so far stable performance for F7&F9, decrease for H10

Electrostatic precipitation = promising technique

→ (stable) and high efficiency in full range (10nm-100µm) & low pressure drop

→ effect of ionized air on health?

further research







1. **Decision tree**
   → suitable technique in function of desired degree of filtration/purification
2. Defining a **risk management strategy** in case of peak pollutions outdoor
   → what to do with a ventilation system in this case?
3. **Recommendations** regarding
   → conscious use of ventilation systems and maintenance
   → smart ventilation strategies for a city environment

OUT2IN

Thank you for your attention!



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http://www.bbri.be

AIVC 2019
October 15-16 2019 - Ghent - Belgium

Het Pand, 16th October 2019
Session 8A - Reducing exposure to outdoor pollutants, 13:45-14:45

"Future trends in laboratory methods to predict HVAC in service filter performance"

J. Marval[1], L. Medina[1], E. Norata[1], P. Tronville[1]
[1]Politecnico di Torino, Turin, Italy



POLITECNICO DI TORINO
Department of Energy "Galileo Ferraris"



AEROSOL TECHNOLOGY LAB

1

Parameters characterizing HVAC air filters

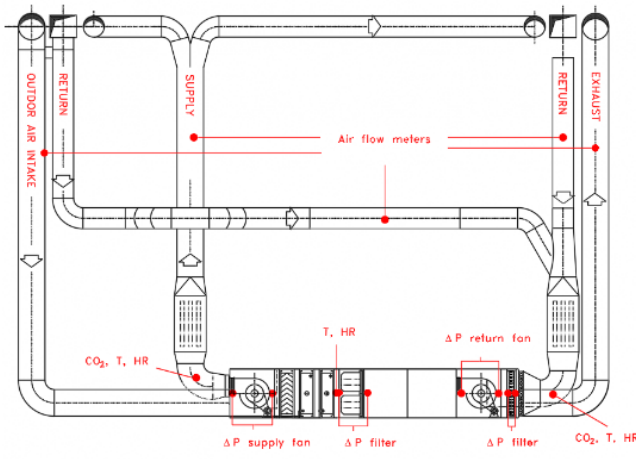
- Efficiency: ability to capture aerosol particles; the reason why air filters are installed in an HVAC system
- Airflow resistance: the price to pay for cleaning the air; linked to the energy use (not obviously) and to the airflow rate in the system
- Service life: the expected amount of time before the filter needs to be replaced; it depends on how fast its airflow resistance increases while capturing the aerosol particles

We studied how air filters are aged naturally in an HVAC system and compared the data obtained with a standardized test

2

Comparison between in-situ and artificial filter ageing

HVAC system serving a large classroom at Politecnico di Torino



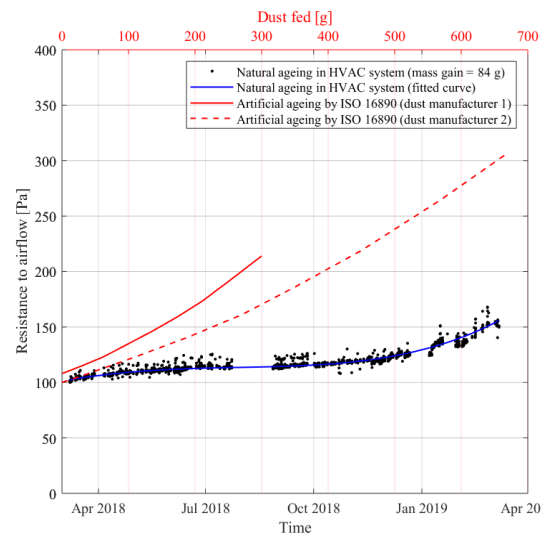


3

Comparison between in-situ and artificial filter ageing

The in-situ aged filter shows different pressure drop trend throughout its service life, compared to the ones aged in the laboratory test

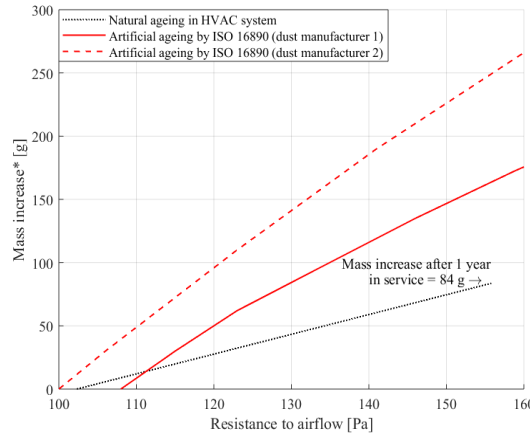
- Surface filtration vs. deep filtration



4

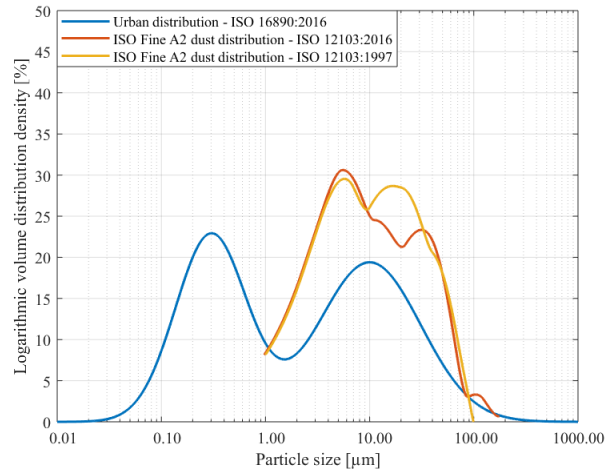
Comparison between in-situ and artificial filter ageing

- Filters used in a real HVAC system reach the same airflow resistance of the artificially-aged filters with much lower mass of captured particles
- Big difference between the two aerosol particle size distributions and their effect on the loading kinetics of the filtering media



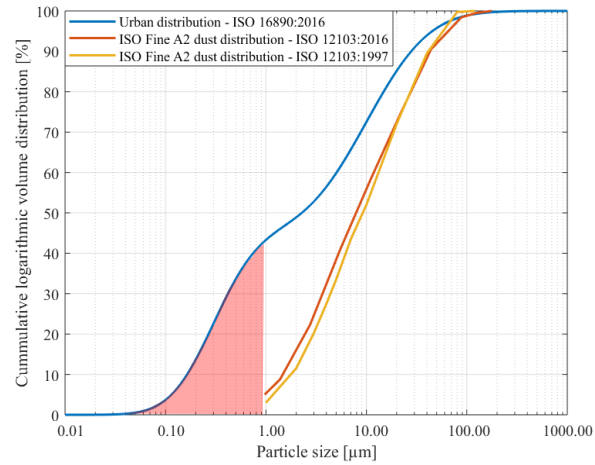
Urban atmospheric aerosols vs synthetic dusts

The volume (i.e. the mass) distributions as a function of particles size of currently standardized test dusts (ISO Fine dust used by ISO 16890) are very different from typical urban atmospheric aerosols

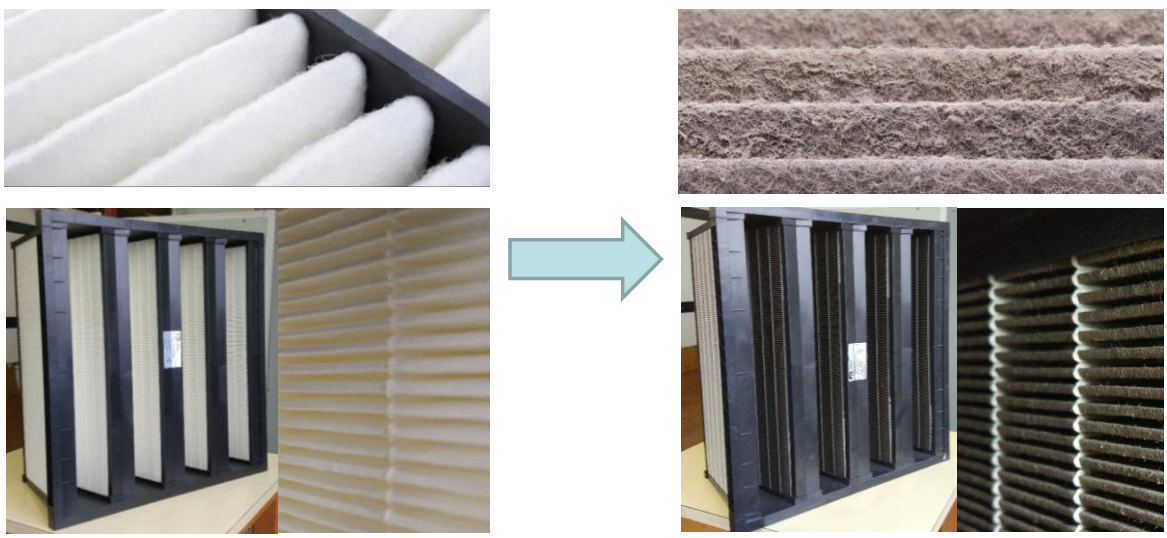


Urban atmospheric aerosols vs synthetic dusts

About 45% of the mass of the particles in the urban aerosol distribution proposed by ISO 16890 are smaller than the smallest particles in the ISO fine dust

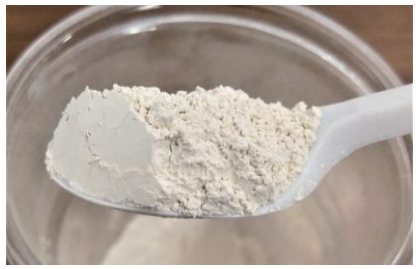


Natural ageing of HVAC filters



Artificial ageing with ISO Fine dust

ISO Fine dust prescribed by ISO 16890 to assess the test dust capacity of HVAC air filters





Artificially-aged fine filter

Motivation for a new ultrafine synthetic aerosol

- The main goal of current standardized test methods is to compare one HVAC air filter to another, not to predict their in service performance
- ISO 16890:2016 made a big step ahead by providing *e*PMx values for a typical application (100% outdoor air in urban and rural areas)
- The different behavior of air filters during laboratory tests and in service is linked to their ageing process (artificial or natural), i.e. to the different characteristics of the challenging aerosols in these two conditions
- Current procedures are not able to predict quantitatively the in-situ air filters performance, nor their energy impact (energy rating in lab is not able to predict energy use in practice)
- Need to generate in laboratory a synthetic aerosol simulating much better the atmospheric one, i.e. to fill in the gap preventing a more realistic simulation in the laboratory (ASHRAE RP-1734)

Nanoaerosol thermal generator

This device can be used to generate large amounts of ultrafine particles (nanoaerosol)

Parameters

- Salt stick feed rate into the oxy-propane flame (1 to 25 mm/min)
- Diameter of the salt stick (10 or 12 mm)

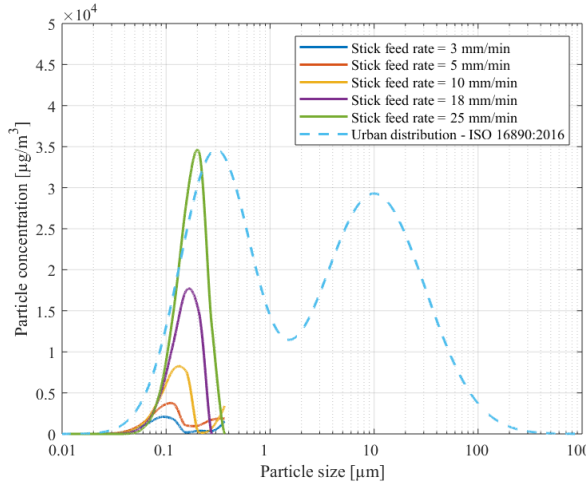


Test conditions

- Standardized ISO 16890 test duct operated at 3400 m^3/h
- The temperature between 20.6 and 34.6 °C
- Relative humidity between 33 and 55%
- The aerosol thermal generator injected the particles from the same point where the dust feeder is usually placed to age air filters with the standardized synthetic dusts
- The particle size distributions were measured with a TSI 3910 nanoparticle sizer and a PMS LAS-X II

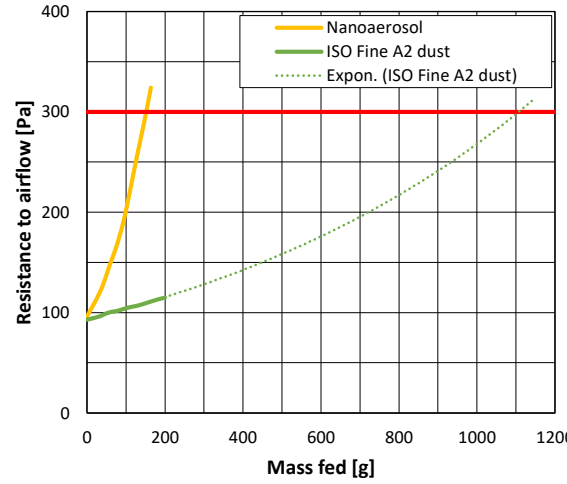
Mass distribution of ultrafine synthetic aerosol

- The synthetic nanoaerosol produced by the thermal generator can represent the accumulation mode of a typical urban aerosol
- The concentration of the generated nanoaerosol is increasingly higher for faster salt stick feed rates



Clogging tests – ISO Fine dust vs nanoaerosol

- Around 1100 g of ISO Fine dust needed to reach 300 Pa
- Only 150 g of KCl nanoaerosol were necessary to reach the same final pressure drop (10 mm-diameter salt stick at 10 mm/min)
- The trend of the clogging curves is quite different



Conclusions

- The ageing behavior of air filters in HVAC systems is dramatically different from what current laboratory simulations provide
- To bring the laboratory simulations closer to reality, it is essential to simulate the filter ageing with much smaller particles than those present in current normalized synthetic dusts
- To generate large amounts of ultrafine particles, a controlled combustion process is a promising solution
- In a few hours the nanoaerosol thermal generator could completely clog an air filter with a test dust capacity of around 1100 g
- New approach looks promising and it will be developed further

Thank you for your attention!

A study of the influence of the position of a chimney terminal on the vertical walls of a building on the air quality of the ventilation air supply

AIVC conference 2019, Ghent

Xavier Kuborn, Sébastien Pecceu

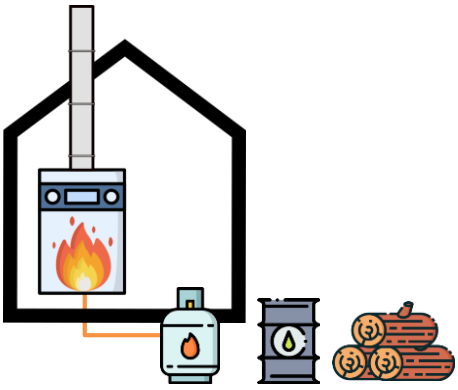
Belgium Building Research Institute
Avenue Pierre Holoffe, 21
1342 Limelette, Belgium

economie NBN cstc.be

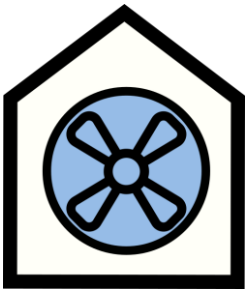
1

1

Heat and DHW are often produced by gas, oil or wood-fired boilers



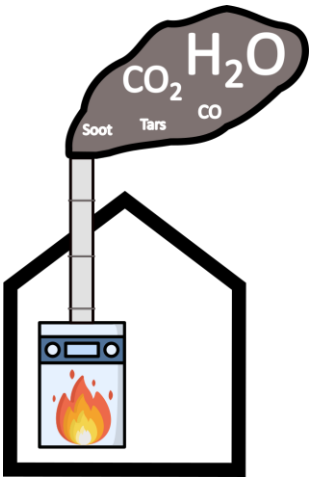
All buildings need to be ventilated



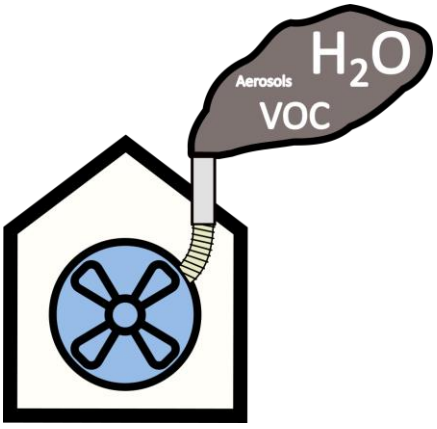
cstc.be

2

2



Fuel-fired boilers
emit smoke



Ventilation systems
emit polluted air

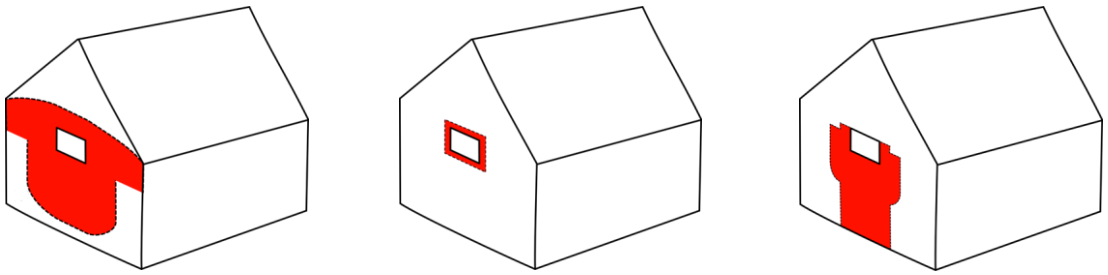
3

To maintain good indoor air quality : **smoke** (fuel-fired appliances) and **exhaust air** (ventilation systems) must be prevented from going back into the building

→ Careful choice of the **position of the terminal**

4

Methods for positioning chimney terminals are available in Belgian and European **standards**. The comparison of the results is confusing :



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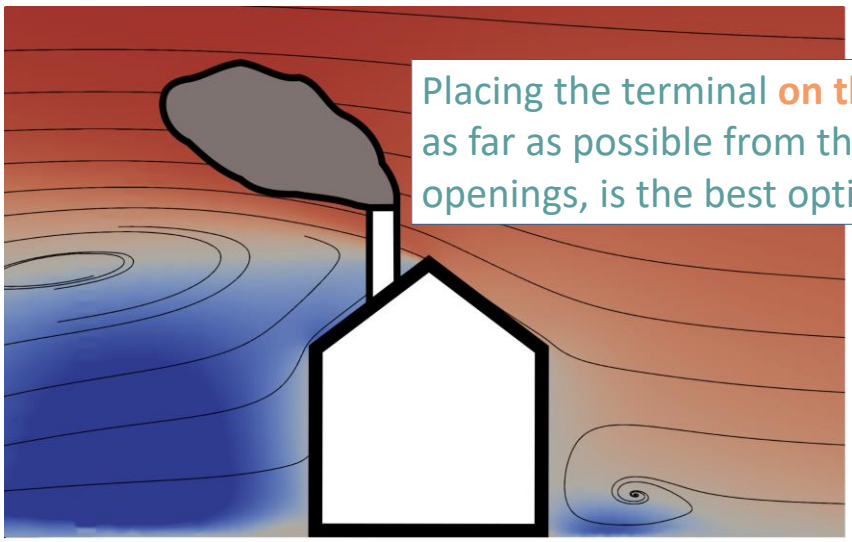
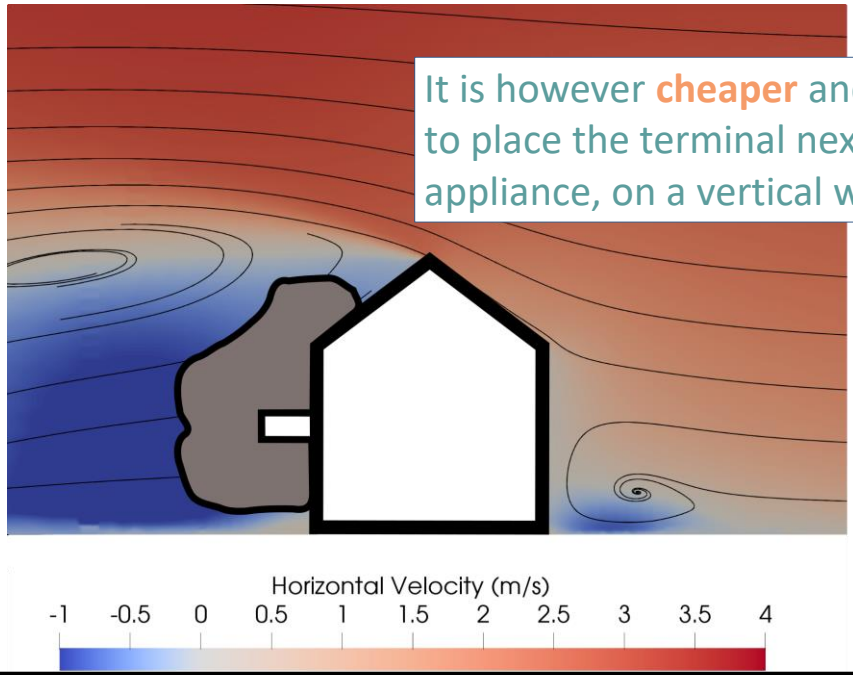


Placing the terminal **on the roof**, as far as possible from the openings, is the best option

6



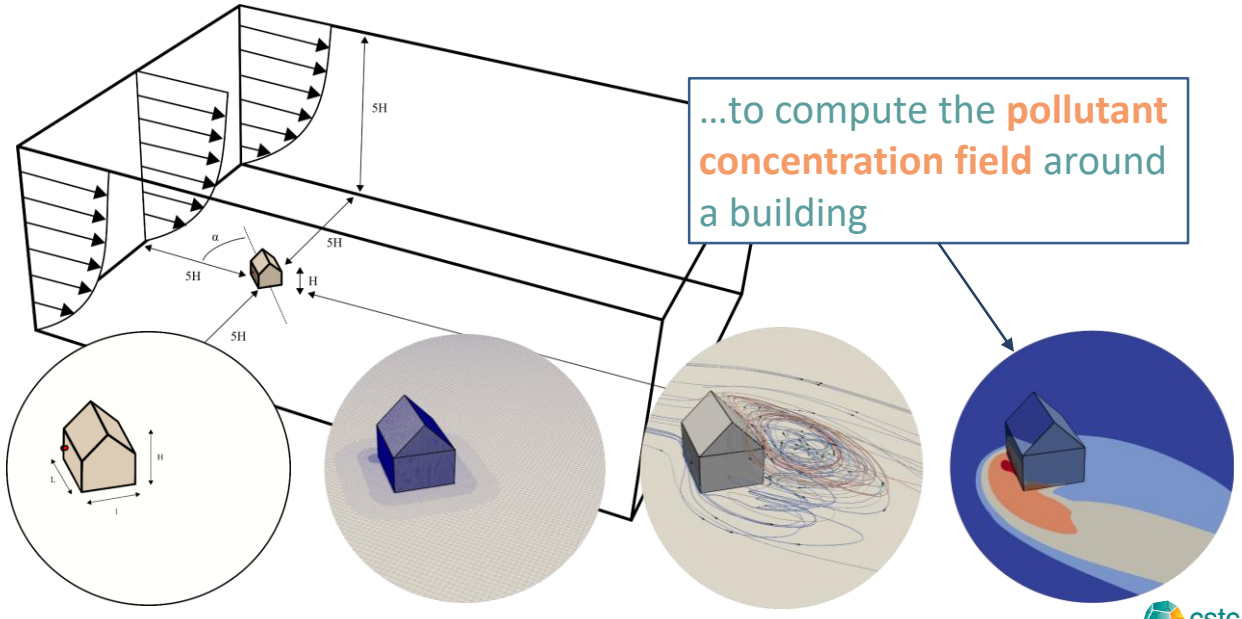
It is however **cheaper** and **easier** to place the terminal next to the appliance, on a vertical wall

7

There is a need for a **scientific** approach to assess the validity of the different methods and/or to develop a **new method**

8

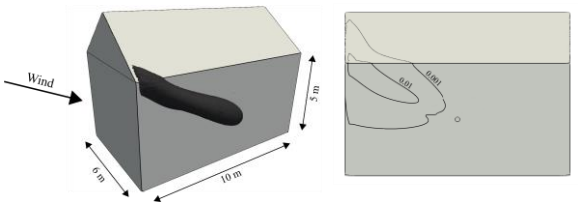
A CFD tool has been developed using OpenFOAM…



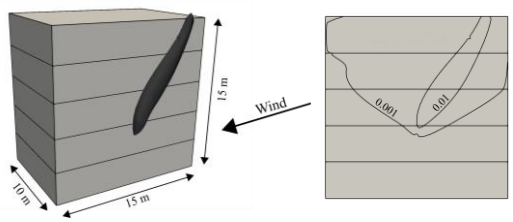
…to compute the **pollutant concentration field** around a building

9

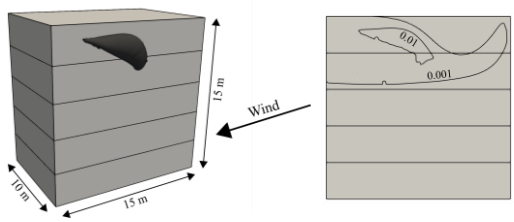
Preliminary results show the capabilities of the CFD tool



Wind velocity	: 3 m/s
Outside temperature	: 5°C
Smoke temperature	: 100°C
Terminal diameter	: 0,2 m
Fumes flow	: 100 m³/h (around 60 kW)

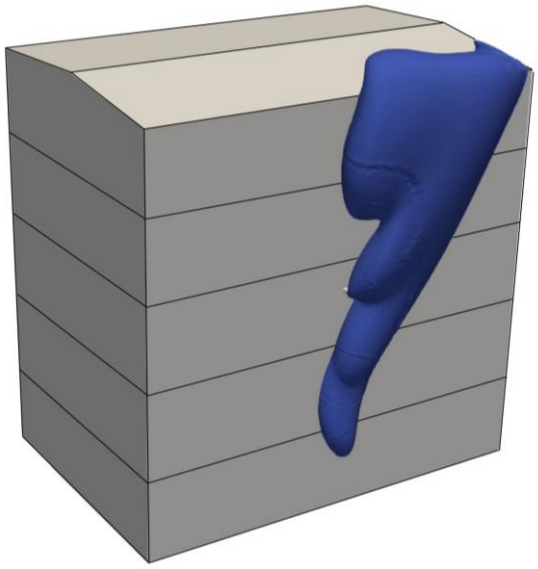


Wind velocity	: 0.5 m/s
Outside temperature	: 5°C
Smoke temperature	: 50°C
Terminal diameter	: 0,2 m (unrealistic)
Fumes flow	: 50 m³/h (around 30 kW)



10

Simultaneous operation of multiple appliances



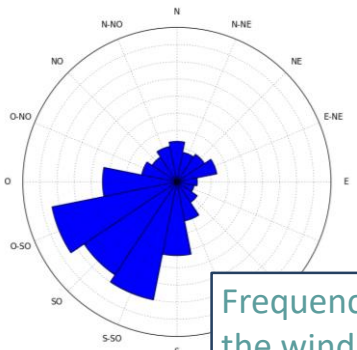
Wind velocity	: 0.5 m/s
Outside temperature	: 5°C
Smoke temperature	: 50°C
Terminal diameter	: 0,2 m (unrealistic)
Fumes flow	: 50 m³/h (around 30 kW)

11

The challenge is - how to build a method, usable by the **heating technicians**, from the **raw numerical results ?**

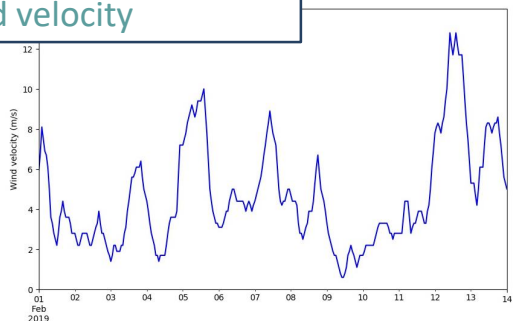
12

The most important parameter is the **wind direction** with respect to the building orientation, as it completely changes the **streamlines of the flow** around the building



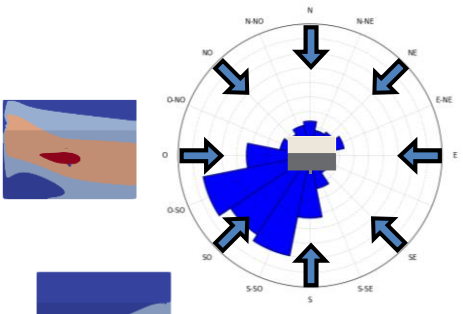
Frequency of time that the wind blows from a specific direction

Time-evolution of the wind velocity



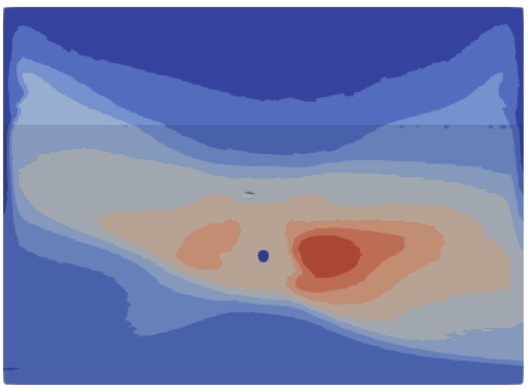
13

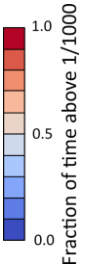
For a given orientation of the building and position of the terminal, the results from 8 numerical simulations are combined to create a **map of the façade**



Iso-contour of concentration

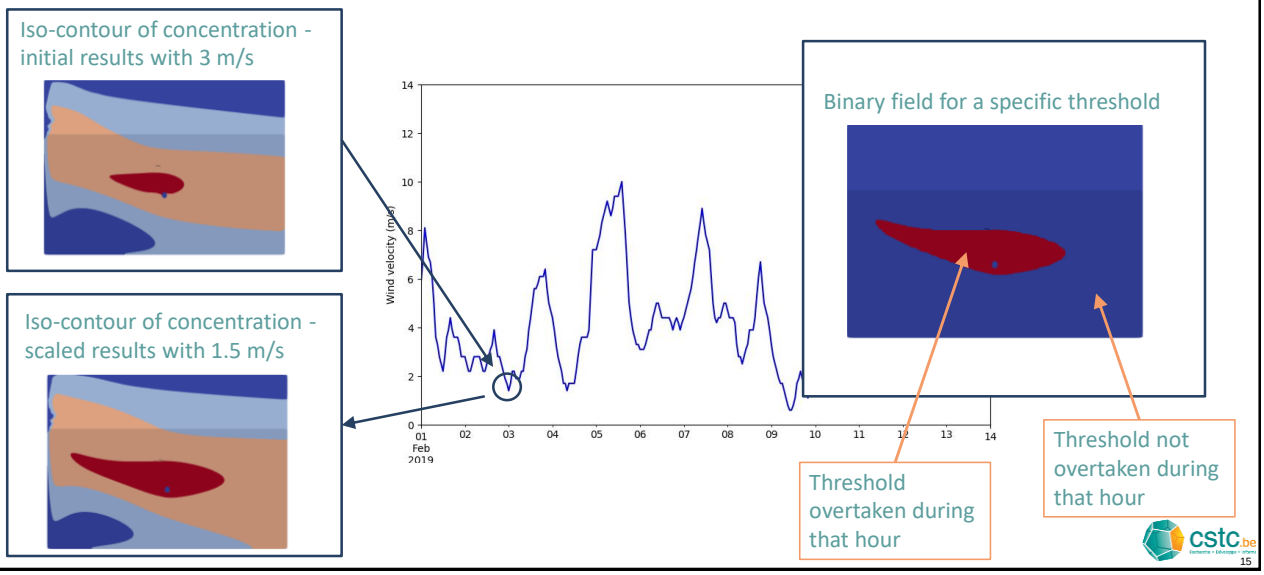
Fraction of time above threshold (dilution = 1000)





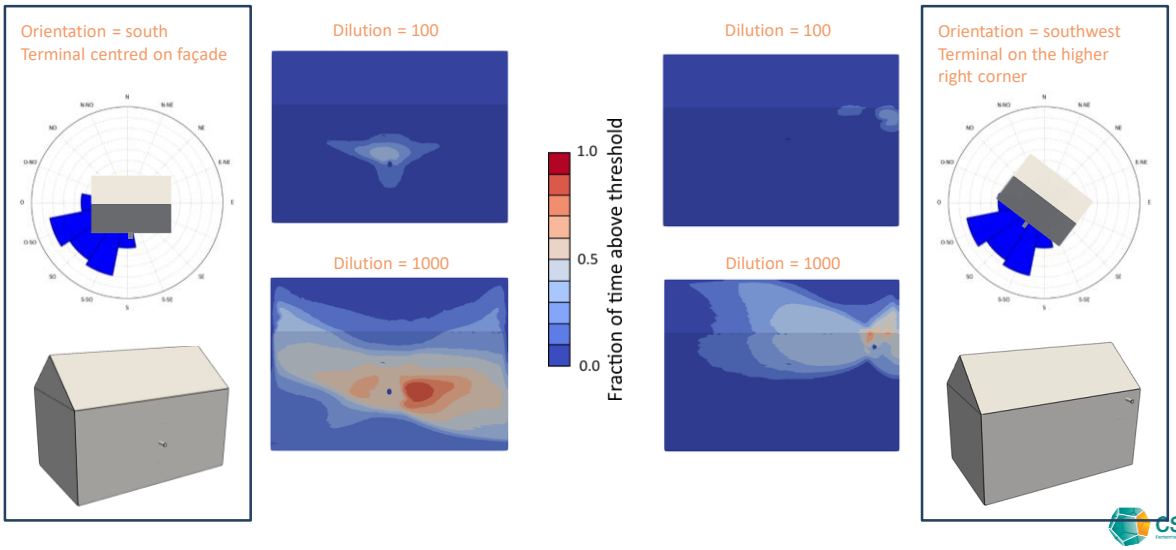
14

To reduce the number of numerical simulations, the **results are scaled** using a velocity ratio V_{ref}/V_{scaled}



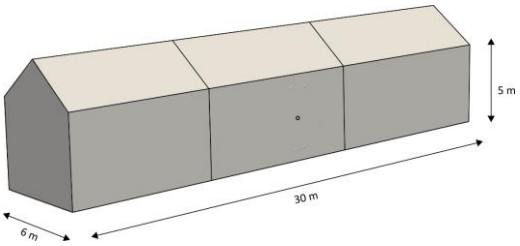
15

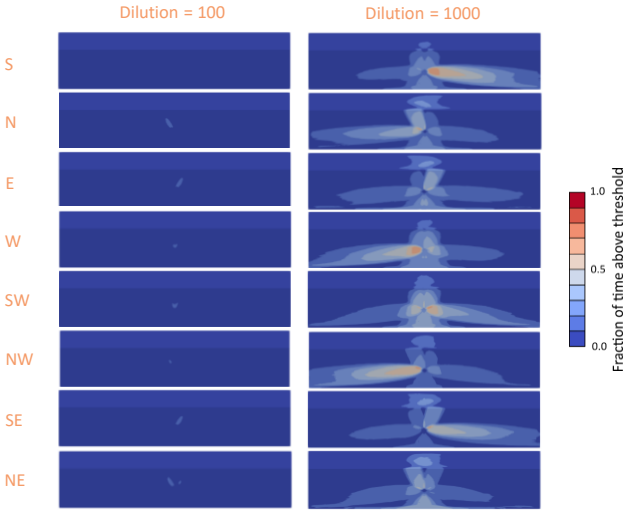
The binary fields are **averaged over the whole year** to obtain a map for a specific configuration



16

The method can be extended to other building configurations





Outside temperature	: 5°C
Smoke temperature	: 50°C
Terminal diameter	: 0,06 m
Fumes flow	: 50 m³/h (around 30 kW)

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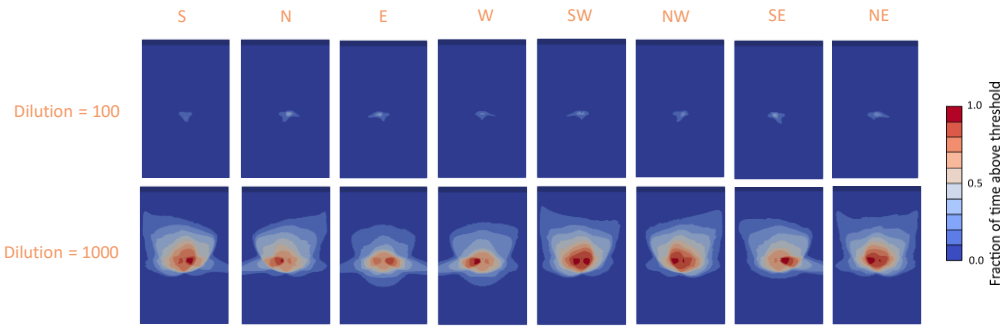
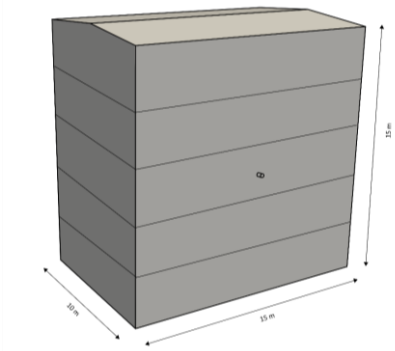
17

17





Outside temperature	: 5°C
Smoke temperature	: 50°C
Terminal diameter	: 0,20 m (unrealistic)
Fumes flow	: 50 m³/h (around 30 kW)

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18

18

- A tool has been developed to compute the pollutant concentration field around an isolated building on a flat and unobstructed environment
- A method has been developed to account for the changing wind direction and velocity on the concentration field on a façade
- The scaling method needs to be further validated
- There is no information on which dilution is suitable
- There is no information on which fraction of time the dilution threshold can be overtaken
- The effect of the exhaust velocity should be investigated

The results are based on an ongoing research project (In-Vent-Out) partly supported by the Belgian Bureau for Standardisation (NBN) and by the Federal Public Service Economy (SPF Economie)

HISTORY AND BACKGROUND IN THE DEVELOPMENT OF LOW PRESSURE VENTILATION SYSTEMS

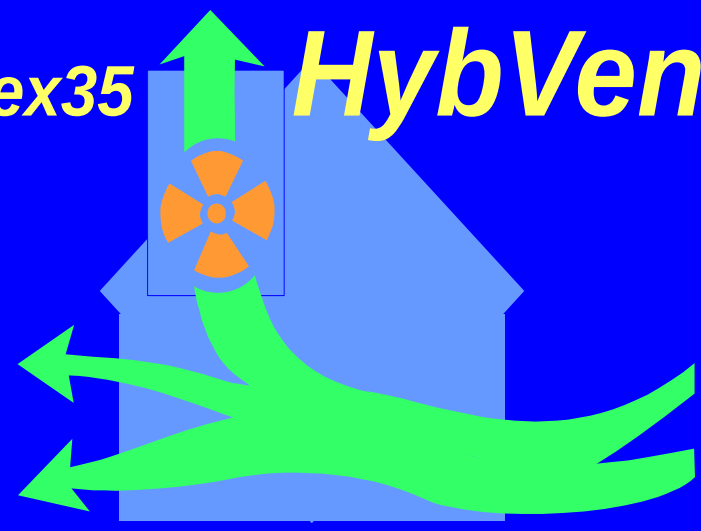
PER HEISELBERG

DEPARTMENT OF CIVIL ENGINEERING

AALBORG UNIVERSITY
DENMARK

1

Annex35 HybVent



Hybrid Ventilation in New and Retrofitted Office Buildings

1997 - 2002

2

A LOW PRESSURE DROP IN AIR PATH THROUGH BUILDING

- Efficient air distribution in the building to exploit the ventilation air optimally (reduce air flow rate)
- Controlling ventilation air flow rates according to demand
- Using as few ventilation components as possible and components with low pressure loss through aerodynamic shape or large dimensions
- Minimising the need for distribution channels by intake of air through the façade and using direct air transfer between rooms
- Using air paths with large dimensions and good aerodynamic design, where air speeds are lower than 1 m/s at design conditions

3

ANNEX 35 CASE STUDIES

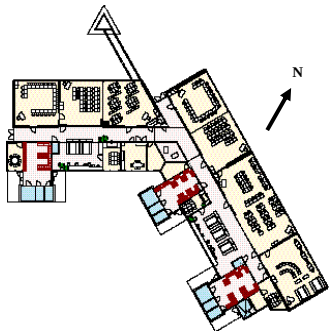


4

MEDIÅ SCHOOL, GRONG, NORWAY





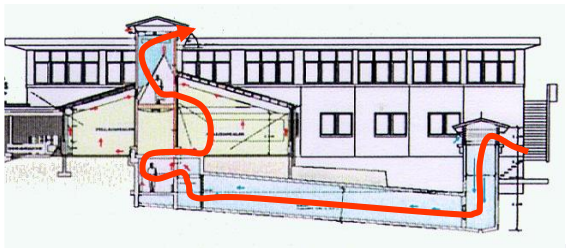


Courtesy of:
Professor Per Olaf Tjelflaat, Norwegian University for Science and Technology, Trondheim, Norway

AIR EXHAUST SYSTEM

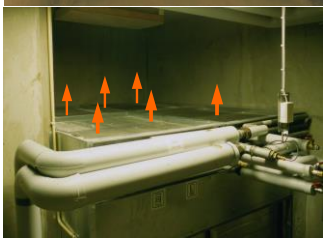


MEDIÅ SCHOOL, GRONG, NORWAY




MEDIÅ SCHOOL, GRONG, NORWAY

LOW PRESSURE LOSS IN SYSTEM
VENTILATION SUPPLY ABOUT 35 PA

- Filter about 15 pa
- Heat recovery about 10 pa
- Heating about 5 pa

VENTILATION EXHAUST ABOUT 20 PA

- Heat recovery about 12 pa

TOTAL PRESSURE LOSS

WINTER ABOUT 55 PA

SUMMER ABOUT 28 PA

IEA EBC ANNEX 62

VENTILATIVE COOLING

2012 - 2017

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9

POTENTIAL AND LIMITATIONS

OUTDOOR CLIMATE POTENTIAL

- Outdoor temperature lower than the thermal comfort limit in most part of the year in many locations
- Especially night temperatures are below comfort limits
- Natural systems can provide “zero energy” cooling in many buildings

LIMITATIONS

- Temperature increase due to climate change might reduce potential
- Peak summer conditions and periods with high humidity reduce the applicability
- An urban location might reduce the cooling potential (heat island) as well as natural driving forces (higher temperature and lower wind speed). Elevated noise and pollutions levels are also present in urban environments
- **High energy use for air transport limit the potential for use of mechanical systems**
- Building design, fire regulations, security are issues that might decrease the potential use of natural systems

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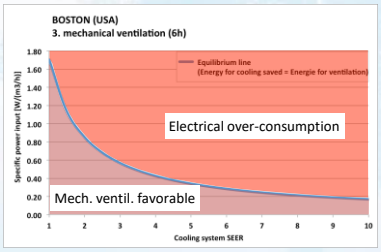
ENERGY INDICATORS

3. Ventilative cooling advantage (ADV_{VC})

This indicator defines the benefit of the ventilative cooling, i.e. the cooling energy difference divided by the energy for ventilation.

$$ADV_{VC} = \frac{SEER_{VC}}{SEER_{AC}} = \frac{E_{cool,ref} - E_{cool,scen}}{E_{VC}}$$



Equilibrium line is sliding in fonction of :

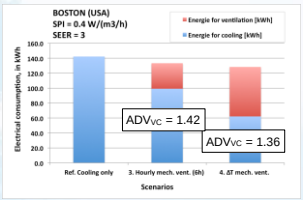
- Cooling requirements
- Hours of ventilation use
- Airflow rate

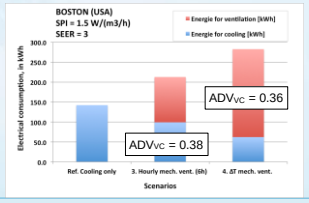
Example

Mech. system + cooling

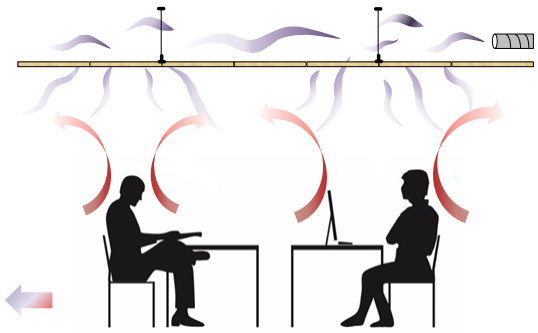
Dual flow : ~ 0.40 W/(m³/h)

Single flow : 0.08 -**0.7** W/(m³/h)





DIFFUSE CEILING VENTILATION



Thermal comfort

Energy saving

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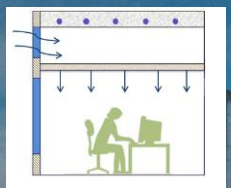
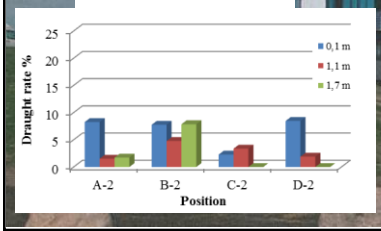
VENTILATIVE COOLING OFFICES IN COLD CLIMATE



Extreme winter condition:
Supply air temperature <-5 ºC, ACH =4





SUMMARY

IN RECENT YEARS DEVELOPMENT OF NZEB BUILDING TECHNOLOGY HAS DEVELOPED CONSIDERABLY IN A NUMBER OF AREAS (AIR TIGHTNESS, INSULATION, GLAZING, LIGHTING,..)

BUT IN THE FIELD OF ENERGY USE FOR TRANSPORTATION OF AIR IN VENTILATION SYSTEMS THE DEVELOPMENT HAS BEEN MUCH MORE LIMITED.

THERE IS A LOT OF KNOWLEDGE AND SOLUTIONS FOR LOW PRESSURE VENTILATION SYSTEMS COLLECTED THROUGH MANY YEARS

WHY IS IT NOT APPLIED IN A LARGER SCALE?

DEPARTMENT OF CIVIL ENGINEERING
AALBORG UNIVERSITY

Per Heiselberg
Aalborg University
E-mail: ph@civil.aau.dk
www.civil.aau.dk



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DENMARK

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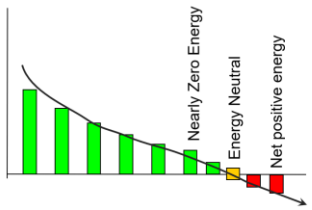
When the EPR hits the fan…

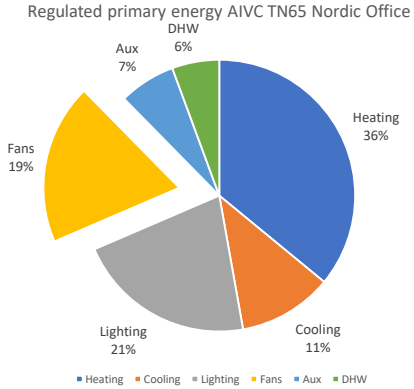
Examples and lessons from practice

Ad van der Aa
ABT
16-10-1207

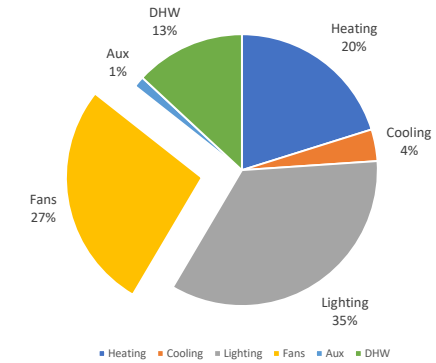
Fan energy development



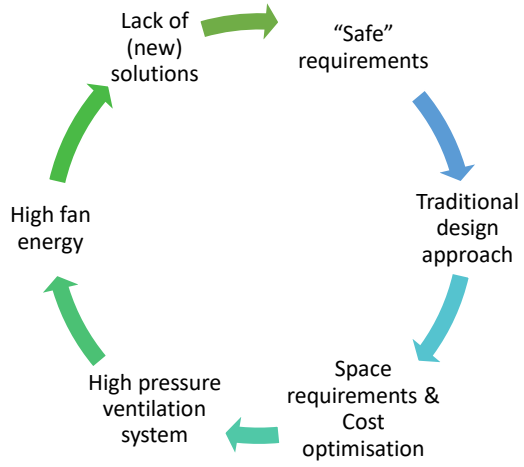
Regulated primary energy AIVC TN65 Nordic Office



Regulated primary energy Energy neutral design 2019



The continuous fan energy story

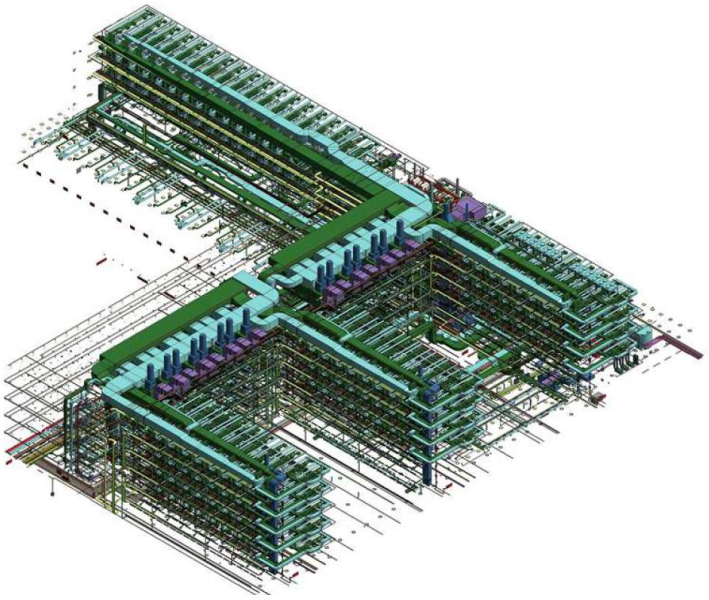


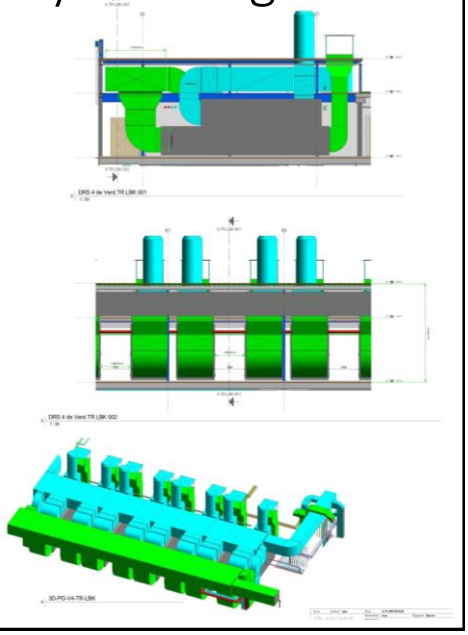
To break the circle

- Low pressure solutions
- Rethinking of requirements
- Holistic design approach
- Demonstration projects and examples

3

Example 1. A new built laboratory building





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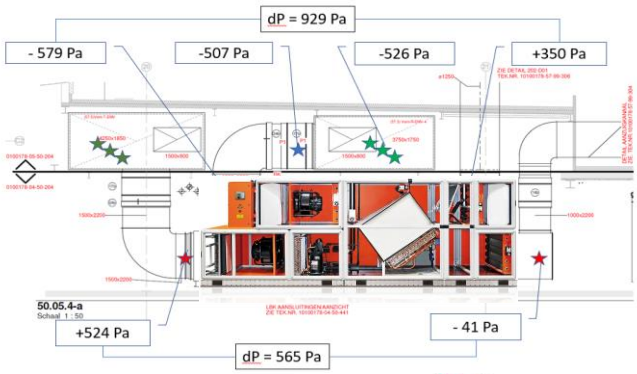
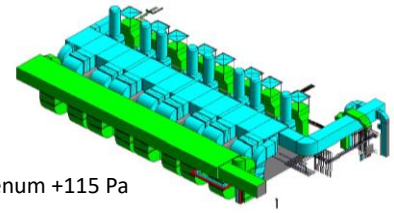
Pressure measurements





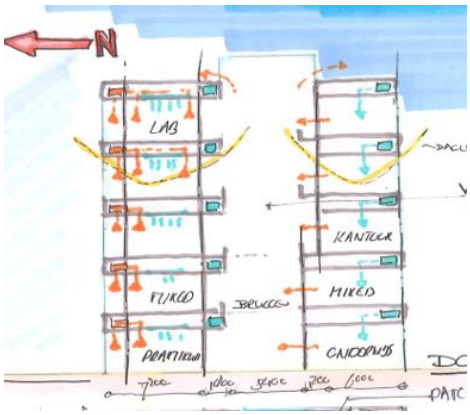
Plenum +115 Pa

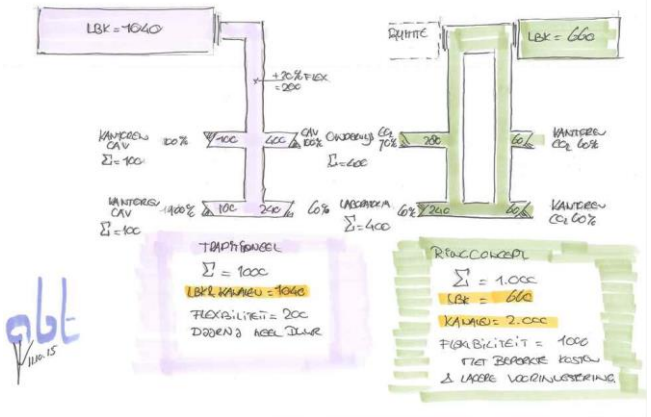


Chimney +350 Pa

5

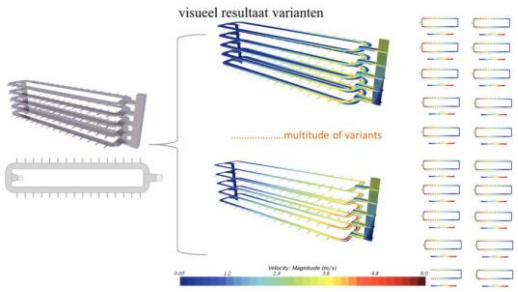
New laboratory Phase II - Conceptual ideas

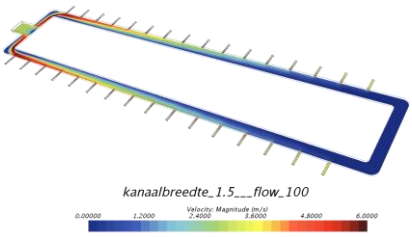


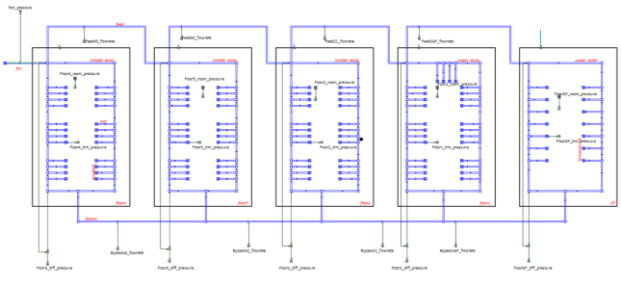


6

Ventilation simulations CFD and Multizone modelling

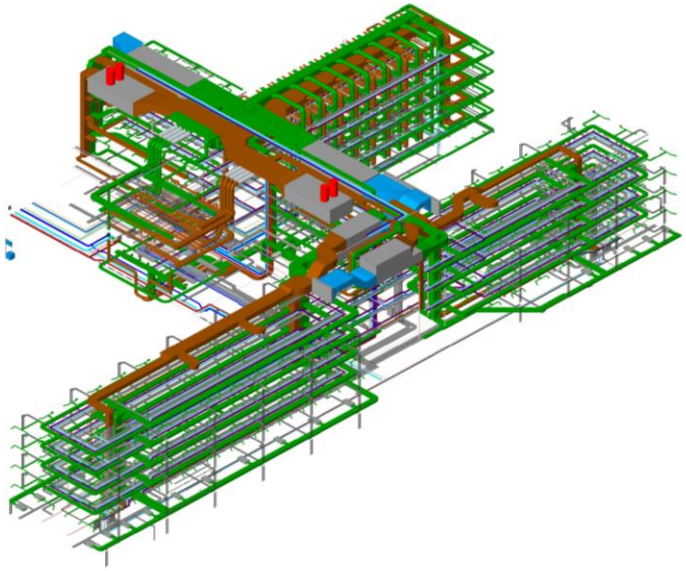






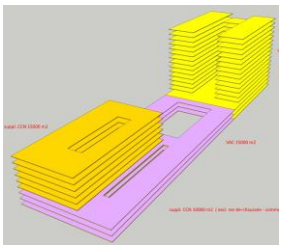
CASE		2.1	2.2	2.3	2.4	2.5	2.6
Fan_pressure	Pa	43,8	49,0	84,9	50,6	75,5	231,4
Bypass43_flowrate	kg/s	0,4	1,0	1,0			
Bypass32_flowrate	kg/s	0,9	1,9	1,9			
Bypass21_flowrate	kg/s	1,3	2,8	2,9			
Bypass1GF_flowrate	kg/s	3,1	3,8	3,8			
Feed43_flowrate	kg/s	13,7	13,2	13,2	14,1	14,1	14,1
Feed34_flowrate	kg/s	11,6	10,6	10,6	12,5	12,5	12,5
Feed21_flowrate	kg/s	9,6	8,1	8,0	10,9	10,9	10,9
Feed1GF_flowrate	kg/s	6,0	5,3	5,3	9,0	9,0	9,0
Air speed bypass_43	m/s	0,1	0,3	0,3			
Air speed bypass_32	m/s	0,3	0,6	0,6			
Air speed bypass_21	m/s	0,4	0,9	0,9			
Air speed bypass_1GF	m/s	1,0	1,2	1,2			
Air speed feed_43	m/s	1,6	1,5	1,5	1,6	1,6	1,6
Air speed feed_32	m/s	1,3	1,2	1,2	1,4	1,4	1,4
Air speed feed_21	m/s	1,1	0,9	0,9	1,2	1,2	1,2
Air speed feed_1GF	m/s	0,7	0,6	0,6	1,0	1,0	1,0

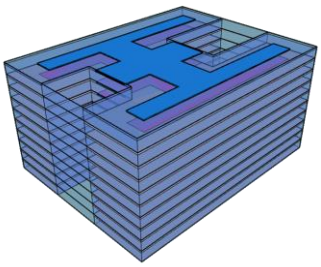
Lessons learned, barriers and concerns

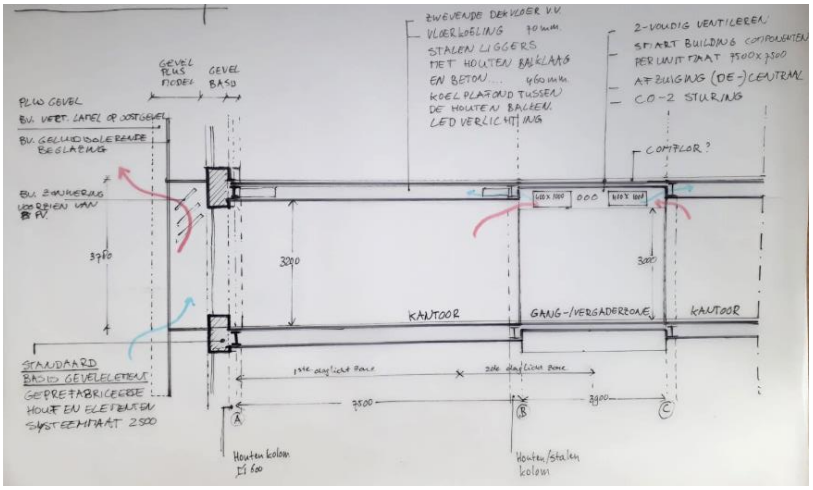


- Pro's
  - Low pressure
  - High flexibility
  - Uniformity of sizing
  - Simple control
- Con's
  - More ductwork
  - Space requirements
  - Lack of suitable calculation and dimensioning tools
  - Uncertainty for designers to guarantee constant flows
  - Available examples/demonstration projects

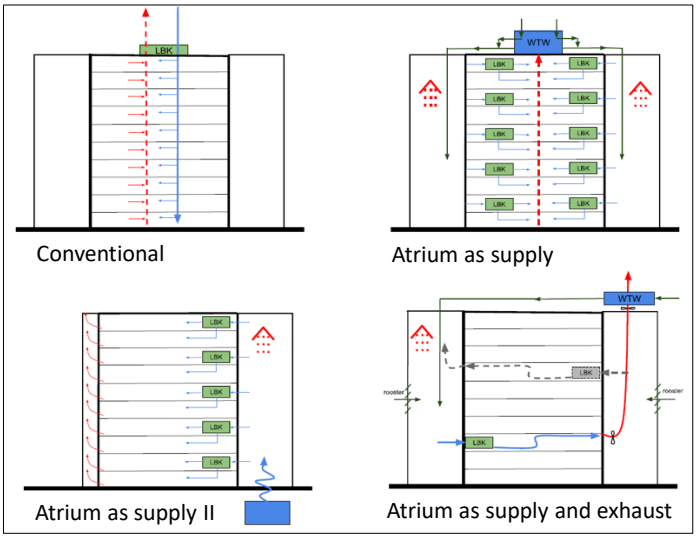
Example 2. New 70.000 m^2 office building

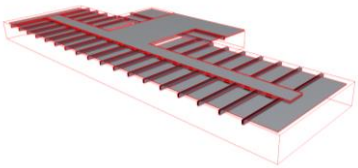






Ventilation concept variants

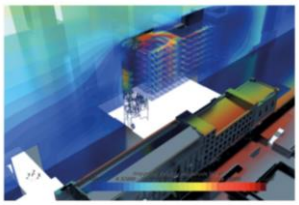


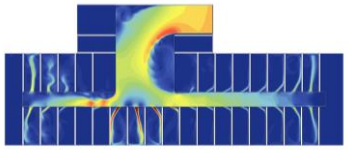


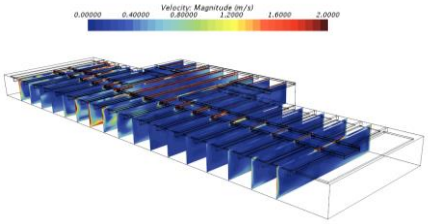


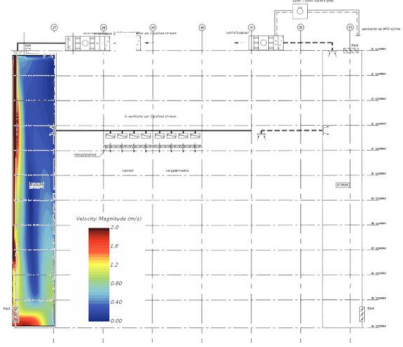
Diffuse ceiling ventilation via wooden floors

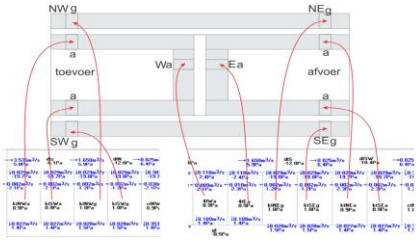
Ventilation simulations CFD and Multizone modelling











11

Lessons learned, barriers and concerns







- Pro's
  - Low pressure
  - High flexibility
  - Uniformity of sizing
  - Simple control
  - Cost effective
  - Sustainable
- Con's
  - Not easy to convince client
  - Discussion about requirements
  - Lack of demonstration projects
  - Lack of (practicle) design tools
  - Lack of understanding on components

12

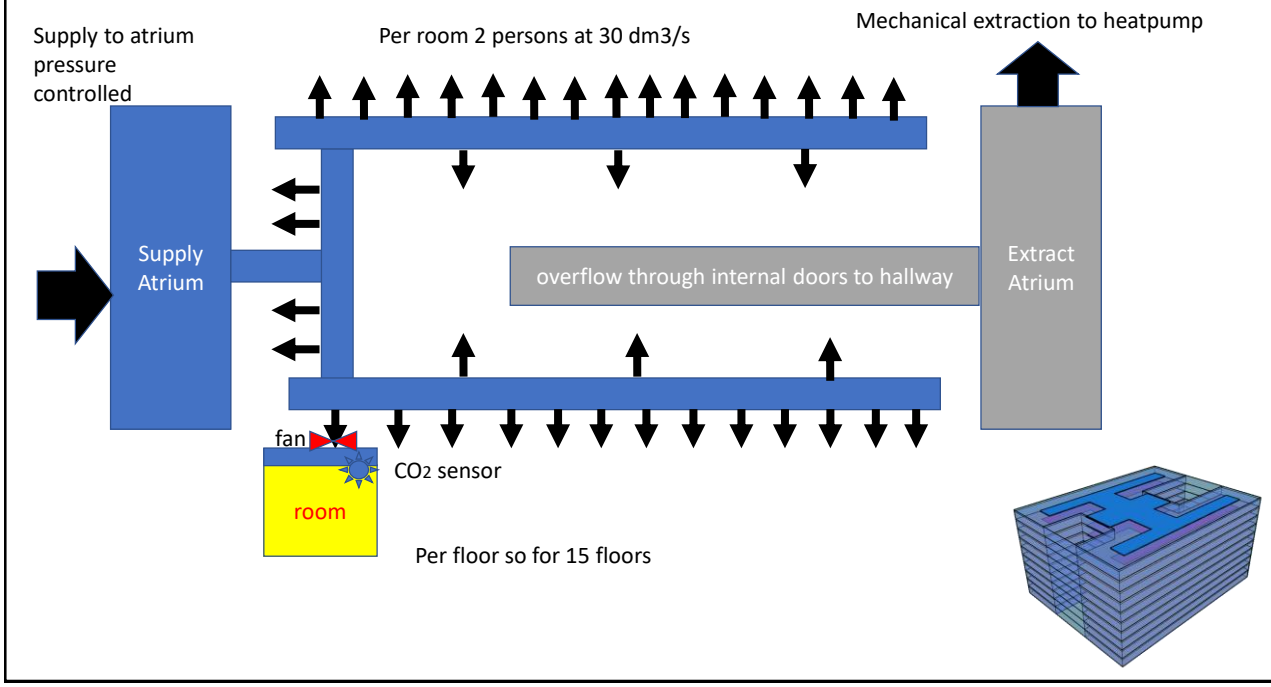
Further work and research questions

- Is fan energy a solvable barrier for low energy commercial buildings?
- How to achieve ventilation systems with an extreme low pressure?
- Is an automatic choiche for filtering, preconditioning, heat recovery and control of air logical?
- Are the (increasing) requirements valid and needed?
- How to realize suitable design methods and sizing tools?
- Where to find practical examples and demonstration projects?
- What practical measures and provisions have to be (further) developed?

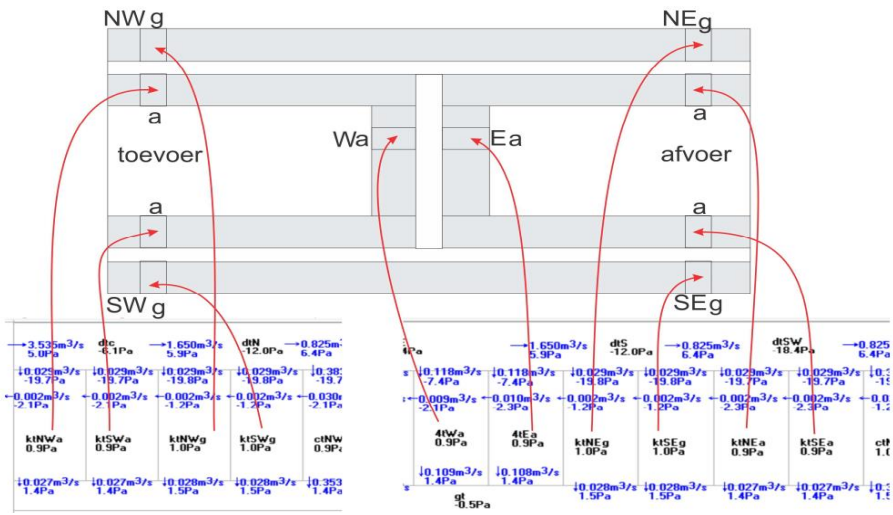
Multi zone calculations

Maximum wind and thermal pressures against the room fan

1



2

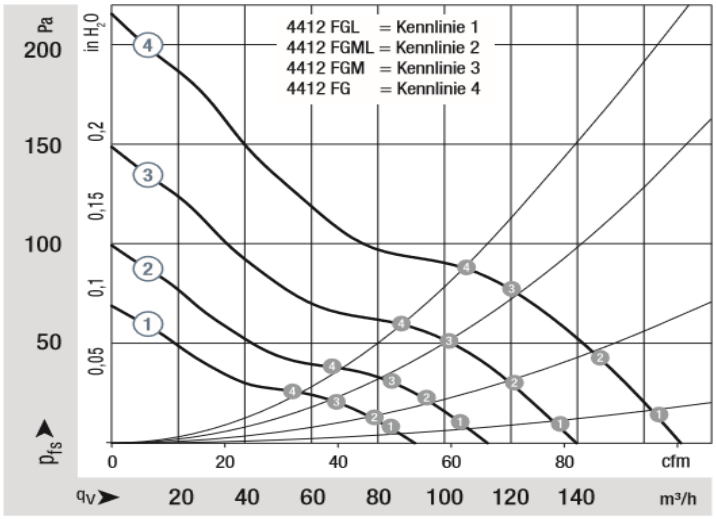


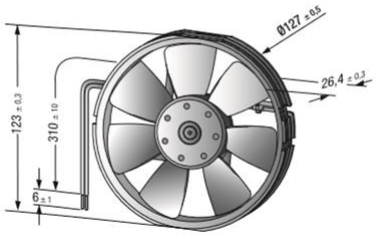
3

Model nr	Temp buiten°C	Temp atrium°C	Wind m/s	Richting °	Stroom pp m³/h	Bezetting %	fan min pa	fan max pa
10	-10	0	10	0	54		-29.6	-3.9
11	-10	0	10	180	54		-30.4	-4.8
12	-15	0	4	0	54		-24.7	0.9
13	-10	5	10	0	54		-23.4	-3.8
14	5	10	4	0	54		-23.9	-10.0
15	5	10	4	180	54		-24.0	-10.1
16	5	15	4	0	54		-18.3	-9.8

4

Curves





5

Fan power calculations

- flow 50 m3/s
- fan efficiency 0,5

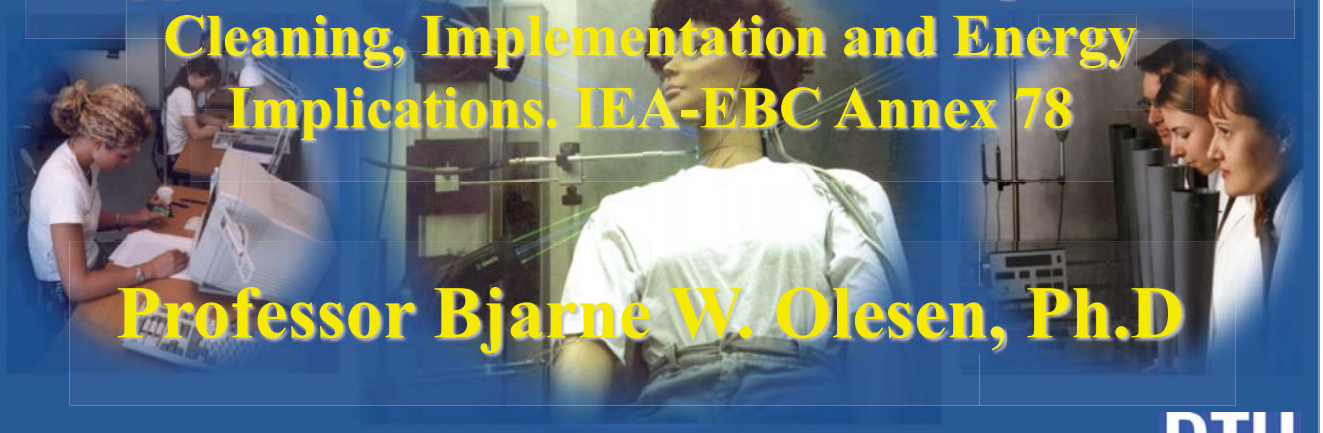
- Traditional system 2000 Pa 200 kW
- Low pressure system 40 Pa 4 kW

- For the same time of running hours of the system the low pressure system requires
- 200/4= 50 times less energy for air distribution

6

International Centre for Indoor Environment and Energy

Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications. IEA-EBC Annex 78



Professor Bjarne W. Olesen, Ph.D

www.ie.dtu.dk

Technical University of Denmark

Background

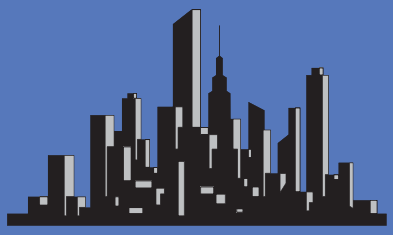
- Worldwide an increasing number of publications related to air cleaning
- An increasing sales of gas phase air cleaning products.
- There is however a need for verifying the influence on the indoor air quality and health of using air cleaning.
- Can air cleaning supplement ventilation i.e. partly substitute for the required ventilation rates?
- What is the energy impact of using air cleaning as supplement of ventilation?

Concept for calculation of design ventilation rate

People Component

Building Component



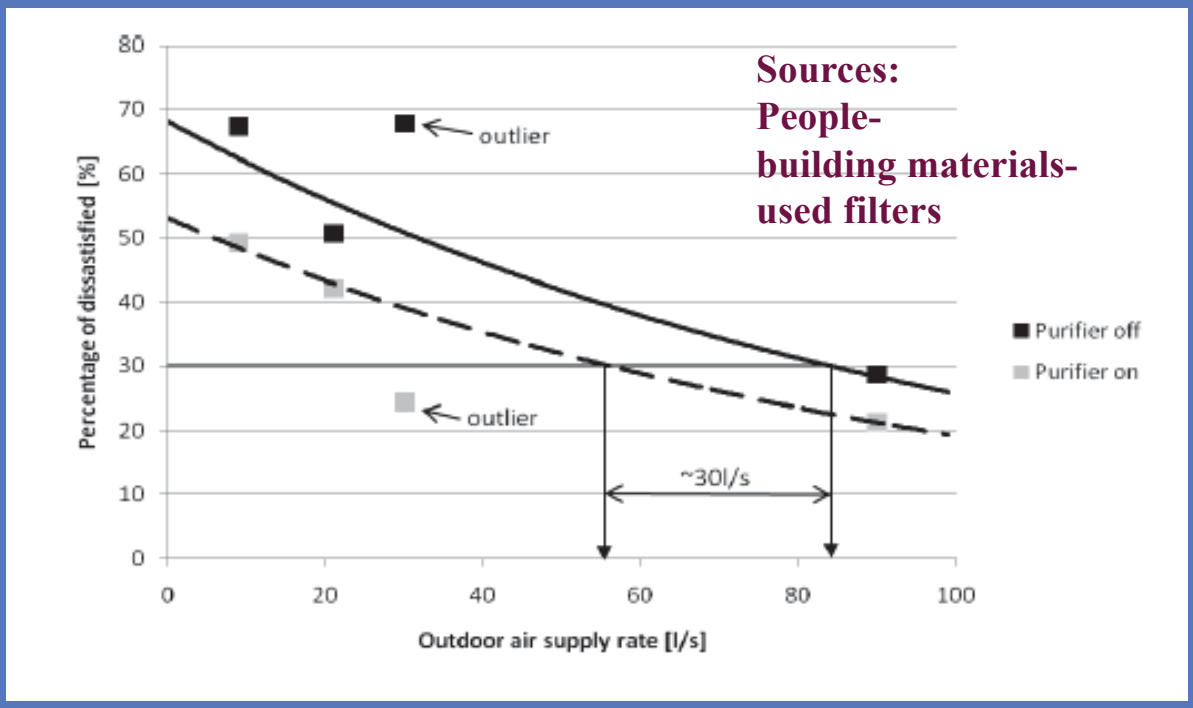


Breathing Zone Outdoor Airflow

$$V_{bz} = R_p P_z + R_s S_d + R_a A_z$$

- $R_p P_z$: Minimum l/s/Person; Number of People
- $R_s S_d$: Ventilation per Smoker; Number of Smokers
- $R_a A_z$: Building Area; Minimum l/s/m²

Effect of air cleaning on perceived Air Quality



ANNEX STRUCTURE

- Subtask A: Energy benefits using gas phase air cleaning
  - Subtask leader: Alireza Afshari, Denmark
  - Co-leader: Sasan Sadrizadeh, Sweden
- Subtask B: How to partly substitute ventilation by air cleaning
  - Subtask leader: Pawel Wargocki, Denmark
  - Co-leaders: Shin-Ichi Tanabe, Japan
- Subtask C: Selection and testing standards for air cleaners
  - Subtask leader: Paolo Tronville, Italy
  - Co-leader: Jinhan Mo, China
- Subtask D: Performance modeling and long term field validation of gas phase air cleaning technologies
  - Subtask leader: Karel Kabele, Czech
  - Co-leader: Jensen Chang, USA

Subtask A: Energy benefits using gas phase air cleaning

- A.1. Energy reduction by cleaning indoor air (recirculation, no outside air) compared to cleaning outside air in areas where the outside air is not good enough for ventilation
- A.2. Energy reduction by decreasing the amount of outside air by use of air cleaning
- A.3. Energy reduction by using air cleaning together with personalized ventilation systems. Could be work place by work place; but could also be an air cleaner serving several workplaces
- A.4.Minimum performance of air cleaners (effectiveness). Establish a metric of assessing air cleaner efficiency in relation to energy: CADR/kWh where CADR is the clean air delivery rate

Energy Use

- The baseline for energy calculations is the energy use of the recommended ventilation rate from existing standard ISO 17772 (EN16798-1)
  - Energy for pre-heating/pre-cooling outside air
  - Fan energy for transportation of air
- Energy use of the air cleaning equipment
  - Hours of operation

Subtask B: How to partly substitute ventilation by air cleaning

- B.1. Existing standards for IAQ-Ventilation
- B.2 Measure perceived IAQ for reducing people part
- B.3 Measure pollution chemical (voc, formaldehyde etc) for reducing the building part

Subtask C: Selection and testing standards for air cleaners

- C.1. Description of gas phase Air Cleaning Technologies
- C.2. Existing standards for testing gas phase air cleaning technologies
- C.3. Measurements of Perceived Air Quality (PAQ)
  - » People-bio effluents as source
  - » Individual substances (VOC, etc)
- C.4. Measure chemical concentrations
  - » Building materials i.e. VOCs as source
- C.5. Test space
  - » Test room for generation of bio effluent and for measuring PAQ
  - » Test channels for supplying and measuring individual substances

Type of Gas Phase Air cleaners

- Sorption (charcoal, desiccant)
- PCO-Photo Catalytic Oxidation
- Ozone
- UVGI-Ultraviolet
- Plasma
- Electrostatic
- ????

Subtask D: Performance modeling and longterm field validation of gas phase air cleaning technologies

- D1 Review of available models for predicting the performance of gas phase air cleaning technologies: identify knowledge gaps and trends, and select promising ones for D2
- D2 Advance existing models for selected gas phase air cleaning technologies to account for effects of realistic environmental conditions (T, RH, multi-pollutants) typical of field applications
- D3 Perform long term field experiments to validate the selected gas phase air cleaning technologies as well as the performance prediction models

Expert list

- Karel Kabele, Technical University in Prague, Czech Republic
- Alireza Afshari, Aalborg University Copenhagen , Denmark
- Chandra Sekhar, Kwok Wai Tham, David Cheong, National University Singapore, Singapore
- Sasan Sadrizadeh, KTH, Sweden
- Paolo Tronville, Politecnico Torino, Italy
- Pawel Wargocki, Lei Fang , Bjarne W. Olesen, ICIEE.DTU, Denmark
- Jingjing Pei, Tianjing University, China
- Junjie Liu Tianjing University, China
- Jinhan MO, Yinping Zhang, Tsinghua University, China
- Yin Wei, Hunan University of Science and Technology, Hunan, China
- Wei Ye, Tongji University, China
- Jianshun Zhang, Syracuse University
- Shin-ichi Tanabe, Waseda University
- Bill Bahnfleth, Penn State University, USA
- Jelle Laverge , Gent University, Belgium
- Iain Walker, Brett Singer, LBNL-Berkeley, USA
- Dean Tompkins, Air Chemistry Laboratory, USA

AVTIVITIES

- Submit Work items to ISO TC146SC6_Indoor Air Quality
  - ISO TC146 SC6 decided in October, 2019 to establish a new WG to develop a standard for measuring PAQ in relation to testing gas phase air cleaning
- Submit Work Item to ISO TC 142WG8 Testing Gas Phase Air Cleaners
  - ISO TC 142 decided in September, 2018 to start a preliminary new work item to develop a standard for testing of gas phase air cleaning technologies including using PAQ as a measure of performance
- 2018-06-07 RoomVent2018, Helsinki: Workshop
- 2018-07-25 IndoorAir2018, Philadelphia: F2F meeting
- 2018-09-20 , AIVC, France (Nice): Workshop, F2F + WEB
- 2019-05-29/30 CLIMA2019, Bucharest, Workshop, F2F+ WEB
- 2019-10-16/17 AIVC 2019, Ghent, Workshop F2F + WEB

EBC ANNEX 78
EXISTING AIR CLEANING TECHNOLOGIES

ALIREZA AFSHARI, PROFESSOR

STATENS BYGGEFORSKNINGSINSTITUT
AALBORG UNIVERSITET KØBENHAVN

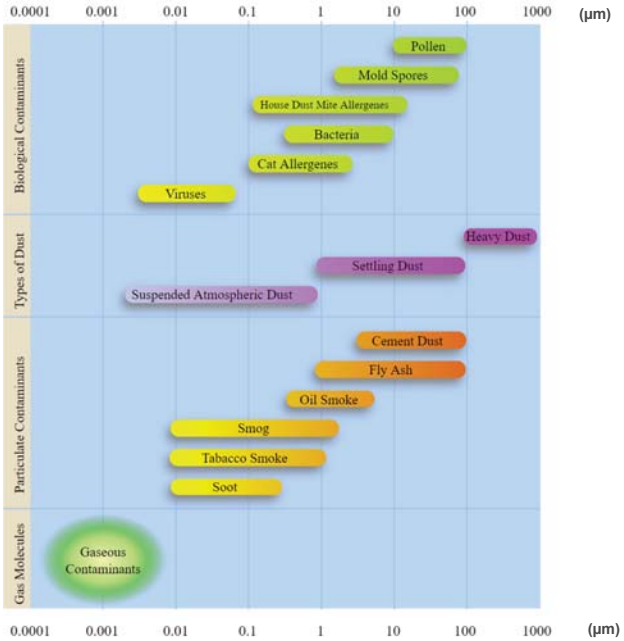
Background

The Chemical Composition of Air

The air in the atmosphere consists of five gases: nitrogen (78.084%), oxygen (20.947%), water vapor (1-5%), argon (0.934%), and carbon dioxide (0.0314%).

Several other compounds are also present: Ozone (0.000007%), Nitrogen Dioxide (0.000002%), etc.

CRC Handbook of Chemistry and Physics, edited by David R. Lide, 1997.



https://en.wikipedia.org/wiki/File:Airborne-particulate-size-chart.svg

Background

Worldwide Air Quality

Aalborg Air Quality Monitoring Stations

http://aqicn.org/here/



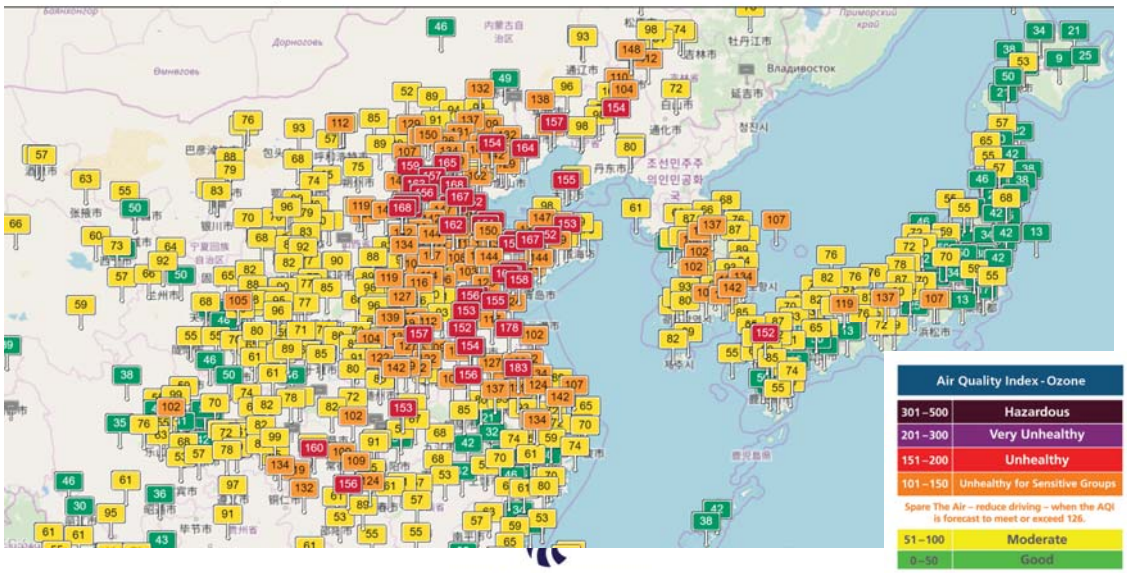
Background

Worldwide Air Quality

Aalborg Air Quality Monitoring Stations

North China Institute of Aerosp

http://aqicn.org/here/



Background

Global ranking of risk factors by total number of deaths from all causes for all ages and both sexes in 2017.

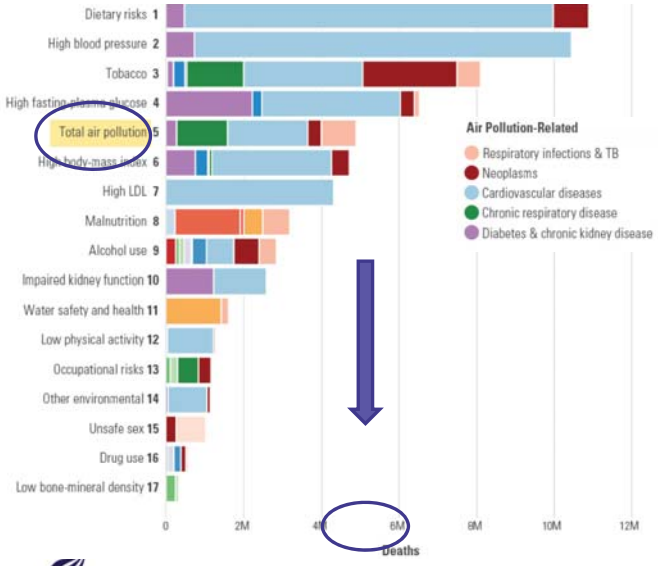
State of Global Air 2019 provides worldwide estimates of lower life expectancy that can be attributed to air pollution.

These estimates were based on a global analysis conducted by Joshua Apte of the University of Texas at Austin and his colleagues.

Air pollution ($PM_{2.5}$, ozone, and household air pollution) is **the fifth leading risk factor for mortality** worldwide.

In 2017, **air pollution** is estimated to have contributed to close to **5 million deaths globally** — nearly 1 in every 10 deaths.

https://www.healtheffects.org/announcements/state-global-air-2019-air-pollution-significant-risk-factor-worldwide



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AALBORG UNIVERSITET KØBENHAVN

Background

Table 10.1 Premature deaths attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28, 2015

		$PM_{2.5}$		NO_2		O_3	
Country	Population (1 000)	Annual mean (a)	Premature deaths (b)	Annual mean (a)	Premature deaths (b)	SOMO35 (a)	Premature deaths (b)
Austria	8 576	13.3	5 900	19.8	1 200	6 170	380
Belgium	11 237	13.0	7 400	20.9	1 500	2 790	220
Bulgaria	7 202	24.1	14 200	16.1	640	4 180	350
Croatia	4 225	17.4	4 500	17.3	430	6 240	230
Cyprus	1 173	16.9	750	14.1	30	6 390	40
Czechia	10 538	17.0	10 100	16.6	490	5 560	460
Denmark	5 660	9.7	2 800	10.5	80	2 200	90
EU-28	**506 030**	**13.9**	**391 000**	**18.9**	**76 000**	**4 250**	**16 400**
Total	**538 278**	**14.1**	**422 000**	**18.8**	**79 000**	**4 310**	**17 700**

Notes: (a) The annual mean (in µg/m³) and the SOMO35 (in µg/m³ days), expressed as population-weighted concentration, is obtained according to the methodology described by ETC/ACM (2017a) and not only from monitoring stations; (b) Total and EU-28 premature deaths are rounded to the nearest thousand (except for O_3, nearest hundred). The national totals are rounded to the nearest hundred or ten.



STATENS BYGGEFORSKNINGSINSTITUT
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Background

Impacts of air pollution on health - EU-28

Europe's most serious pollutants in terms of harm to human health, are **PM, NO2 and ground-level O3**.



Estimates of the health impacts attributable to exposure to air pollution indicate that **PM2.5** concentrations in 2015 (1) were responsible for about 422 000 premature deaths originating from long-term exposure in Europe (over 41 countries; see Table 10.1), of which around 391 000 were in the EU-28.

The estimated impacts on the population in these 41 European countries of exposure to **NO2 and O3** concentrations in 2015 were around 79 000 and 17 700 premature deaths per year, respectively, and in the EU-28 around 76 000 and 16 400 premature deaths per year, respectively.

Background

A total of **10,000 litres** of air enters the lungs every day

In many locations in the world, the outdoor **air quality is so bad** that ventilation decreases the quality of indoor air rather than it improves it.

In these cases, **the alternative to use ventilation is to substitute** it with **gas-phase air cleaning** so that the indoor air can be kept at high quality.

Even when outdoor air is of a good quality, the use of air cleaning substituting or supplementing ventilation could **reduce the rate of outside air supplied indoors** and thereby energy can be saved for its conditioning (heating/cooling) and transporting (fan energy).

Since it is expected that gas-phase air cleaning may in parallel improve the indoor air quality and reduce energy use for ventilation, it should be considered as **a very interesting technology that can be used in the future.**

Background

There is however a need for better **evaluation of the potential of gas-phase air cleaning** to improve indoor air quality and **to substitute ventilation rates**, as well as of the energy implication when it is used.

There is also a need to **develop standard test methods** of the performance of gas-phase air cleaning devices. Consequently, it is proposed to begin development of a standard for testing of gas phase air cleaning technologies.

There is an increasing of use of gas phase air cleaning products

Technologies commonly used for gaseous pollutant air cleaning

Gas phase air cleaning products:

- ✓ **Sorbents,**
- ✓ **Chemisorbents,**
- ✓ **Photocatalytic oxidation,**
- ✓ **Ozone generators,**
- ✓ **Plants**

ASHRAE Position Document on Filtration and Air Cleaning, 2015

Technologies commonly used for gaseous pollutant air cleaning

Sorbents

- Gaseous pollutants **adsorb on porous granular** media or **condense in pores** of media.
- Many types of sorbents with **activated carbon** most commonly used.

- Widely available technology
- Can **remove broad range of gaseous pollutants** with moderate to high efficiency

- Pollutants can be **released from sorbent into indoor air**
- **Low effectiveness** for low molecular weight pollutants including **formaldehyde**
- Must **periodically replace** sorbent
- Sorbent **lifetime** for indoor air applications **not well understood**
- **Large amount** of sorbent needed **for long lifetime**
- **High** sorbent **cost**
- Often high airflow resistance increasing **fan energy use**

- Installed in heating, ventilating and air conditioning systems or in stand-alone portable air cleaners

ASHRAE Position Document on Filtration and Air Cleaning, 2015

Technologies commonly used for gaseous pollutant air cleaning

Chemisorbents

- Gaseous pollutants **adsorb on** and **chemically react** with porous granular media

- Widely available technology
- Can **remove broad range of gaseous pollutants** with **moderate to high efficiency**

- **High** chemisorbent **cost**
- Often high airflow resistance increasing **fan energy use**

- Installed in heating, ventilating and air conditioning systems or in stand-alone portable air cleaners

ASHRAE Position Document on Filtration and Air Cleaning, 2015

Photocatalytic oxidation

- Gaseous pollutants **adsorb on a surface coated with a photocatalyst** that is irradiated with a light source, usually a source of ultraviolet light; some adsorbed pollutants decompose

- Can **remove a range of gaseous** pollutants
- Usually **lower airflow resistance** than sorbents and chemisorbents, thus, **lower fan energy use**
- Can destroy some bioaerosols

- Many systems have **low pollutant removal efficiency**
- Lamp **energy use**
- **Cost** of periodically replacing lamps
- Photocatalysts become inactive, with unknown photocatalyst life
- Incomplete breakdown of some pollutants can result in **formation of new pollutants potentially harmful to health**

- Installed in heating, ventilating and air conditioning systems or in stand-alone portable air cleaners

ASHRAE Position Document on Filtration and Air Cleaning, 2015

Ozone generators

- Ozone **generated** and released into indoor air can react with and **breakdown some airborne volatile organic compounds**

- Quiet and **energy efficient**

- Releases **ozone into indoor air** and **ozone is a harmful pollutant**
- Generally **ineffective** in **significantly reducing** airborne volatile organic compounds unless ozone concentrations are very high
- Reactions of ozone with airborne volatile organic compounds can lead to production of **formaldehyde** and **ultrafine particles** that pose health risks

- Usual application is a standalone portable air cleaner

ASHRAE Position Document on Filtration and Air Cleaning, 2015

Technologies commonly used for gaseous pollutant air cleaning

Plasma air cleaners

- Radicals (small reactive molecules) created by electric discharge can oxidize and decompose volatile organic compounds and nitrogen oxides

- **Quiet and energy efficient**
- May **improve particle removal performance** of some particle air cleaners

- Very limited data available on pollutant removal performance in buildings
- **Can produce ozone**, see comments on ozone air cleaners

- Usual application is a standalone portable air cleaner

ASHRAE Position Document on Filtration and Air Cleaning, 2015

Combined filters

An air cleaning technology for indoor air has to be able to:

- ✓ remove a wide variety of pollutants at relatively low concentrations
- ✓ perform effectively at room temperature and humidity,
- ✓ be noiseless and affordable,
- ✓ generate no waste,
- ✓ use little energy

Plants

- Plants in buildings can **remove some** volatile organic compounds
- Quiet and **energy efficient**
- **Not** proven to **significantly reduce** indoor pollutant levels with practical number of plants
- Plants and molds on plants and soil can be a **source of pollutants**
- Plants placed throughout building or in attached greenhouse
- One system forces air through plant root zone.

ASHRAE Position Document on Filtration and Air Cleaning, 2015

Combined filters

There are several combined filter systems:

- ✓ Plasma-catalytic hybrid system
- ✓ Biological process + photocatalytic oxidation hybrid system
- ✓ Biological process + adsorption hybrid system
- ✓ Adsorption + photocatalysis hybrid system
- ✓ Hybrid ozonation systems
- ✓ Etc.

PhD project, Aalborg University Copenhagen

- ✓ A new filter material that is able to remove both particles and gaseous pollutants

Combined filters

PhD project, Aalborg University Copenhagen

A new filter material that is able to remove **both particles and gaseous pollutants**

The filter is designed to be **part of an air supply for residential** buildings, with the aim to improve the indoor air quality. A crucial requirement of the filter is to introduce a **low pressure drop**, so to be installed in **natural ventilated buildings**.

The filter consists in an **electrospun nanofiber filter**.
The first experimental study in Aalborg University Nanotechnology Department consists in electrospun several materials, analysing the fiber morphology and characteristics of different nanofibers.

The study is focusing on two polymers, **polyvinyl alcohol** (PVA) and **polyurethane** (PU), and the use of different additives that promote certain chemical characteristics to the nanofibers.



Figure 1: Manual electrospinning set up



Figure 2: Electrospinner

THANK YOU FOR YOUR ATTENTION!

ANY QUESTIONS?



AIVC 2019
October 15-16 2019 - Ghent - Belgium

Het Pand, 16th October 2019
Session 8C - Topical Session (EBC Annex 78 - Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications), 13:45-14:45

"Existing standards for testing gas phase air cleaners"

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POLITECNICO DI TORINO
Department of Energy "Galileo Ferraris"

AEROSOL TECHNOLOGY LAB

Gas-phase air cleaning performance metrics

Why are we interested in a test method for such equipment?

1. Removal efficiency of gaseous pollutants (if supplementing ventilation, typically VOCs) (1 minus the ratio of downstream to upstream VOC concentration)
2. Service life of device/media: time elapsed between installation and replacement/maintenance
3. Airflow resistance through the gas-phase air cleaning system (linked to fan energy use and/or airflow reduction)
4. Total cost of gas-phase air cleaning per unit delivery of VOC-free air (no standard available for this)

Standards for building applications

- ISO 10121-2:2013 "Test methods for assessing the performance of gas-phase air cleaning media and devices for general ventilation - Part 2: Gas-phase air cleaning devices (GPACD)"
- ISO 10121-1:2014 "Test method for assessing the performance of gas-phase air cleaning media and devices for general ventilation - Part 1: Gas-phase air cleaning media"
- ANSI/ASHRAE Standard 145.2-2016 "Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems: Air-Cleaning Devices" (first edition in 2011)
- ANSI/ASHRAE Standard 145.1-2015 "Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems: Loose Granular Media" (first edition in 2008)

Some more standards …

- JIS B 9901:1997 "Gas-removal – Method of test for performance of gas-removal filters"
- JIS K 1474:2014 "Test Methods For Activated Carbon"
- ASTM D6646 - 03(2014) "Standard Test Method for Determination of the Accelerated Hydrogen Sulfide Breakthrough Capacity of Granular and Pelletized Activated Carbon"
- … many more ASTM standards
- ISO 11155-2:2009 "Road vehicles - Air filters for passenger compartments - Part 2: Test for gaseous filtration" (first publication in 2002)

Particulate vs. gas removal equipment assessment

- Particulate
  - Pressure drop gradually increases
  - Filter efficiency increases
  - Filter is visibly working
  - Standards and test procedures to rate filters well established and being improved (still not so close to applications for ageing)
- Gas
  - Pressure drop remains the same
  - Filter efficiency decreases
  - Filter is not visibly working
  - Standards and test procedures to rate filters still being developed

Figure taken from ASHRAE Standard 145.2

Figure missing because of copyright

Layout similar to particle filter test rig (with more safety prescriptions)

Performance vs. Features

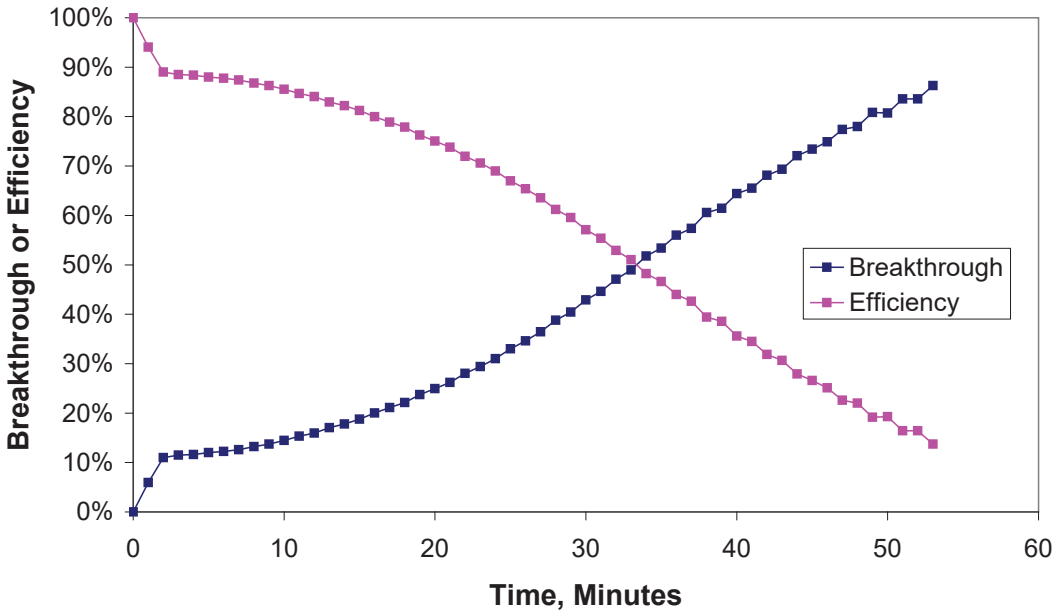
Features

- Amount of sorbent media
- Residence time (airflow rate)

Performance

- Dynamic breakthrough or efficiency
- Capacity
- Life

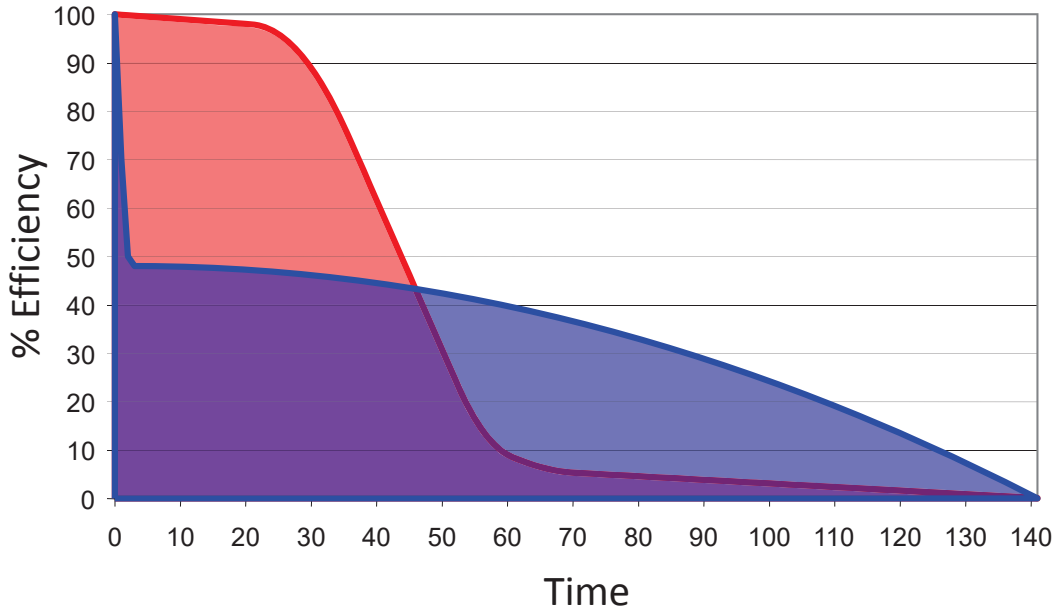
Dynamic breakthrough/Efficiency curve



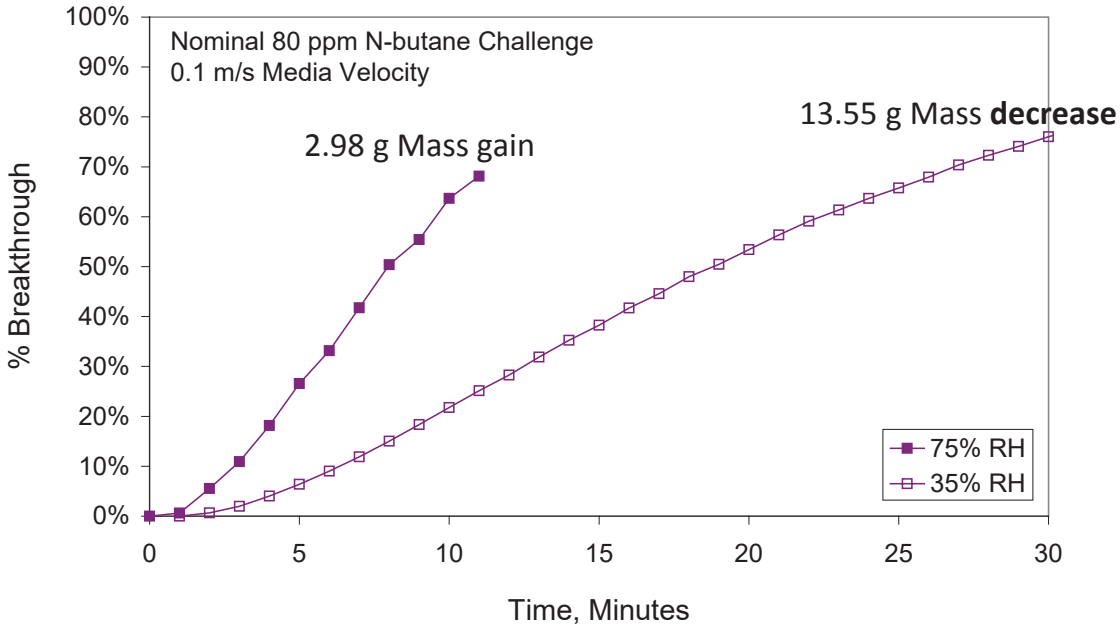
Performance - Capacity

- Method?
  - Calculation
  - Efficiency/Breakthrough Level
  - Equilibrium mass gain
  - Controlled conditions
- What challenge concentration?

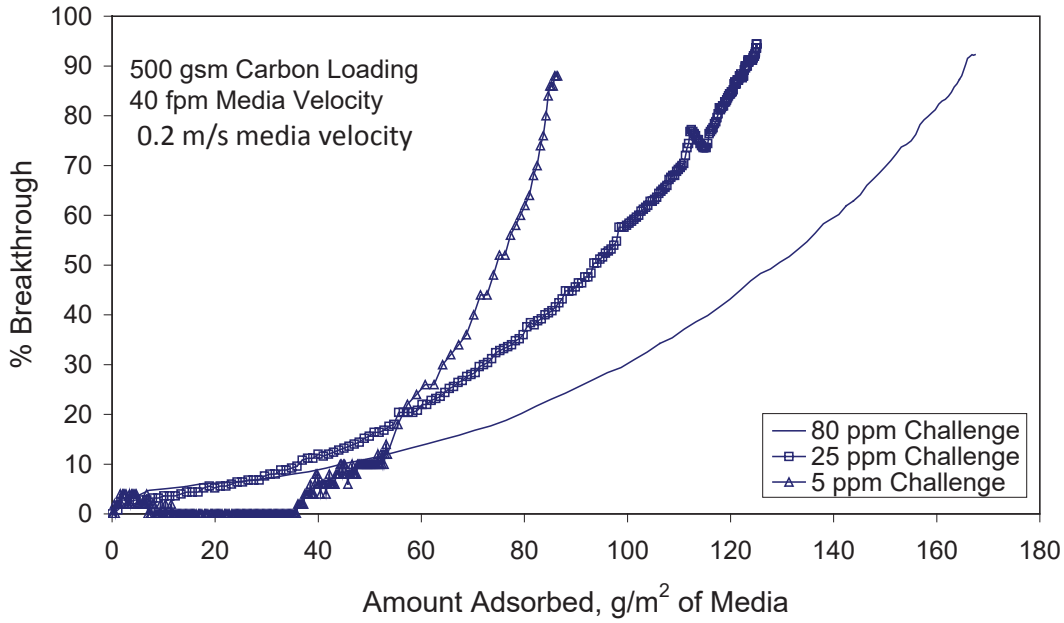
Capacity vs. Efficiency



Butane breakthrough vs. relative humidity



Effect of concentration on VOC adsorption



Performance - Life

- End point?
  - Minimum efficiency (vs. 100% Breakthrough)
  - Maximum concentration
  - Pressure drop (ensure proper pre-filtration)
- What concentration?
  - Level
  - Pattern
- Comparisons vs. absolute

Traditional and emerging gas-phase electronic filtration technologies

- Traditional gas-phase removal equipment based on adsorption process, e.g. activated carbon or permanganate alumina pellets
- Adsorption technologies have long been used in wide ranges of applications, so the performances and the efficiencies under various conditions are well understood
- Some current standards have limitations in their scope which make them not suitable for emerging gas-phase electronic filtration technologies

Emerging gas-phase electronic filtration technologies

- Newer technologies are used in electronic air cleaners such as UV, UV with photocatalysts (UV-PCO), plasmas, plasma with catalysts, ozone generators, etc.
- These may generate oxidizing agents like radicals and ozone that remove the gases and vapors through the oxidation process; upon complete oxidation, VOCs can be converted into carbon dioxide and water
- They can generate intermediates such as carbon monoxide, formaldehyde, acetaldehyde, and acetic acid in cases of incomplete oxidation as well as generating pollutants like ozone and nitrogen oxides inherently depending on the system

Work in progress

- ISO/AWI 10121-3 "Test method for assessing the performance of gas-phase air cleaning media and devices for general ventilation - Part 3: Classification system for treatment of make up air"
- Need for a classification system to specify gas-phase cleaning equipment in ventilation standards (e.g. EN 16798-3, ASHRAE 62.1, etc.)

- Perceived air quality approach should be discussed in a specific task group of ISO/TC142/WG8

Conclusions

- A few standards already exist on the market
- Not widely used and not yet evaluated rigorously by interlaboratory comparisons
- Data obtained from standards require expert advice on how to use them
- In situ performance must be simulated to avoid testing for months
- Classification system and PAQ approach being developed by ISO/TC142
- New technologies likely to need some more specific measurements to be safely implemented

Thanks for your attention!

Methods to evaluate gas phase air-cleaning technologies

Pawel Wargocki

International Centre for Indoor Environment and Energy
Department of Civil Engineering
Technical University of Denmark



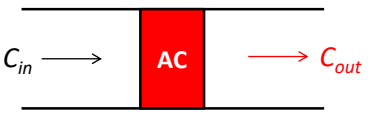
Content

- Measurements of air cleaner performance
- Chemical measurements
- Sensory measurements

Performance of air cleaning devices

- Single-pass efficiency (η)
- Clean air delivery rate (CADR)
- Effectiveness (ε)

Single-pass efficiency (η)

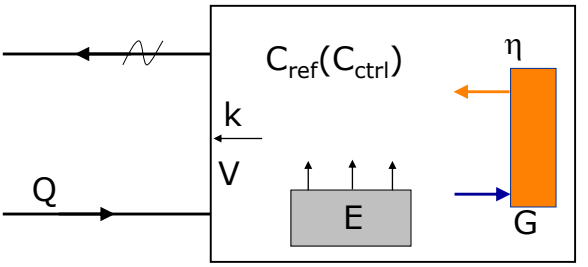


$$\eta = \frac{C_{in} - C_{out}}{C_{in}} \cdot 100\ [\%]$$

- Fraction of pollutants removed as it passes through the device (C_{in}=concentration at the inlet; C_{out}=concentration at the outlet)
- Maximum conversion is 100% indicating that contaminant(s) have been removed completely.

Clean air delivery rate (CADR)

$CADR = \eta \cdot G$ [m³/h or cfm] or $CADR = \frac{\eta \cdot G}{V}$ $[h^{-1}]$

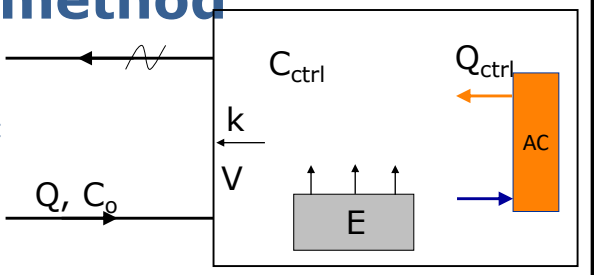


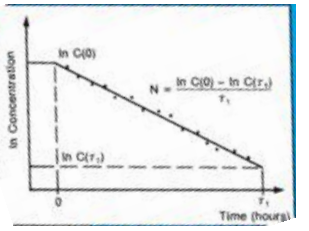
Testing air cleaners

- Pull-down chamber test method
- Constant-source test

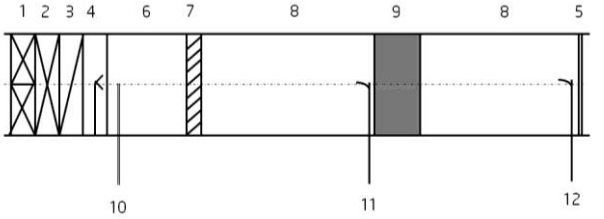
Pull-down chamber-test method

- Contaminant is generated in a well-mixed sealed test chamber until steady-state is reached at which the generation is stopped.
- The air cleaner is then turned on and the concentration decay is monitored.
- The rate of decay can be used to estimate **CADR** using mass balance equation adjusting for removal rate without air cleaner in operation (removal rate by surfaces and leakages)
- Most common





Constant-source test



- Contaminant is generated at a constant rate during testing in the test duct rig and the concentration of contaminant is measured sequentially upstream and downstream of the air cleaner. Based on the measurements the efficiency of the air cleaner (**single-pass efficiency**) can be estimated
- Method used for in-duct air cleaning devices; recommended by ANSI/ASHRAE Standard 52.2-1999 "Method of testing general ventilation air cleaning devices for removal efficiency by particle size"

Potential problems related to air cleaning devices

- Challenge pollutants
- Poisoning
- By-products, intermediates
  no intermediates which are known/suspected carcinogens (e.g. formaldehyde, benzene) should be accepted
- Maintenance

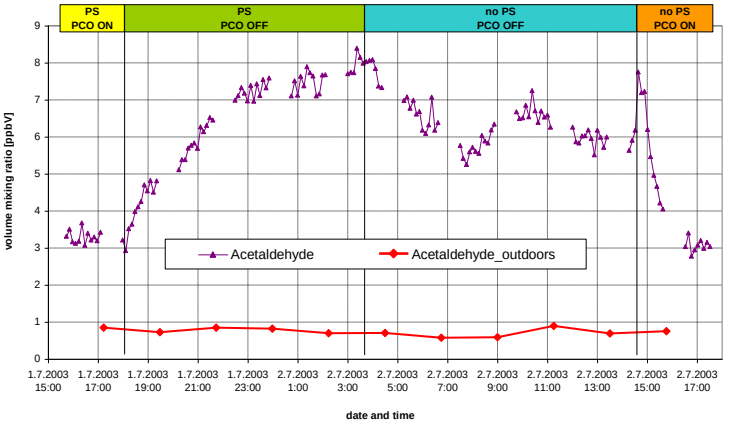
Chemical measurements







PTR-MS: results -1



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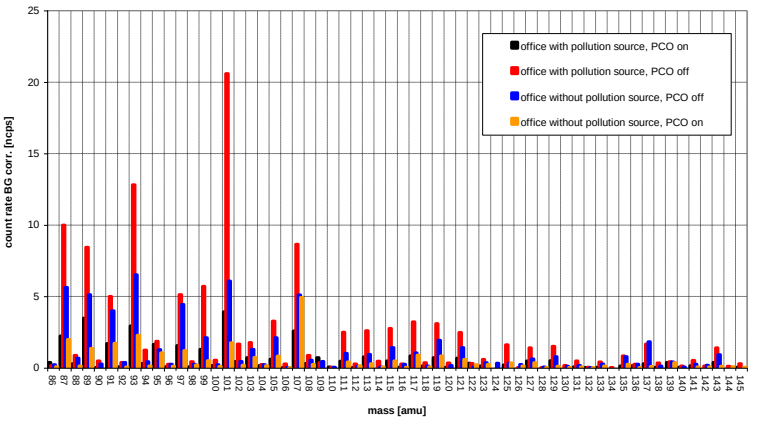
PTR-MS: results -2



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Sensory measurements



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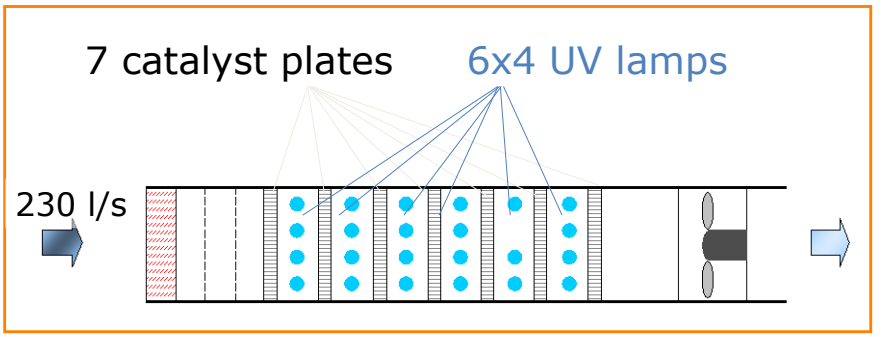
Air Purifier



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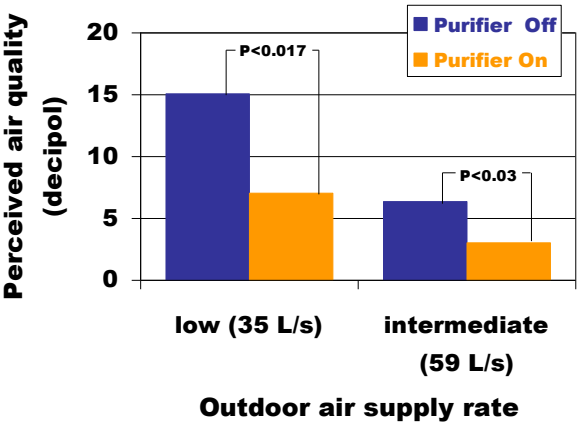
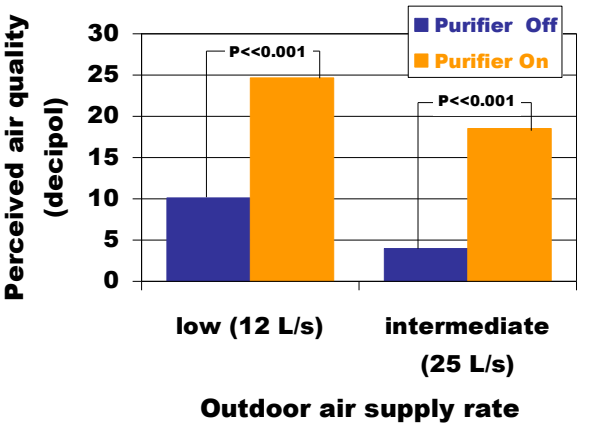
Results: Bldg mat, PCs, filters



Results: Human bioeffluents



Main human bioeffluents

- Methanol (2.5 mg/h per person)
- Ethanol (2.4 mg/h per person)
- Amyl alcohol (0.9 mg/h per person)
- Propylalcohol (0.5 mg/h per person)
- Other alcohols (0.01-0.1 mg/h per person)

- Concentration of alcohols (up to 0.4 mg/m^3) >> than in previous study when isopropylacohol was present at concentration of 0.001 mg/m^3

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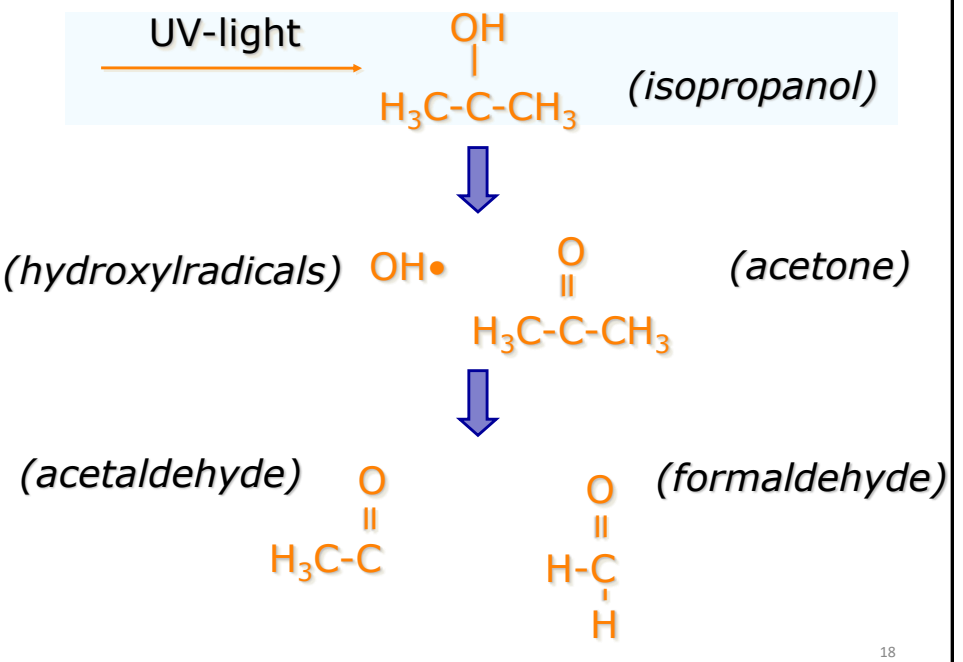

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Conclusion

- Sensory measurements should supplement chemical measurements when testing gas-phase air cleaners
- Challenge pollutant (sources of pollution) by which performance of air cleaners is examined must be defined

Questions……





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AIVC 2019

Session 9A (IEQ-metrics and evaluation) October 16th, 2019

Development of Subjective Evaluation Tool of Work Environment for Office Workers' Work Performance and Health Promotion

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Toshiharu Ikaga
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Yoshihisa Fujino
University of Occupational and Environmental Health, Japan

The University of Kitakyushu Shiraishi Laboratory

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1

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1. Research background and aim
2. Overview of related tools in CASBEE-Office
   - Overview of CASBEE-WO
   - Overview of CASBEE-OHC
3. Overview of WEB questionnaire
4. Result of analysis
   - Simple Tabulation
   - Multiple regression analysis
   - Logistic regression analysis
5. Conclusions

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1.1 Research background and aim

Improving the social environment

- ■Residence
- ■Working environment
- ■regional environment

The effort of health promotion has attracted attention.

A place to spend a lot of time for the office worker

The working environment and the way of working has the possibility to influence **intellectual productivity**, not only the **health** of the office worker.

1.1 Research background and aim

Improving the social environment

- Residence
- Working environment
- regional environment

The effort of health promotion has attracted attention.

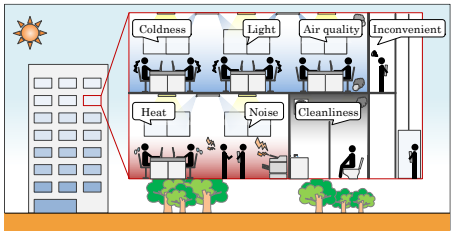
A place to spend a lot of time for the office worker

However,
what kind of **environmental improvement** should be done has not been specifically clarified.

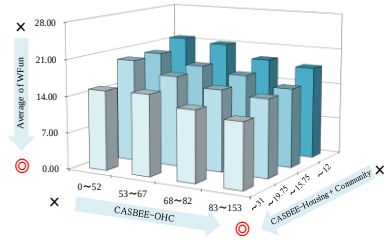
1.1 Research background and aim

In this research…

We developed **CASBEE-OHC** (**CASBEE-O**ffice **H**ealth **C**hecklist)
which is an "**subjective**" evaluation tool of the work environment.



Overview of checklist



Result of analysis

We developed **CASBEE-OHC**
and verified the effectiveness of the tool.

2. Overview of related tools in CASBEE-Office

1. Research background and aim
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2-1. Overview of CASBEE-WO

"objective" evaluation tool of the work environment:
CASBEE-WO（CASBEE-Wellness Office）

» CASBEE-OHC was developed based on this.

Environmental performance
for workers working in buildings
to work healthy and productively

← assess — architectural experts

Unlike the conventional CASBEE and related instruments,
the scope of CASBEE-WO is **the interior layout** and **furniture present**,
and **the efforts of the tenants**.

2-1. Overview of CASBEE-WO

Major items	Second items	Third items
Ⅰ. Basic performance of the building	(1) Health and comfort	①Space, interior
		②Sound, noise
		③Lighting
		④Air and air conditioning
		⑤Refresh
		⑥Exercise
	(2) Convenience improvement	①Mobile space and communication
		②Telecommunications
	(3) Ensuring safety	①Disaster
		②Harmful substance
		③Water safety
		④Security
		①Maintenance plan

All evaluation items are scored according to a 5-level scale (level 1 to level 5), as is done in CASBEE-New Construction.

2-2. Overview of CASBEE-OHC

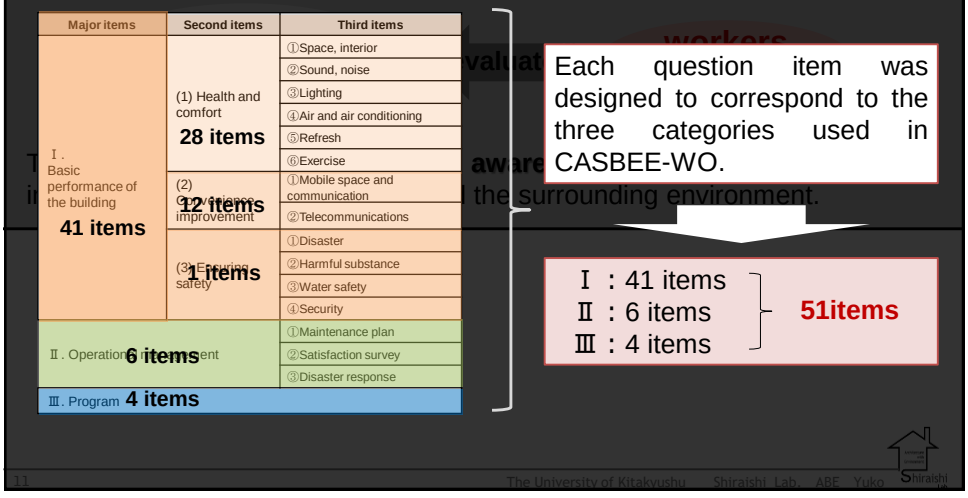
"subjective" evaluation tool of the work environment:
CASBEE-OHC（**CASBEE-O**ffice **H**ealth **C**hecklist）

job satisfaction and health ← **evaluate** — **workers themselves**

This tool evaluates the **behavior** and **awareness** influenced by physical conditions and the surrounding environment.

2-2. Overview of CASBEE-OHC

"subjective" evaluation tool of the work environment:
CASBEE-OHC（CASBEE-Office Health Checklist）



2-2. Overview of CASBEE-OHC

CASBEE-OHC (**CASBEE-Office Health Checklist**)

All 51 items were classified into **three question categories** and were further grouped according to the general categories of "**Achievement of optimal factors**" and "**Removal of dysfunctional factors**".

Achievement of optimal factors		Removal of dysfunctional factors	
Q1-1	There is planting that can feel green	Q1-10	Feeling that work space and storage place are narrow
Q1-2	There is desk corresponding to standing work	Q1-11	Feeling discomfort due to heat or cold
Q1-3	There is a chair suitable for both work and rest	Q1-12	Making the air-conditioning air flow uncomfortable
Q1-4	You can enjoy the outside view from inside the office	Q1-13	Remembering the dryness and moisture of the air
Q1-5	You can feel a sense of freedom of space	Q1-14	Feeling the air stagnation, dustiness, unpleasant smell
Q1-6	Openable windows open to the outside are well introduced	Q1-15	Feeling uneven brightness
Q1-7	It has become a comfortable interior	Q1-16	Feeling that the work space is dark
Q1-8	You can freely choose the desk that suits your daily work style	Q1-17	Feeling that sunshine and lighting equipment are dazzling
Q1-9	During the daytime, you can feel the light from the outside	Q1-18	Feeling that sunshine and lighting equipment are dazzling
		Q1-19	Anxious about other people's conversation and equipment machine noise

2-2. Overview of CASBEE-OHC

CASBEE-OHC (CASBEE-Office Health Checklist)

Q1 Regarding the environment and equipment of your work space in the office

Achievement of optimal factors	
Q1-1	There is planting that can feel green
Q1-2	There is desk corresponding to standing work
Q1-3	There is a chair suitable for both work and rest
Q1-4	You can enjoy the outside view from inside the office
Q1-5	You can feel a sense of freedom of space
Q1-6	Openable windows open to the outside are well introduced
Q1-7	It has become a comfortable interior
Q1-8	You can freely choose the desk that suits your daily work style
Q1-9	During the daytime, you can feel the light from the outside

Removal of dysfunctional factors	
Q1-10	Feeling that work space and storage place are narrow
Q1-11	Feeling discomfort due to heat or cold
Q1-12	Making the air-conditioning air flow uncomfortable
Q1-13	Remembering the dryness and moisture of the air
Q1-14	Feeling the air stagnation, dustiness, unpleasant smell
Q1-15	Feeling uneven brightness
Q1-16	Feeling that the work space is dark
Q1-17	Feeling that sunshine and lighting equipment are dazzling
Q1-18	Feeling that sunshine and lighting equipment are dazzling
Q1-19	Anxious about other people's conversation and equipment machine noise

2-2. Overview of CASBEE-OHC

CASBEE-OHC (CASBEE-Office Health Checklist)

Q2 Regarding the environment and equipment of the entire office or building

Achievement of optimal factors	
Q2-1	There is an easy-to-use refresh space
Q2-2	There are easy-to-use meals and cafes
Q2-3	There is an easy-to-use mini kitchen etc.
Q2-4	You can choose meeting space depending on the situation
Q2-5	There is a staircase located in a convenient location
Q2-6	There is a space to take an easy-to-use nap
Q2-7	There is an easy-to-use internal information sharing infrastructure
Q2-8	There is a space promoting easy-to-use conversations
Q2-9	There is an entrance hall where you can easily meet and talk
Q2-10	Becoming it goes ahead through the barrier-free in a building
Q2-11	Facilities to promote daily exercise are abundant
Q2-12	There is a comfortable toilet that is fully equipped
Q2-13	There is a safe and comfortable elevator

Removal of dysfunctional factors	
Q2-14	Having a bad taste or smell in tap water
Q2-15	Waiting in the bathroom
Q2-16	Waiting for the elevator
Q2-17	Dissatisfaction with outlet capacity, wiring etc.
Q2-18	Feeling stress on the communication network
Q2-19	Feeling that meeting space is not enough

2-2. Overview of CASBEE-OHC

CASBEE-OHC (**CASBEE-O**ffice **H**ealth **C**hecklist)

Q3 Regarding activities and affiliated organizations in the building

Achievement of optimal factors	
Q3-1	Questionnaires are conducted to improve the office or building environment
Q3-2	Sufficient efforts are being made to maintain and improve mental health
Q3-3	Efforts are being made for smoke separation and smoking cessation
Q3-4	A well-developed health promotion program is being implemented
Q3-5	There are many postings to promote the use of stairs
Q3-6	There is a comfortable green space around the building
Q3-7	The scenery is in harmony with the city and surrounding buildings
Q3-8	Evacuation drills are conducted regularly
Q3-9	Emergency response manual has been prepared and is well known

Removal of dysfunctional factors	
Q3-10	Feeling uneasy on crime prevention
Q3-11	Feeling uneasy at the time of disaster or emergency
Q3-12	Feeling unsanitary throughout the building
Q3-13	Dissatisfaction with management of building, administration method

The classification of “Achievement of optimal factors” and “Removal of dysfunctional factors are omitted when conducting the actual survey.

3. Overview of WEB questionnaire

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3. Overview of WEB questionnaire

Implementation period	Implementation method
2018.07.31-08.02	WEB questionnaire
Target	
① Working in the Kanto district of Japan	
② Working for a company with more than 50 employees	
③ Doing office work	
Number of total	**Number of valid responses**
3,730 s	3,552 s
Outline of question	
① CASBEE-OHC（51questions）	
② CASBEE-Housing（6questions）	assesses the health effects on the resident associated with the house or community
③ CASBEE-Community（8questions）	
④ WFun（7questions）	measure the degree of dysfunction in labor
⑤ Work efficiency	self-evaluation of routine work performance.
⑥ Sleep, Occupation, Position, Age, Gender, Annual income etc.	

3. Overview of WEB questionnaire

➢Overview of questionnaire analysis

①Simple Tabulation

Check score distribution, Correlation analysis etc…

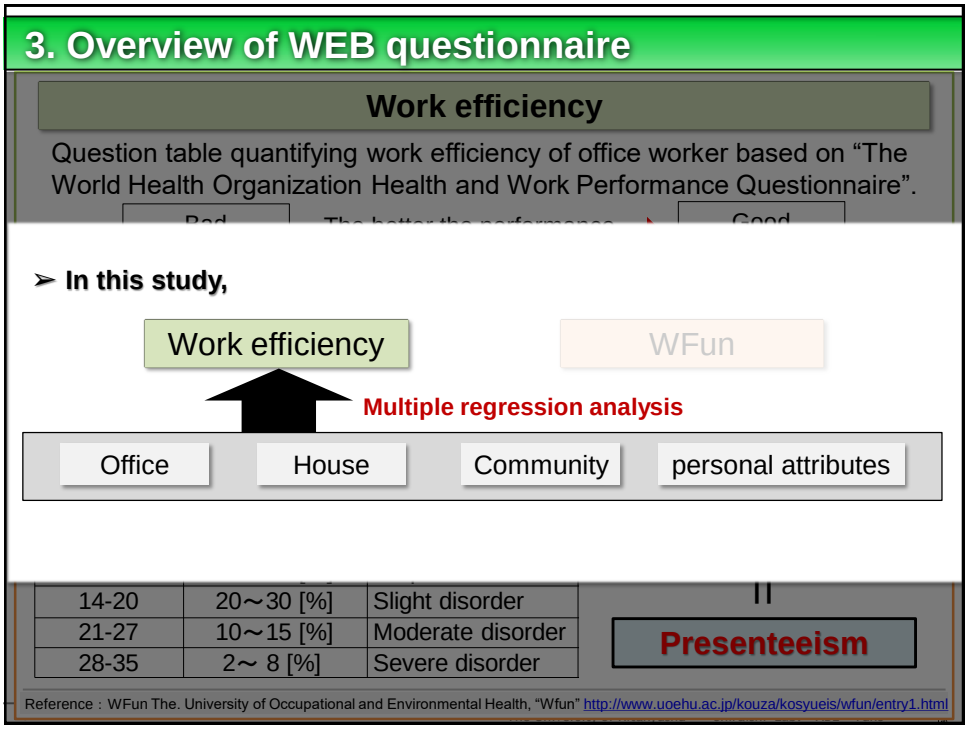
Confirm the effectiveness of CASBEE-OHC and its relation to health

② Regression analysis (Multiple regression analysis, Logistic regression analysis)

・Multiple regression analysis（Work efficiency）
・Logistic regression analysis（WFun）

Confirm the relationship between the surrounding environment and health (Considering confounding factors)

Confirmation of the effectiveness of CASBEE-OHC and its relationship with health status and intellectual productivity


3. Overview of WEB questionnaire
Work efficiency
Question table quantifying work efficiency of office worker based on “The World Health Organization Health and Work Performance Questionnaire”.
Bad
The better the performance
Good
➢ In this study,
Work efficiency
WFun
Multiple regression analysis
Office
House
Community
personal attributes
14-20
20～30 [%]
Slight disorder
21-27
10～15 [%]
Moderate disorder
28-35
2～ 8 [%]
Severe disorder
=
Presenteeism
Reference：WFun The. University of Occupational and Environmental Health, “Wfun” http://www.uoehu.ac.jp/kouza/kosyueis/wfun/entry1.html

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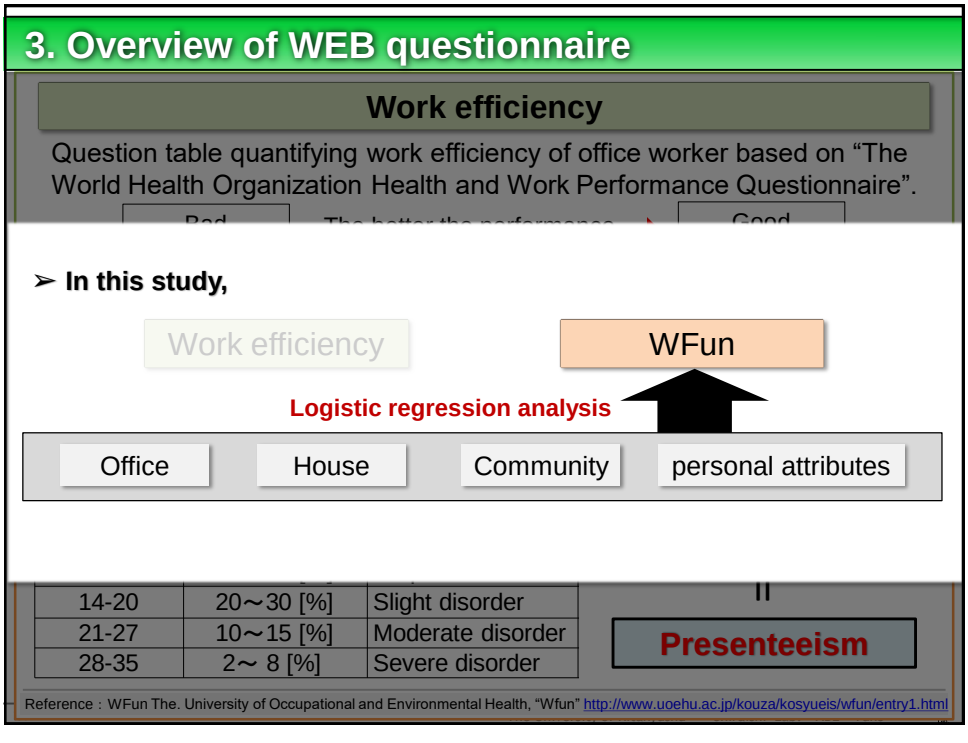
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Severe disorder
=
Presenteeism
Reference：WFun The. University of Occupational and Environmental Health, “Wfun” http://www.uoehu.ac.jp/kouza/kosyueis/wfun/entry1.html

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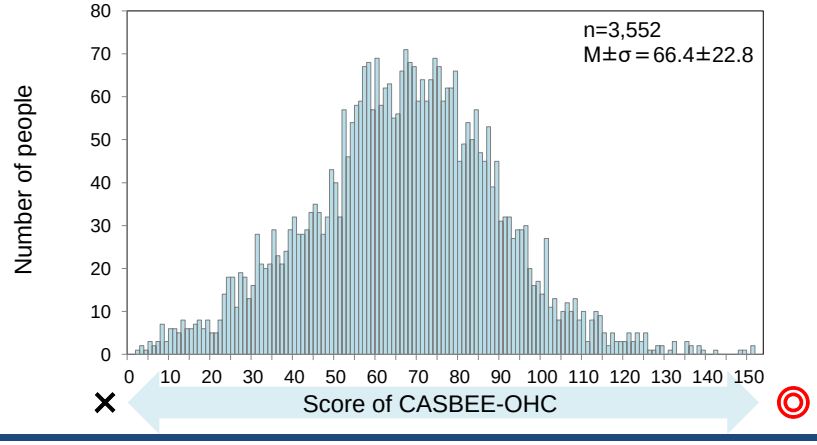
4. Result of analysis

1. Research background and aim
2. Overview of related tools in CASBEE-Office
   - Overview of CASBEE-WO
   - Overview of CASBEE-OHC
3. Overview of WEB questionnaire
4. Result of analysis
   - Simple Tabulation
   - Multiple regression analysis
   - Logistic regression analysis
5. Conclusions

4-1. Simple tabulation

Score distribution of CASBEE-OHC



The score of CASBEE-OHC distribution is generally normal.

4-1. Simple tabulation

Correlation analysis

* : p < 0.05, ** : p < 0.01

	WFun	Pittsburgh	Work efficiency
CASBEE-OHC	-.281**	-.211**	.346**
CASBEE-Housing	-.304**	-.240**	.160**
CASBEE-Community	-.224**	-.181**	.237**

Negative correlation

eneral environments:**up**
WFun・Pittsburgh:**down**

Positive correlation

general environments:**up**
Work efficiency:**up**

The degree of labor dysfunction and sleep disorders will decrease and work efficiency will increase.

4-1. Simple tabulation

Correlation analysis (Each the evaluation items of CASBEE-WO)

Major items	Second items	Third items	WFun
Ⅰ. Basic performance of the building	(1) Health and comfort	①Space, interior	0.201**
		②Sound, noise	0.227**
		③Lighting	0.212**
		④Air and air conditioning	**0.255****
		⑤Refresh	0.203**
		⑥Exercise	0.150**
	(2) Convenience improvement	①Mobile space and communication	0.217**
		②Telecommunications	0.249**
	(3) Ensuring safety	①Disaster	0.250**
		②Harmful substance	0.210**
		③Water safety	0.122**
		④Security	0.193**
Ⅱ. Operational management		①Maintenance plan	0.254**
		②Satisfaction survey	0.076**
		③Disaster response	0.109**
Ⅲ. Program			0.140**

A strong relationship between air quality and dysfunction in labor.

4-1. Simple tabulation

Correlation analysis (Each the evaluation items of CASBEE-WO)

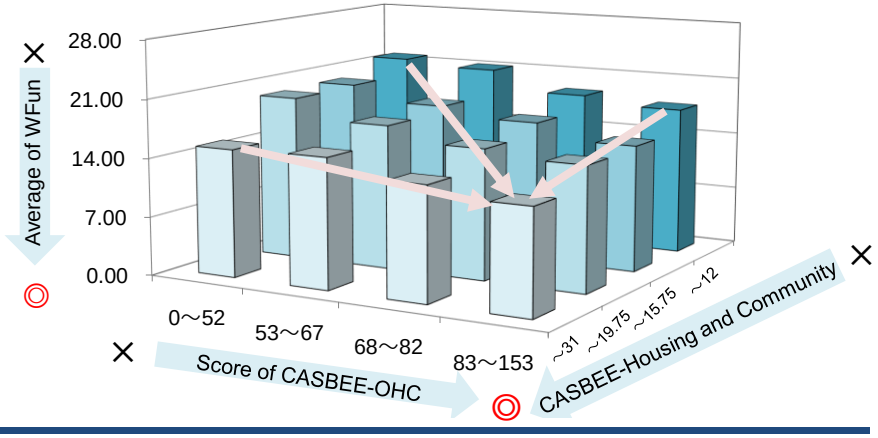
Major items	Second items	Third items
Ⅰ. Basic performance of the building	(1) Health and comfort	①Space, interior
		②Sound, noise
		③Lighting
		④Air and air conditioning
		⑤Refresh
		⑥Exercise
	(2) Convenience improvement	①Mobile space and communication
		②Telecommunications
	(3) Ensuring safety	①Disaster
		②Harmful substance
		③Water safety
		④Security
Ⅱ. Operational management		①Maintenance plan
		②Satisfaction survey
		③Disaster response
Ⅲ. Program		

		WFun
Q1-11	Feeling discomfort due to heat or cold	-.196**
Q1-12	Making the air-conditioning air flow uncomfortable	-.206**
Q1-13	Remembering the dryness and moisture of the air	-.209**
Q1-14	**Feeling the air stagnation, dustiness, unpleasant smell**	**-.224****

In assessing air conditioning and air quality fields,
the influence of air quality is greatest.

4-1. Simple tabulation

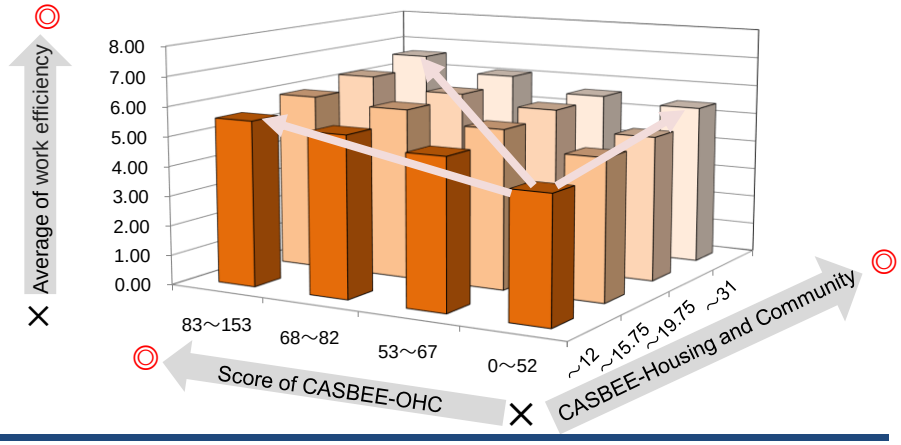
The relationship between the general environments and WFun



As the score of the environment-related index increases,
WFun scores decrease.

4-1. Simple tabulation

The relationship between the general environments and work efficiency



As the score of the environment-related index increases,
Work efficiency scores increases.

4-2. Multiple regression analysis

■Multiple regression analysis
(Objective variable：Work efficiency)

4-2. Multiple regression analysis

Correlation analysis result -work efficiency-

➢ **About general environments**

	CASBEE-OHC	CASBEE-Housing	CASBEE-Community
Work efficiency	**.346****	**.160****	**.237****

➢ **About personal attributes**

	Pittsburgh	Gender	Age	Position	Number of employees	Annual income	Married or not
Work efficiency	**-.200****	-.071**	0.014	**.131****	.073**	**.155****	-.093**

Variables with a correlation coefficient of 0.1 or more were input as explanatory variables

Objective variable : Work efficiency
Explanatory variable : Pittsburgh, Position, Annual income, CASBEE-OHC, CASBEE-Housing, CASBEE-Community

4-2. Multiple regression analysis

➢ Result of multiple regression analysis

Objective variable	**Work efficiency**	Standard partial regression coefficient	Significance probability
Explanatory variable	CASBEE-OHC	0.315	< 0.001
	CASBEE-Community	0.128	< 0.001
	Pittsburgh	-0.110	< 0.001
	Annual income	0.057	0.007
	Position	0.043	0.039
	Constant		< 0.001
Conformity degree of the model	Adjusted R^2 value	0.194	
	ANOVA	p < 0.001	

The working environment have a big influence on Work efficiency.

4-3. Logistic regression analysis

■ Logistic regression analysis
(Objective variable：WFun score)

4-3. Logistic regression analysis

➢ **Input variables in logistic regression analysis**

Objective variable: WFun score				
Model-1	[0] No disorder		[1] Have a disorder	
Model-2	[0] No disorder or have a slight disorder		[1] Have moderate or severe disorder	
Model-3	[0] No disorder or have slight or moderate disorder		[1] Have a severe disorder	
Explanatory variable				
General environments	CASBEE-OHC	[1] Top 30% of respondents	[2] 40% of respondents	[3] Lower 30% of respondents
	CASBEE-Housing	[1] Top 30% of respondents	[2] 40% of respondents	[3] Lower 30% of respondents
	CASBEE	[1] Top 30% of respondents	[2] 40% of respondents	[3] Lower 30% of respondents
Personal attributes	Pit			disorder
	G			
	P			manager class
	Number of employees	[1] Less than 100	[2] Less than 1000	[3] Less than 2000
		[4] Less than 3000	[5] Less than 5000	[6] More than 5000
	Annual oncome	[1] Less than 5 million	[2] Less than 10 million	[3] Less than 15 million
		[4] Less than 20million	[5] More than 20 million	
	Marital status	[1] Married	[2] Unmarried	

Interpretations of WFun

WFun Score	Reference ratio	Degree of disability
7-13	50～60 [%]	No problem
14-20	20～30 [%]	Slight disorder
21-27	10～15 [%]	Moderate disorder
28-35	2～ 8 [%]	Severe disorder

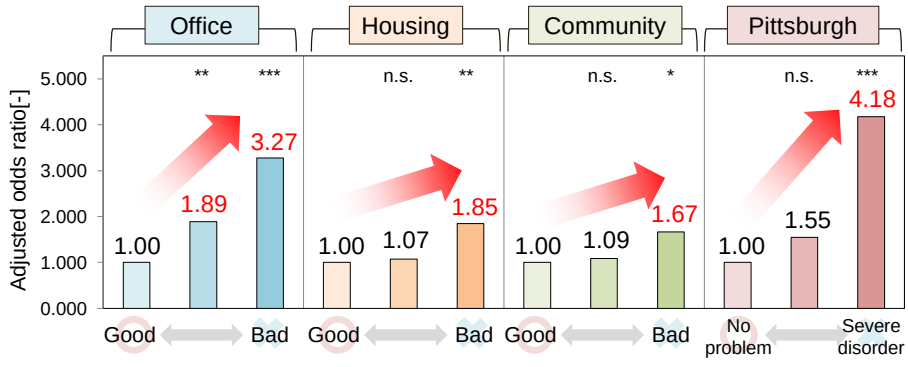
4-3. Logistic regression analysis

➢ Result of logistic regression analysis (Model- 3)

Objective variable	WFun	[0] No disorder or have disorder (7～27 points) [1] Severe disorder (28～35 points)	Adjusted odds ratio	Significance probability
Explanatory variable	CASBEE-OHC	[1] Office environment: Good group (78～153 points)		< 0.001
		[2] Office environment: Normal group (56～77 points)	1.888	0.003
		[3] Office environment: Bad group (0～55 points)	3.274	< 0.001
	CASBEE-Housing	[1] Housing environment: Good group (5.5～8.0 points)		0.001
		[2] Housing environment: Normal group (4～5.4 points)	1.070	0.737
		[3] Housing environment: Bad group (0～3.9 points)	1.845	0.003
	CASBEE-Community	[1] Community environment: Good group (14～23 points)		0.011
		[2] Community environment: Normal group (10～13 points)	1.088	0.689
		[3] Community environment: Bad group (0～9 points)	1.666	0.015
	Pittsburgh	[1] No problem		< 0.001
		[2] Slight disorder	1.548	0.099
		[3] Severe disorder	4.175	< 0.001
	Gender	[0] Man / [1] Woman	0.652	0.006
	Age	[1] 20's / [2] 30's / [3] 40's / [4] 50's / [5] 60's	0.832	0.003
	Constant		0.055	< 0.001
Conformity degree of the model	Hosmer-Lemeshow test		p=0.095	
	Discriminative hit ratio		89.4%	

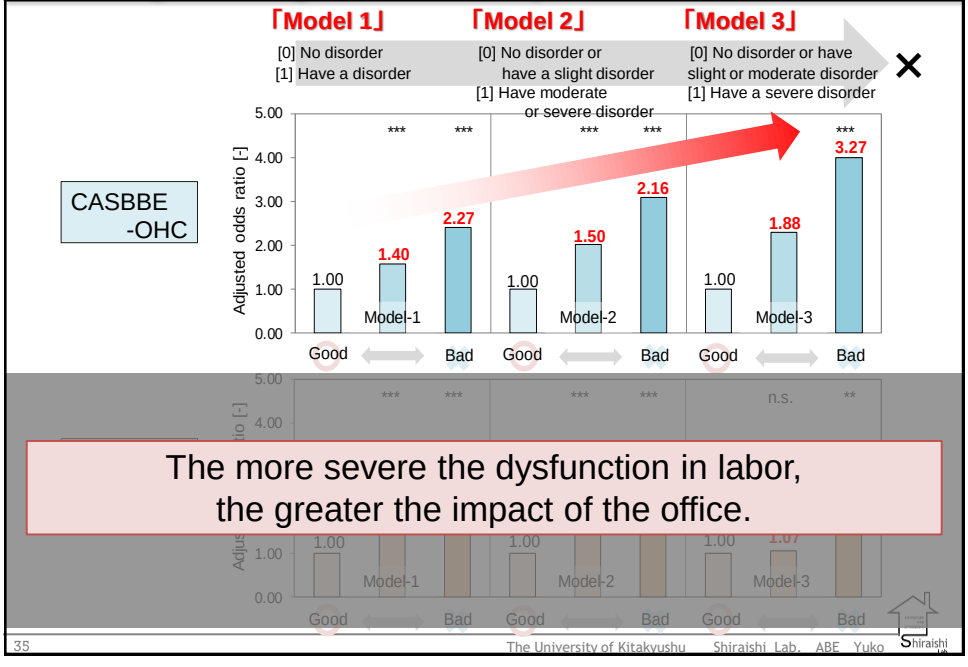
4-3. Logistic regression analysis

➢ Result of logistic regression analysis (Model-3)



Lower scores for general environments are associated with elevated risk of high levels of dysfunction in labor.

4-3. Logistic regression analysis



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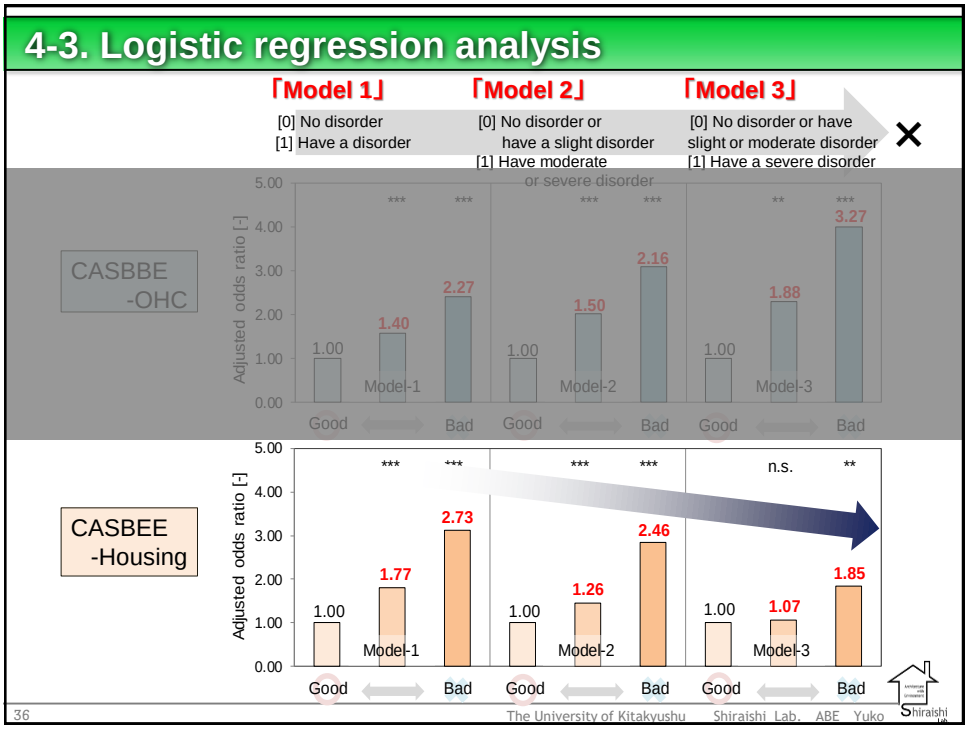
4-3. Logistic regression analysis



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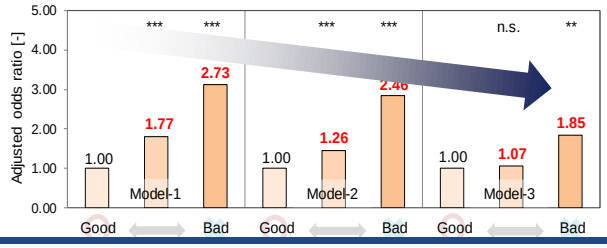
4-3. Logistic regression analysis

CASBBE -OHC



CASBEE -Housing



The office environment strongly influences the probability of severe labor dysfunction.

5. Conclusions

1. Research background and aim
2. Overview of related tools in CASBEE-Office
   - Overview of CASBEE-WO
   - Overview of CASBEE-OHC
3. Overview of WEB questionnaire
4. Result of analysis
   - Simple Tabulation
   - Multiple regression analysis
   - Logistic regression analysis
5. Conclusions

5. Conclusions

➢ Conclusion

- It was confirmed that if the office environment and residence, community of the office worker are good, it will have a good influence on health condition and workers' intellectual productivity.
- The correlation analysis for evaluation item indicated that the correlation between office air conditioning, air quality and dysfunction in labor was high. Furthermore, among air conditioning and air quality field, it was confirmed that the influence of the item regarding air quality was the largest.

➢ Future work

A field survey for multiple offices is planned. From this, We plan to verify the validity as an evaluation tool, and CASBEE-OHC will be improved.

Thank you for your listening.

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■Supplementary materials

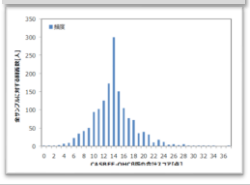
2-2. Overview of CASBEE-OHC

CASBEE-OHC β version (2016 ver.)

Answer format：
2 options (Yes or No)

- ☑ 外部の音などが気になること
- ☐ 他の人の会話や設備機械音が気になること
- ☑ 明るさのムラを感じること
- ☐ 暑さや寒さによって不快に感じること
- ☐ 空気の乾燥やジメジメ感を覚えること
- ☐ 空調の気流を不快に感じること
- ☑ 空気のよどみや埃っぽさ、臭いを感じること

score distribution ：
non-normal



CASBEE-OHC (2018 ver.)

Answer format ：**4-choice format (degree or frequency)**

Achievement of optimal factors				
There is planting that can feel green	very well	A little	Not true	Not at all true
Removal of dysfunctional factors				
Feeling that work space and storage place are narrow	No	Rare	Sometimes	Common
	3 point	**2 point**	**1 point**	**0 point**

2-2. Utilization scene of CASBEE-OHC

Utilization scene of CASBEE-OHC

Building owner, Designer, Builder, and Building manager

Company (General affairs department etc.)

Industrial doctor of company

Related questionnaire

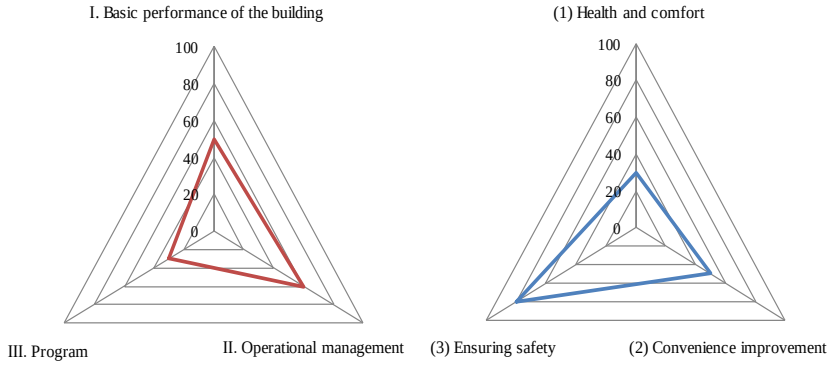
CASBEE-OHC

workers' surrounding environment (Housing, Community)

Workers' health status

2-2. Utilization scene of CASBEE-OHC

Image diagram of the evaluation result and the feedback output



This is intended to encourage not only workers but also building managers to create rules for environmental improvement.

3. Overview of WEB questionnaire

Work efficiency

Question table quantifying work efficiency of office worker based on “The World Health Organization Health and Work Performance Questionnaire”.

Bad performance → The better the performance, the better the score → Good performance

0 1 2 3 4 5 6 7 8 9 10

Reference：The World Health Organization Health and Work Performance Questionnaire https://www.hcp.med.harvard.edu/hpq/info.php

WFun

Situation which workers can not stay in the office and can not afford to work.（Absence etc…）	Situation which the worker works with physical condition
II	II
Absenteeism	**Presenteeism**

Reference：WFun The. University of Occupational and Environmental Health, “Wfun” http://www.uoehu.ac.jp/kouza/kosyueis/wfun/entry1.html

3. Overview of WEB questionnaire

Pittsburgh

This is a questionnaire to check if respondents have insomnia. This is a questionnaire to check if the respondent is insomnia. It is possible to calculate the score from these seven elements and understand the degree of sleep disorder.

0～5 points		No problem
6 points～	6 ～ 8 points	Slight disorder
	9 points～	Severe disorder

Reference：Ujimoto, K. et al: Assessment of sleep disturbance using the Pittsburgh sleep quality index in patients with dizziness, Equilibrium Res Vol. 73 (6), pp.502-511, 2014 (in Japanese)

➢ **In this study,**

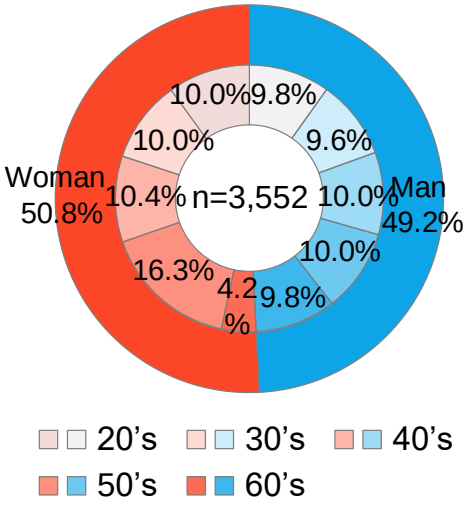
Work efficiency ← Multiple regression analysis

WFun　Pittsburgh

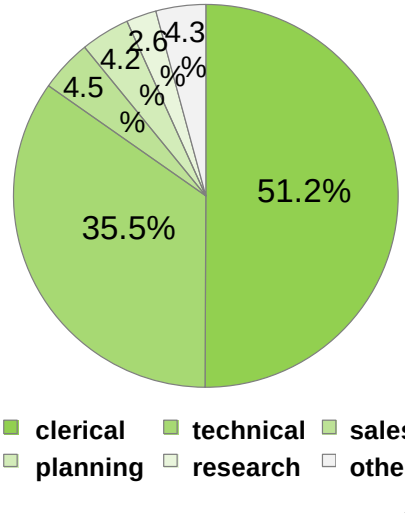
Office　House　Community　personal attributes

4-1. Simple tabulation

Gender and Age

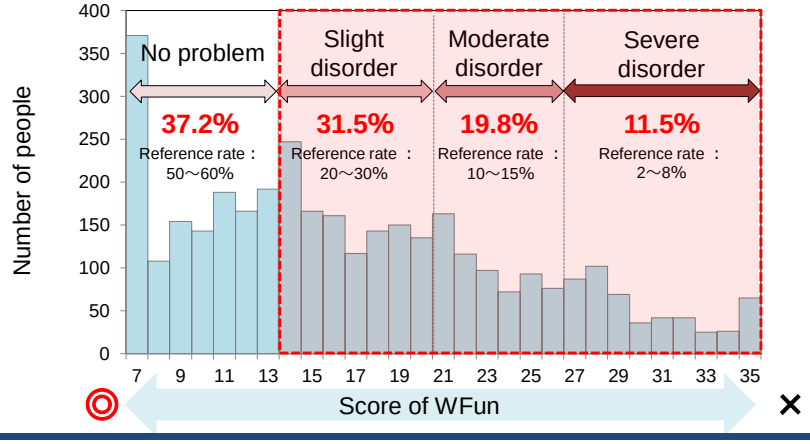


Occupation



4-1. Simple tabulation

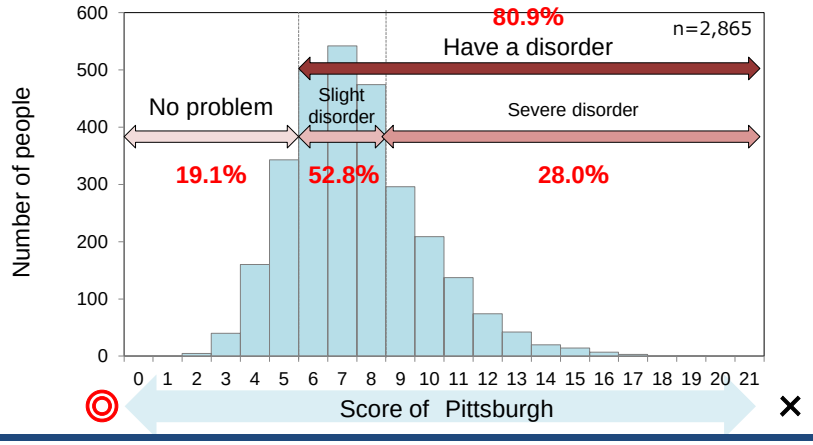
Score distribution of WFun



The number of workers with labor dysfunction is very large.

4-1. Simple tabulation

Score distribution of Pittsburgh



Approximately 80% of workers have a sleep disorder.

4-3-2. Logistic regression analysis ②

■Logistic regression analysis ②

(Objective variable：Pittsburgh score)

4-3-2. Logistic regression analysis ②

➢ Input variables in logistic regression analysis

Objective variable: Pittsburgh score				
Model-1	[0] No disorder		[1] Have a disorder	
Model-2	[0] No disorder or have a slight disorder		[1] Have severe disorder	
Explanatory variable				
General environments	CASBEE-OHC	[1] Top 30% of respondents	[2] 40% of respondents	[3] Lower 30% of respondents
	CASBEE-Housing	[1] Top 30% of respondents	[2] 40% of respondents	[3] Lower 30% of respondents
	CASBEE-Community	[1] Top 30% of respondents	[2] 40% of respondents	[3] Lower 30% of respondents
Personal attributes	G		[2] Woman	
	P			ss
	Number	[4] Less than 3000	[5] Less than 5000	[6] More than 5000
	Annual oncome	[1] Less than 5 million	[2] Less than 10 million	[3] Less than 15 million
		[4] Less than 20million	[5] More than 20 million	
	Marital status	[1] Married	[2] Unmarried	

Interpretations of Pittsburgh

0～5 points		No problem
6 points～	6 ～ 8 points	Slight disorder
	9 points～	Severe disorder

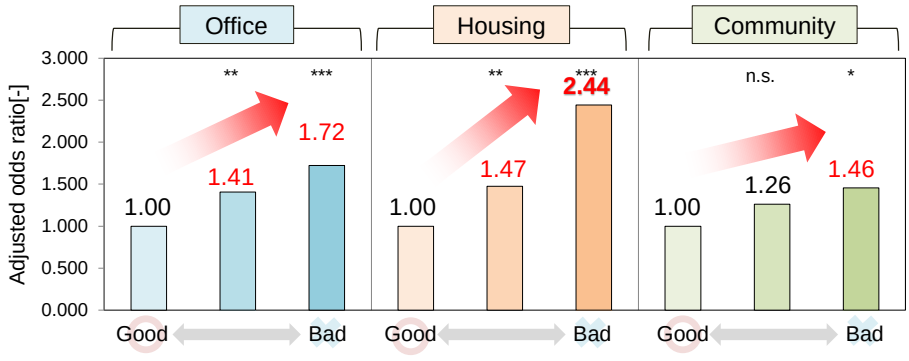
4-3-2. Logistic regression analysis ②

➢ Result of logistic regression analysis (Model-1)

Objective variable	Pittsburgh	[0] No disorder (0～5 points) [1] Have a disorder (6～points)		Adjusted odds ratio	Significance probability
Explanatory variable	CASBEE-OHC	[1] Office environment: Good group (78～153 points)			0.001
		[2] Office environment: Normal group (56～77 points)		1.405	0.006
		[3] Office environment: Bad group (0～55 points)		1.721	< 0.001
	CASBEE-Housing	[1] Housing environment: Good group (5.5～8.0 points)			< 0.001
		[2] Housing environment: Normal group (4～5.4 points)		1.474	0.002
		[3] Housing environment: Bad group (0～3.9 points)		2.442	< 0.001
	CASBEE-Community	[1] Community environment: Good group (14～23 points)			0.042
		[2] Community environment: Normal group (10～13 points)		1.263	0.069
		[3] Community environment: Bad group (0～9 points)		1.456	0.016
	Marital status	[1] Married	[2] Unmarried	1.255	0.046
	Constant			1.228	0.279
Conformity degree of the model	Hosmer-Lemeshow test			p=0.327	
	Discriminative hit ratio			79.7%	

4-3-2. Logistic regression analysis ②

➢ **Result of logistic regression analysis (Model-1)**



Lower scores for general environments are associated with elevated risk of high levels of sleeping disorder.

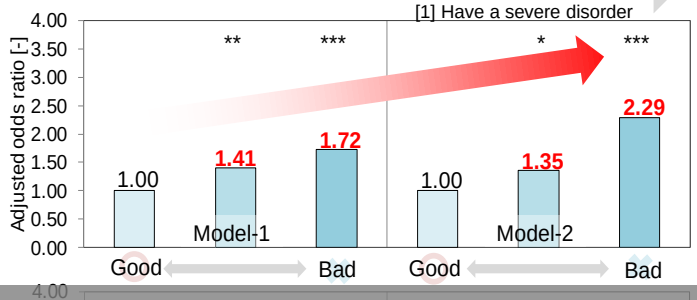
4-3-2. Logistic regression analysis ②

「Model 1」
[0] No disorder
[1] Have a disorder

「Model 2」
[0] No disorder or have a slight disorder
[1] Have a severe disorder

×

CASBBE -OHC



The more severe the sleeping disorder, the greater the impact of the office.

4-3-2. Logistic regression analysis ②

CASBBE -OHC



CASBEE -Housing



As for the prevalence of advanced sleep disorders, the impact of office and housing is comparable.

Evaluation potential of indoor environments' ecological valency

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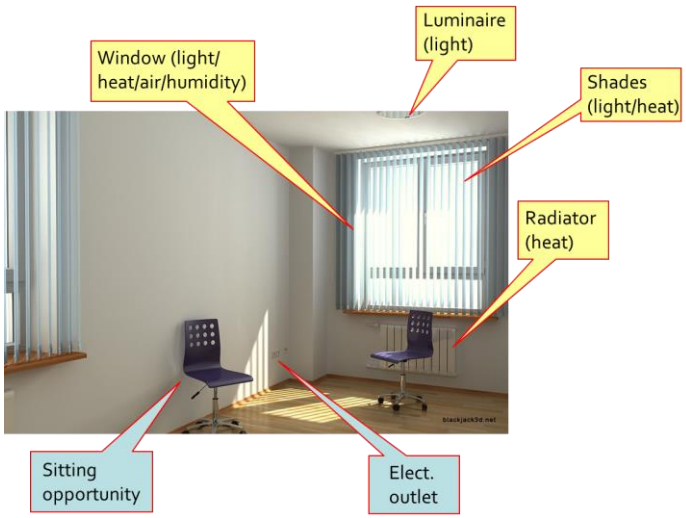
Department of Building Physics and Building Ecology
TU Wien, Austria

AIVC2019 – Ghent, Belgium

1

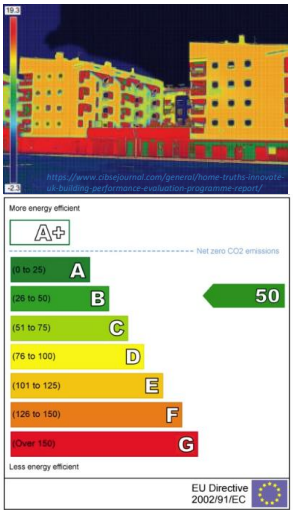
Ecological valency as the space´s responsiveness to occupants needs/requests



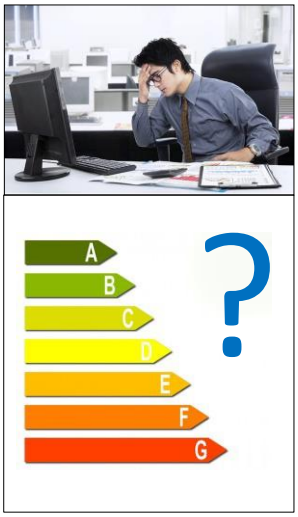
2

Building performance specification

Thermal/energy performance



Responsiveness to user needs

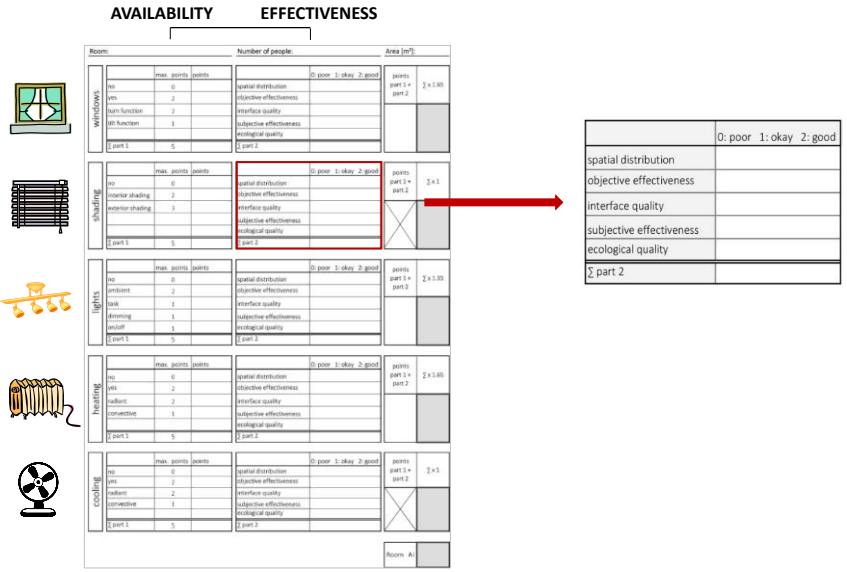


Illustrative taxonomy of buildings' control devices

DEVICES	Radiative energy modulation	Lighting modulation	Convective energy modulation	Air flow modulation	Humidity control
window	○	○	○	✓	○
exterior shades	✓	○	—	—	—
interior shades	○	✓	—	—	—
radiator	✓	—	○	—	—
radiant ceiling	✓	—	○	—	—
floor heating	✓	—	○	—	—

DEVICES	Radiative energy modulation	Lighting modulation	Convective energy modulation	Air flow modulation	Humidity control
air diffusers	—	—	✓	✓	✓
humidifier	—	—	—	—	✓
illumination	○	✓	—	—	—
task lighting	○	✓	—	—	—
fan	—	—	—	✓	—
desk fan	—	—	—	✓	—

An ecological valency measurement protocol

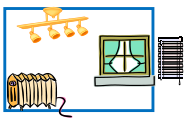


The aggregation challenge

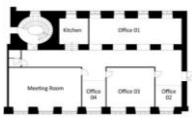
Devices: $EVI_{Di} = EVI_{C1}.w_{C1} + EVI_{C2}.w_{C2} + ...+ EVI_{Cn}.w_{Cn}$



Spaces: $EVI_{Sj} = EVI_{D1}.w_{D1} + EVI_{D2}.w_{D2} + ...+ EVI_{Dn}.w_{Dn}$

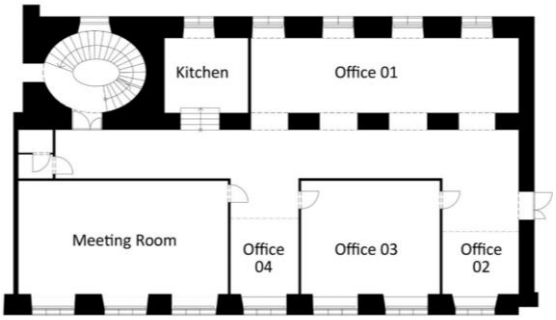


Buildings: $EVI_{B} = EVI_{S1}.w_{S1} + EVI_{S2}.w_{S2} + ...+ EVI_{Sn}.w_{Sn}$



A Pilot Study

Selected office area



- 30 participants (21 female, 9 male)
- 22 visitors, 8 occupants
- Age between 24-29

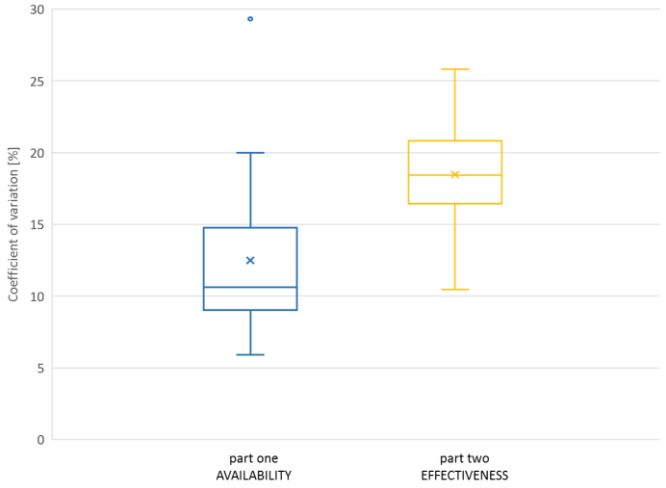
A Pilot Study - Results

Room-wise evaluation



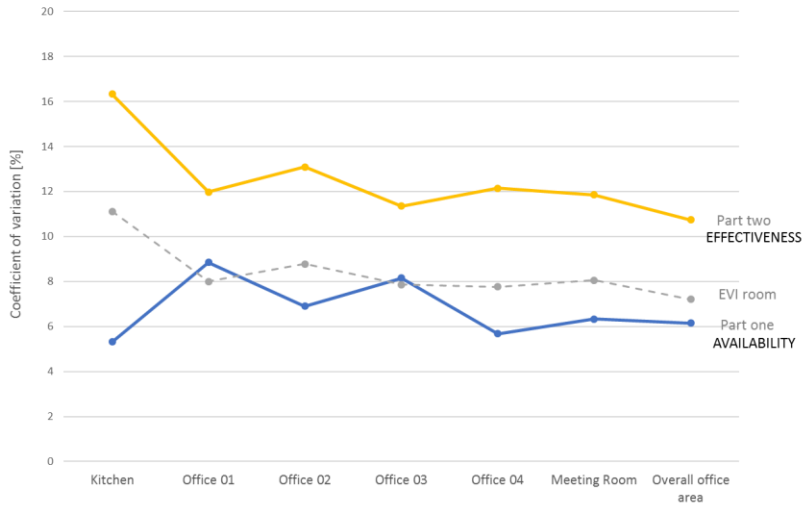
A Pilot Study - Results

Comparison part one – part two



A Pilot Study - Results

Comparison part one – part two



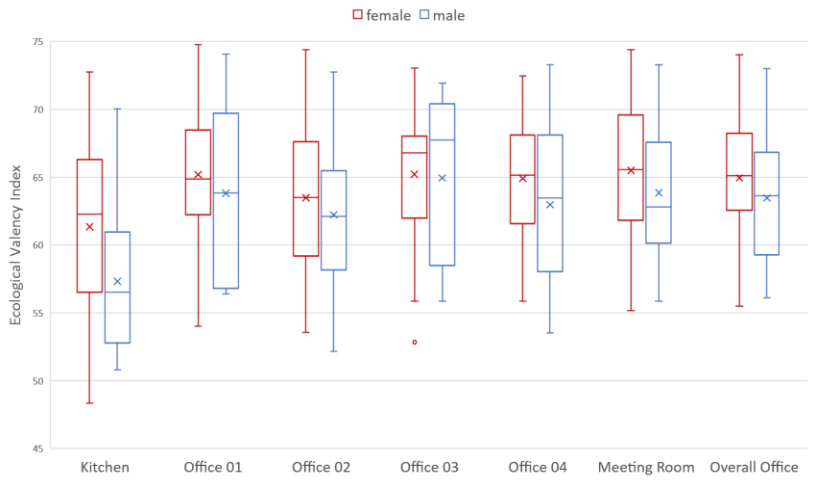
A Pilot Study - Results

Comparison occupants - visitors



A Pilot Study - Results

Comparison female - male participants



Conclusion

- Availability evaluation fairly consistent
- Larger divergence in effectiveness evaluation
- Proposed benchmarking is not trivial but has potential

Limitations

- Participants' sample small and non-representative
- Only one target building with fairly similar spaces

Future research

- Expanded and modified protocol
- Extended sample of participants and buildings

Evaluation potential of indoor environments' ecological valency

Ardeshir Mahdavi – Helene Teufl – Christiane Berger

Department of Building Physics and Building Ecology
TU Wien, Austria

AIVC2019 – Ghent, Belgium

Residential Application of an Indoor Carbon Dioxide Metric

Andrew Persily, Brian Polidoro
National Institute of Standards and Technology
Gaithersburg, Maryland USA



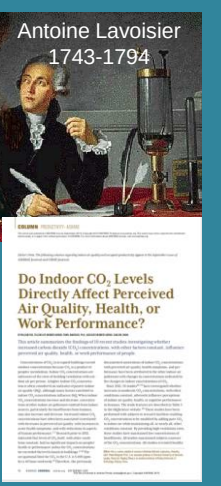
40th AIVC - 8th TightVent & 6th venticool Conference, 2019
Ghent BELGIUM, 15-16 October 2019

1

INTRODUCTION

CO_2 part of ventilation & IAQ discussions since 18th century

- Impacts on building occupants
- Relation to bioeffluent perception
- Estimation of ventilation rates
- Demand controlled ventilation



CO_2 as an IAQ Metric

- Not a comprehensive IAQ indicator
- Typically not an indoor health issue
- Useful indicator of outdoor air per person

2

2018 AIVC Conference Paper

Single-zone mass balance analysis of several commercial spaces

Space: Outdoor air ventilation rate (space type), geometry (area, volume)

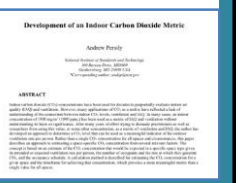
Occupants: number, CO_2 generation rate (sex, age, body mass, met level)

Calculate CO_2: steady-state, 1 h, t_{metric}

Recalculated for 25 % less ventilation

Potential CO_2 metrics for specific spaces at specific times





Space Type	CO_2 concentration metric, above outdoors (mg/m³)	Corresponding time (h after full occupancy)
Classroom (5 to 8 y)	1000	2
Classroom (>8 y)	1500	1
Lecture classroom	2000	1
Restaurant dining room	2000	1
Conference meeting room	2000	1
Hotel/motel bedroom	1000	6
Office space	600	2
Auditorium	3000	1
Lobby	4500	1
Retail/Sales	1500	2

3

Residential buildings (2019)

Variations in dwelling and family size; occupant age, size and schedule

Hours of sleep helpful for bedroom analyses

Analysis

3 families; 2 house sizes, whole house and bedroom

Whole house: ASHRAE 62.2 rate or 0.5 h^{-1}

Bedrooms: 62.2 (uniform or perfect) or 10 L/s•person

Recalculated with 25 % reduction in ventilation

4

Ventilation rates and CO_2 concentrations

	Outdoor air ventilation		Time to steady-state (h)	CO_2 Concentration above outdoors (mg/m^3)		
Large House/Baseline family	L/s per person	h^{-1}		Steady-state	1 h	t_{metric} (2 h)
Whole house – 62.2	12.9	0.27	**11.1**	598	142	250
Whole house – 0.5 h^{-1}	23.8	0.50	6.0	324	127	205
62.2/ MBR/Perfect	12.9	1.13	2.7	461	312	461
62.2/ CBR/Perfect	12.9	0.85	3.5	322	184	320
62.2/MBR/Uniform	**3.1**	0.27	11.1	**1922**	456	**1543**
62.2/CBR/Uniform	4.1	0.27	11.1	1005	238	807
0.5 h^{-1}/MBR/Perfect	23.8	2.08	**1.4**	250	219	250
0.5 h^{-} CBR/Perfect	**23.8**	1.56	**1.9**	**174**	138	**174**
0.5 h^{-1}/MBR/Uniform	5.7	0.50	6.0	1041	409	989
0.5 h^{-1}/ CBR/Uniform	7.6	0.50	6.0	544	214	517
10 L/s per person/MBR/Perfect	10.0	0.88	3.4	594	347	591
10 L/s per person/CBR/Perfect	10.0	0.66	4.6	414	199	406

5

Residential analysis

In contrast to commercial, residences more variable in size, occupancy and ventilation

Difficult to generalize to develop CO_2 metrics

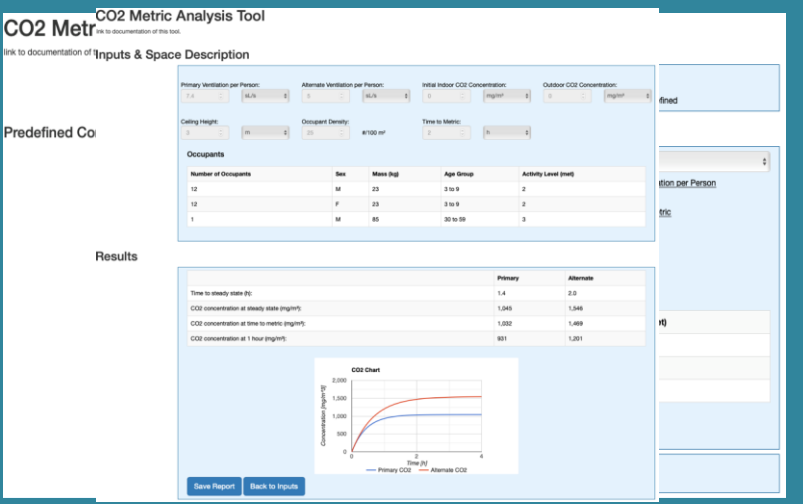
House, occupancy and air distribution need to be considered

Online tool to implement analysis

6

On-Line Calculator

https://pages.nist.gov/CONTAM-apps/webapps/CO2Tool/#/



On-Line Calculator

Commercial or residential

Commercial inputs:

ASHRAE 62.1 space type/default occupant density and outdoor airflow

Or User Defined

Residential inputs:

Whole building (62.2 or h^{-1} value) or

Bedroom (62.2/h^{-1} and air distribution, or L/s•person)

Or User Defined

Summary

Proposed CO_2 metric of ventilation per person

Must be linked to measurement time

Must consider actual occupancy

May not work in spaces with transient occupancy

Must report: Space type, occupant density, time at which full occupancy starts, time of concentration measurement, measured indoor and outdoor CO_2 concentrations.

Online tool, try it and let us know what you think:
Documentation and link for input soon

Trade-offs between ventilation rates and formaldehyde concentrations in new-build dwellings in the UK

40th AIVC – 8th TightVent & 6th venticool Conference

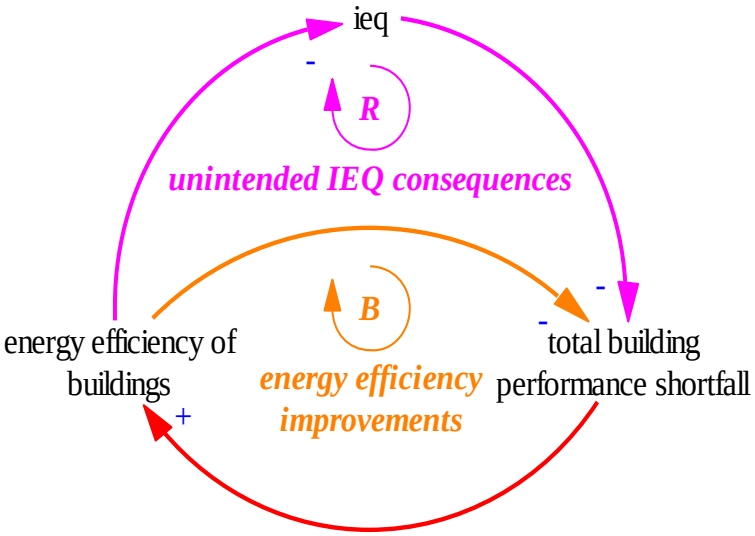
Esfand Burman and Samuel Stamp
UCL Institute for Environmental Design and Engineering

16 October 2019
Ghent University

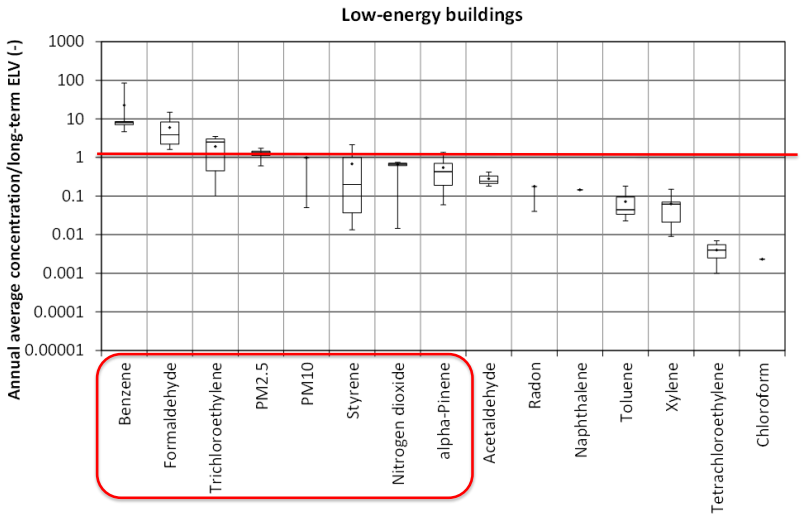
Outline

- Potential conflicts between energy efficiency & IAQ
- Defining the metrics for IAQ in low-energy dwellings (IEA EBC Annex 68)
- A case study from the UK
- Exposure Limit Values (ELVs) for formaldehyde
- Trade-offs between energy efficiency & formaldehyde levels
- Source control measures

Unintended consequences of energy efficiency policies

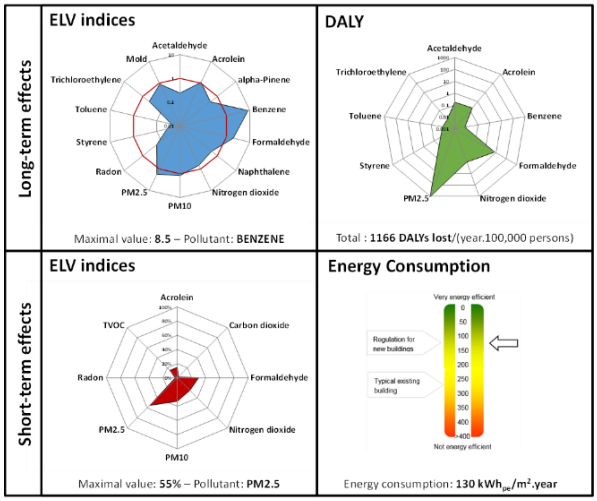


Concentration of pollutants in low-energy building



Source: Abadie et al., 2016. IEA EBC Annex 68 – Indoor Air Quality Design and Control in Low-energy Residential Buildings, SUBTASK 1: Defining the metrics

IAQ-Energy Dashboard



Source: Abadie et al., 2016. IEA EBC Annex 68 – Indoor Air Quality Design and Control in Low-energy Residential Buildings, SUBTASK 1: Defining the metrics

5

Case Study

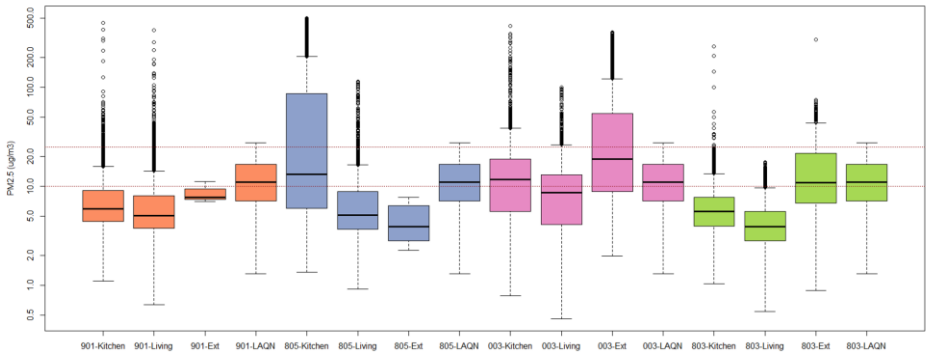




- New-build apartment blocks in East London (completed in 2015)
- Low air permeability: 2-3 m³/hr/m² at 50 Pa
- Mechanical Ventilation with Heat Recovery (MVHR)
- Low ACH (<1 in heating season): indoor sources become more relevant!

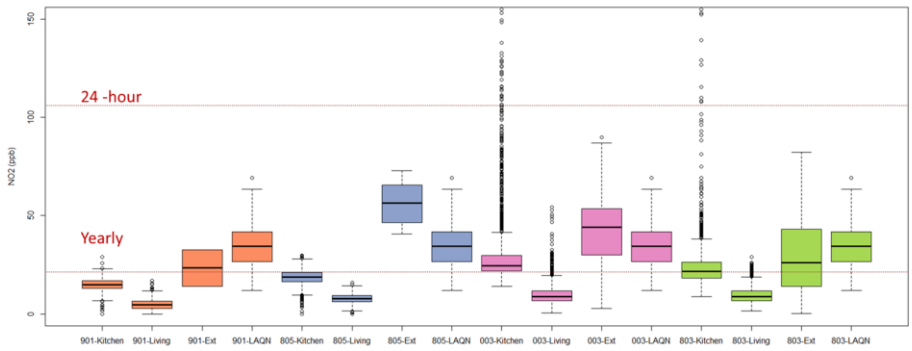
6

PM2.5 Concentrations



Episodes of high concentration on lower apartments close to the main road (Basic G3 filter used in the MVHR units)

NO_2 Concentrations



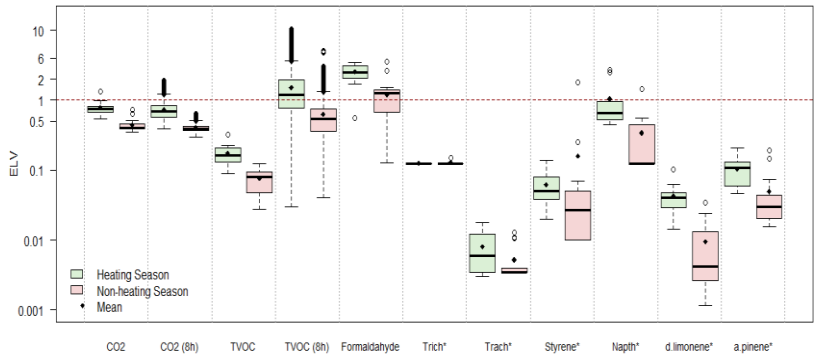
High concentration mainly in the kitchens (background pollutions + indoor events)

VOC concentrations (passive sampling)

VOC	Min	25th pctl.	Median	Average	75th pctl.	Max	Annex 68 ELV
Benzene	**0.55**	**0.55**	**1.20**	**1.14**	**1.48**	**2.8**	0.2
Formaldehyde	1.15	**10.15**	**16.32**	**16.78**	**26.13**	**31.91**	**9**
Trichloroethylene	0.25	0.25	0.25	0.26	0.25	0.3	2
Styrene	0.30	0.63	1.35	1.78	2.00	**53.9**	30
Naphthalene	0.25	0.34	1.00	1.38	1.30	**5.4**	2
Toluene	0.45	1.20	2.15	4.03	3.33	22.8	250
Tetrachloroethylene	0.30	0.35	0.35	0.66	1.09	1.8	100

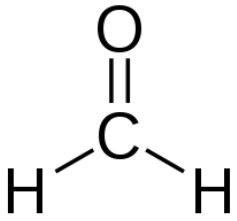
Benzene (primarily driven by outdoor sources) and formaldehyde (driven by indoor sources) consistently show concentrations higher than best practice ELVs.

VOC concentrations (passive sampling)



Internal sources of pollution

- Formaldehyde in all apartments and most zones higher than best practice ELV
- Perceived wisdom of 2-3 years to off-gas is questionable?
- Source control measures
- Boost ventilation mode on MVHR required to be used?









AIR QUALITY STANDARDS

Pollutants generated indoors such as Volatile Organic Compounds (VOCs), combustion byproducts and airborne particles are known to trigger nausea, asthma and allergies. While ambient outdoor air is often better quality, natural ventilation methods, operable windows and doors, and general envelope infiltration can harm indoor air quality if external air quality conditions are poor.

This feature requires that an accredited assessor complete a performance test after occupancy as an independent means of verifying that the building, whether naturally or mechanically ventilated, is meeting critical air quality requirements.



Cardiovascular
Endocrine
Immune
Integumentary
Nervous
Respiratory

PART 1: STANDARDS FOR VOLATILE SUBSTANCES

The following conditions are met:

a.[1] Formaldehyde levels less than 27 ppb. **33.7 µg/m³**

b.[1] Total volatile organic compounds less than 500 µg/m³.

Source: Well Building Standard, 2014

Derivation of ELV for Formaldehyde

Study	Wilhelmsson and Holmstrom, 1992 supported by Edling et al., 1988
Study population	66 human chemical plant workers
Exposure method	Discontinuous occupational exposure
Exposure continuity	8 hr/day, 5 days/week (assumed)
Exposure duration	10 years (average); range 1-36 years
Critical effects	Nasal obstruction and discomfort, lower airway discomfort.
LOAEL	Mean 0.26 mg/m^3 (range 0.05 – 0.6 mg/m3) (described as exposed group)
NOAEL	Mean of 0.09 mg/m^3 (described as control group of office workers)
Benchmark concentration	not derived
Time-adjusted exposure	0.09 mg/m^3 for NOAEL group
Human Equivalent Concentration	not applied
LOAEL uncertainty factor (UF_L)	not applied
Subchronic uncertainty factor (UFs)	not applied
Interspecies uncertainty factor	
Toxicokinetic (UF_{A-k})	1 (default, human study)
Toxicodynamic (UF_{A-d})	1 (default, human study)
Intraspecies uncertainty factor	
Toxicokinetic (UF_{H-k})	1 (no systemic effects)
Toxicodynamic (UF_{H-d})	10 (potential asthma exacerbation in children)
Cumulative uncertainty factor	10
Reference Exposure Level	**9 µg/m^3 (7 ppb)**

Non Observable Adverse Effect Level

Source: California Office of Environmental Health Hazard Assessment, 2014

Reference exposure level for Children

Study	Rumchev et al., 2002
Study population	88 asthmatic children (mean age 25 mo); 104 nonasthmatic controls (mean age 20 mo)
Exposure method	Ambient in home
Exposure continuity	Continuous assumed
Exposure duration	range 0.5-3 years
Critical effects	Parent-reported respiratory symptoms (cough, shortness of breath, wheeze, trouble breathing)
LOAEL	60 µg/m^3
NOAEL	30 µg/m^3 (lower limit of NOAEL range)
Benchmark concentration	not derived
Time-adjusted exposure	not applied
Human Equivalent Concentration	30 µg/m^3
LOAEL uncertainty factor (UF_L)	1
Subchronic uncertainty factor (UFs)	not applied
Interspecies uncertainty factor	
Toxicokinetic (UF_{A-k})	1 (default, human study)
Toxicodynamic (UF_{A-d})	1 (default, human study)
Intraspecies uncertainty factor	
Toxicokinetic (UF_{H-k})	1 (study performed in children)
Toxicodynamic (UF_{H-d})	√10 (inter-individual variation)
Cumulative uncertainty factor	√10
Reference Exposure Level	**10 µg/m^3 (8 ppb)**

Source: California Office of Environmental Health Hazard Assessment, 2014

Table 1. *"Target" VOC List and Reference Levels*

VOC #	Group	CAS #	Chemical Compound	Existing List (see References)											Reference Levels (µg/m³)				
				1	2	3	4	5	6	7	8	9	10	11	Sum	WHO Guidelines [1] (µg/m³)	WHO Guidelines [1] (avg. time)	CREL [2]	OSHA PEL [3]	Odor Detect. Threshold [4]
1	Aldehydes	75-07-0	Acetaldehyde			1		1		1	1	1			5	50	(1 yr)	9	3.6E+05	3.4E+02
2		107-02-8	Acrolein			1			1	1	1	1			5	50	(30 min)	0.06	2.3E+02	4.1E+02
3		100-52-7	Benzaldehyde	1										1	2					1.9E+02
4		123-72-8	Butanal	1											1					2.8E+01
5		112-31-2	Decanal		1										1					5.9E+00
6		50-00-0	Formaldehyde			1		1	1	1	1	1			6	100	(30 min)	3	9.2E+02	1.1E+03
7		98-01-1	Furfural												0				2.0E+04	2.5E+02
8		111-71-7	Heptanal												0					2.3E+01
9		66-25-1	Hexanal	1										1	2					5.8E+01
10		124-19-6	Nonanal	1	1									1	3					1.4E+01
11		124-13-0	Octanal												0					7.2E+00
12		110-62-3	Pentanal	1											1					2.2E+01

Table 3. *Range of Emission Factors of Selected Materials (µg/m²/h) at 24 h*

Group	VOC #	Solid & Engineered Wood Materials							Flooring								Installation Materials				% (Detection)
		OSB		Plywood		Solid wood		MDF	Carpet/ Assembly		Underpad		Laminate/ Assembly		Linoleum/ Vinyl Flooring		Adhesive		Caulking		
		Min	Max	Min	Max	Min	Max		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
Aldehydes	1	41.8	265.5					89.9	1.67	20.85			3.68	11.49	2.0	28.5					46
	2																				0
	3	0.1	2.6			0.2	0.2	0.2	0.08	1.41	0.21	1.42	0.01	0.09	0.90	1.55			6057	6057	60
	4	2.7	59.8	2.1	6.0	0.3	1.7	6.0	0.19	0.48	0.21	0.93	2.33	2.33	0.15	0.15			361	361	52
	5	0.6	44.6	3.3	28.4	1.9	10.4	0.9	13.45	13.45	1.08	7.42	0.55	0.55	0.55	0.71			225	757	63
	6	11.1	53.7					441.6	6.17	40.46	6.70	76.57	1.32	37.66	1.2	19.0					54
	7	4.3	4.3			0.3	0.3														5
	8	0.3	6.5	0.9	3.6	0.7	0.7	1.4			0.15	0.15	0.03	1.62	0.9	1.3					46
	9	29.4	1256.7	12.3	33.0	0.4	5.7	135.7			0.25	0.25	12.67	12.67	21.7	26.2					58
	10	1.1	47.3	3.3	24.7	1.6	12.4	2.5	0.60	0.90	3.03	6.37	0.50	0.50	0.3	1.9	89	89	170	742	67
	11	0.6	6.7	1.0	12.8	0.4	3.6	2.6	0.46	2.43	0.60	0.60	0.30	0.30	1.3	1.6					52
	12	12.9	354.1	3.4	12.2	0.4	4.4	29.0					7.70	7.70	15.5	15.5			762	762	49

Source: NRC Canada, 2005.

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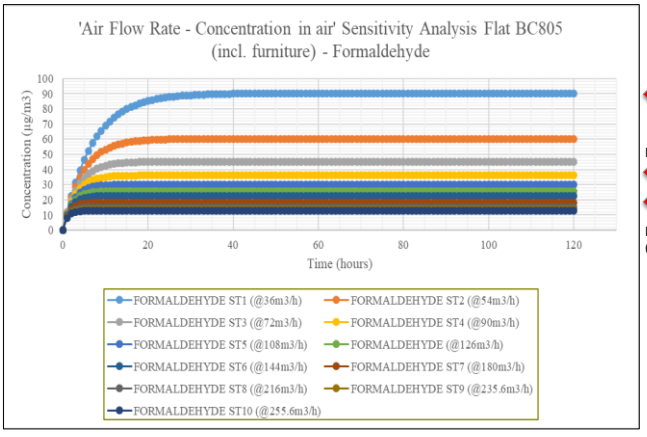

Minimum ACH achievable from installed MVHR (ACH=0.1)

MVHR commissioned flow rate (ACH= 0.5)

Maximum ACH achievable from installed MVHR (ACH= 1.6)

- Given the existing context (material and emission sources) maximum ventilation rate should be around 3 times the commissioning rate to bring formaldehyde concentration down to best practice ELV!
- Increasing the air change rate from 0.5 to 1.6 h-1 with the same MVHR system **will increase the primary energy use of regulated energy end-uses by around 22%**.

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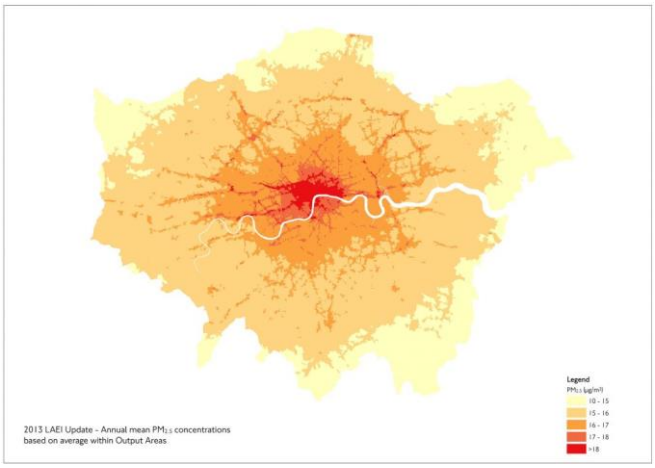
Further energy improvements

- Increase thermal efficiency of the MVHR system from 85% to 90%,
- Reduce the specific fan power of the MVHR system from 1.0 to 0.6 W/L/s,
- Improving seasonal heating efficiency from 87% to 90%.
- These improvements can reduce the excess in primary energy use for regulated energy and total energy to 9% and 5% respectively.

PM2.5 concentrations in London: higher grade filters are required (higher energy use)!



- EU legal limit (annual mean): 25 µg/m³
- **WHO guideline limit (annual mean): 10 µg/m³**

Conclusions

- Wide range of ELVs proposed for formaldehyde
- Formaldehyde is not currently regulated in the UK Building Regulations (TVOC only).
- Current material used in the construction industry and MDF based products may lead to high concentration levels.
- Source control measures are essential to reduce exposure to formaldehyde (**CARB2 and EPA's new Formaldehyde Standards for Composite Wood Products Act (TSCA Title VI**)
- Enhance ventilation should be used only as a complementary measure (with adequate filtration to protect building users against outdoor pollution).

Contact: esfand.burman@ucl.ac.uk

EPSRC
Pioneering research and skills

Formaldehyde emerges as new risk in China's housing boom

By Kerry Allen
BBC Monitoring

6 September 2018 Share



The recent death of a flat-dweller in Beijing has flagged up concerns about formaldehyde, a carcinogenic substance widely used in construction.

FACULTY OF ENGINEERING AND ARCHITECTURE

Modeling Dynamic Behavior of Volatile Organic Compounds in a Zero Energy Building

Ir. Arch. Klaas De Jonge / 15-16.10.2019 / AIVC-TightVent-Venticool Conference

GHENT UNIVERSITY fwo

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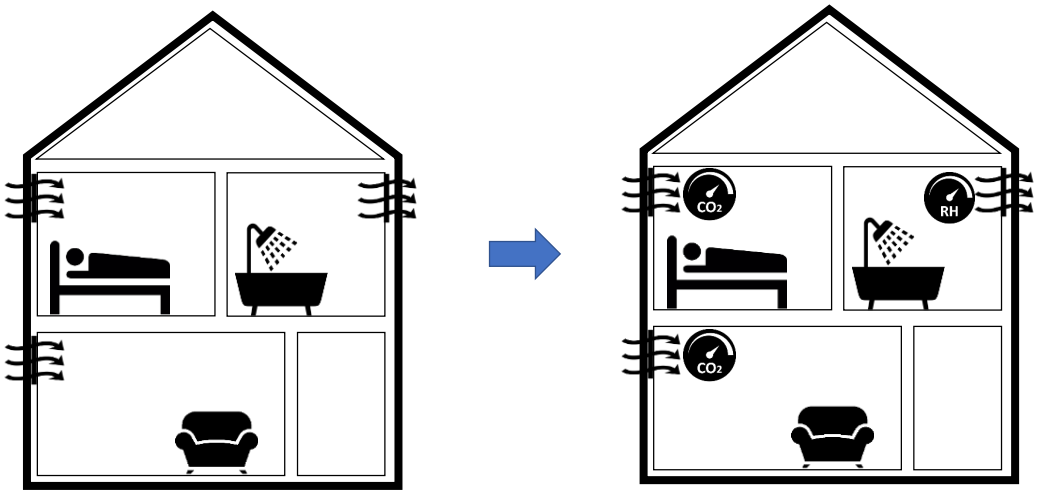
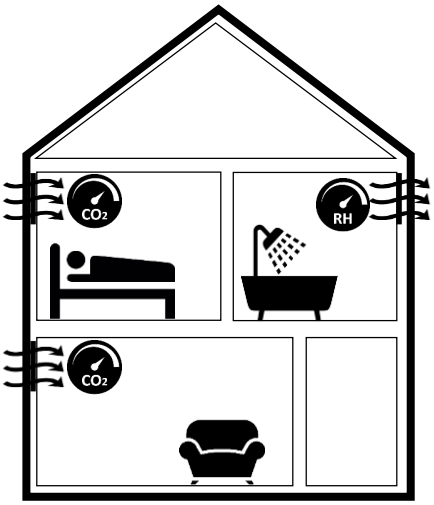


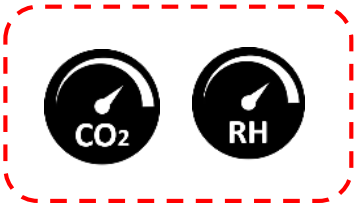
Continuous Ventilation

Demand Controlled Ventilation

2



Comfort

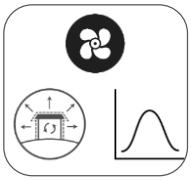




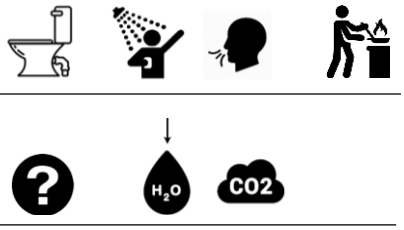
3

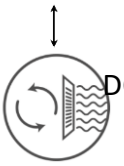
Simulation based assessment

Building Stock
(Monte Carlo)



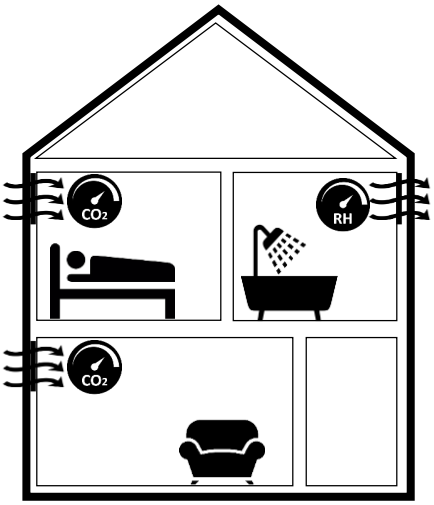
Pollutants





DCV ventilation System

4

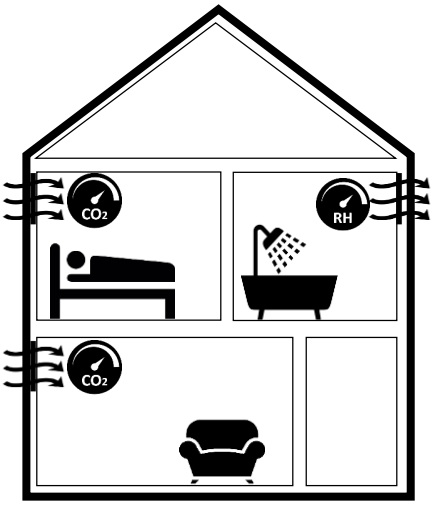


Comfort





5



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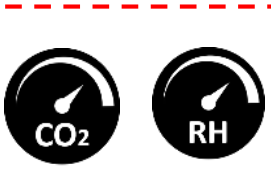
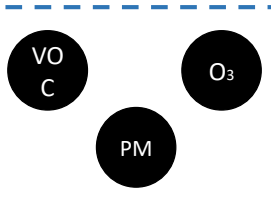




Health





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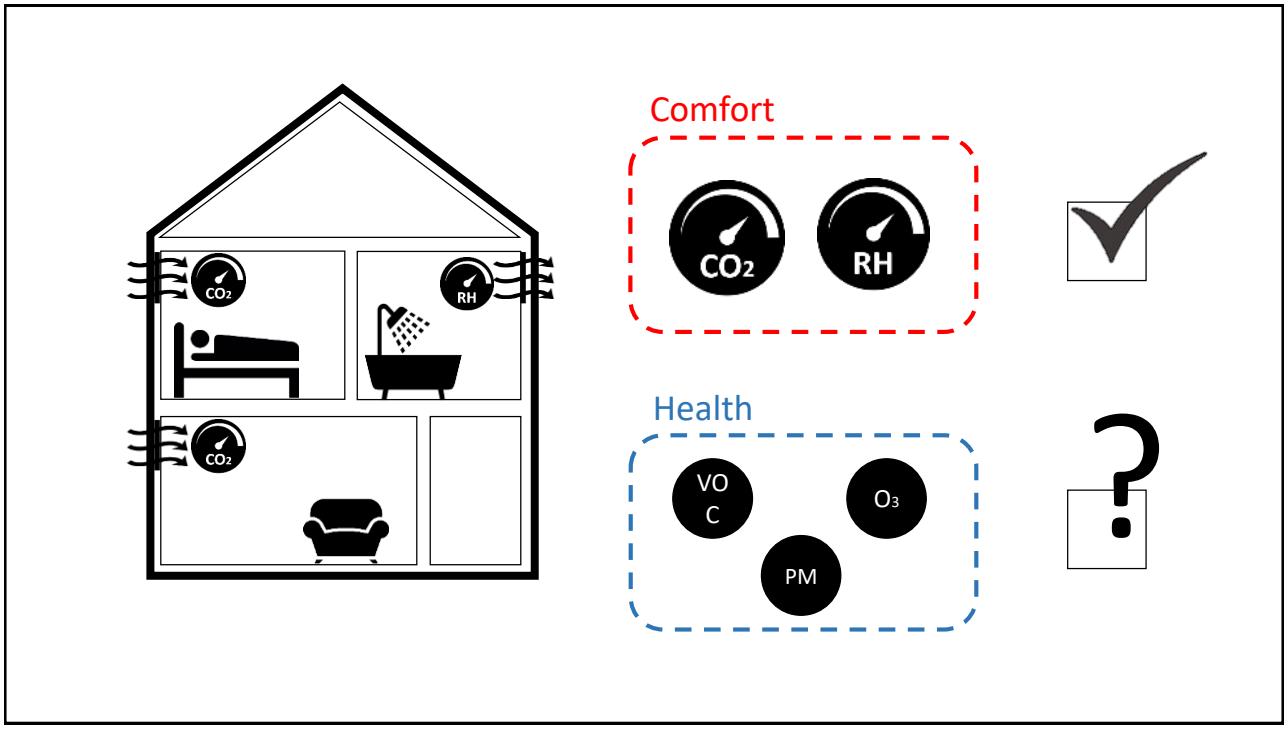
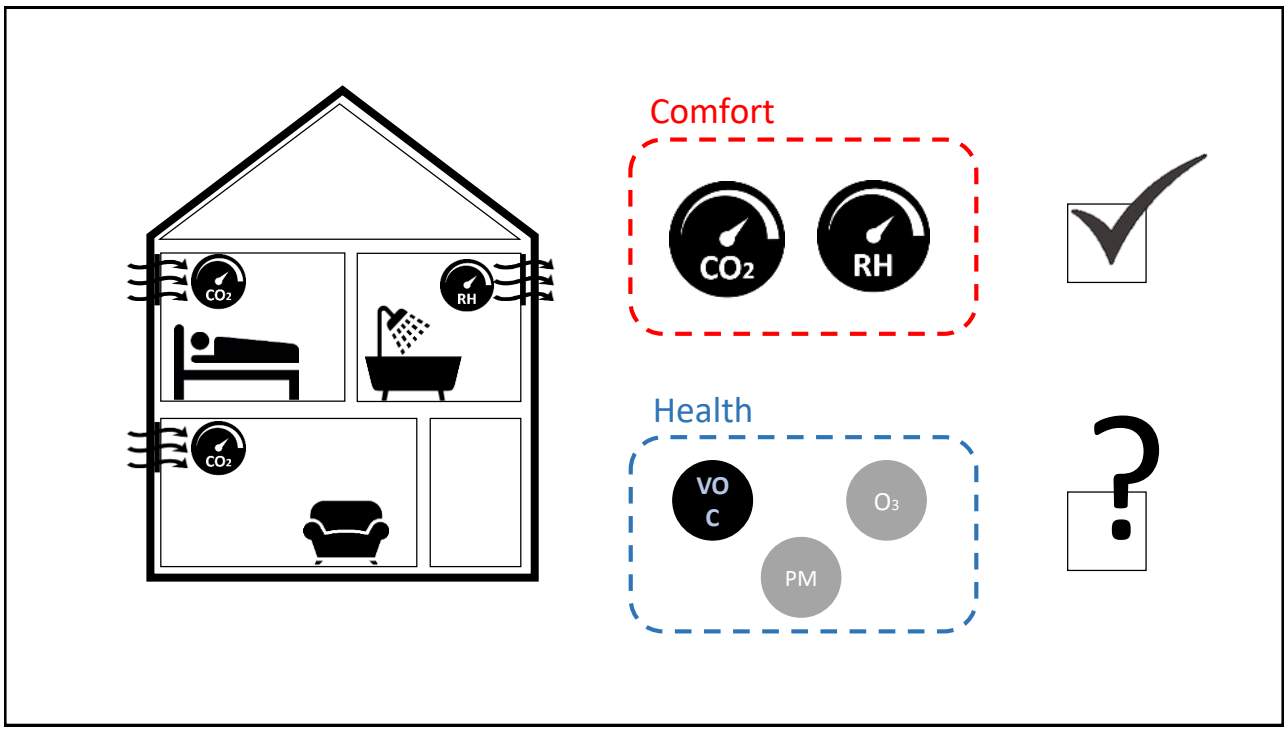

Comfort
CO2
RH
Health
VOC
O3
PM

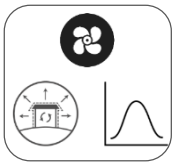
7


Comfort
CO2
RH
Health
VOC
O3
PM

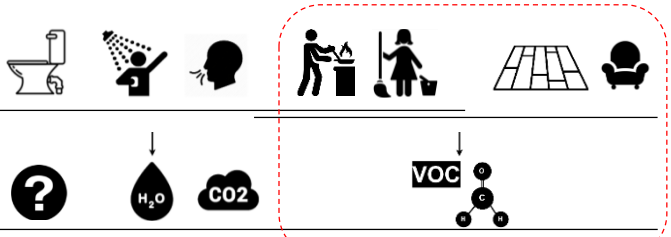
8

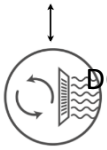
Simulation based assessment

Building Stock
(Monte Carlo)



Pollutants





DCV ventilation System

HEALTH

9



E-cube

Ostend, Belgium

10



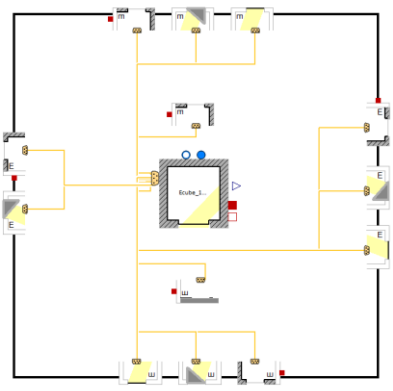
Dymola - Modelica

CONTAM
Multizone Airflow and Contaminant Transport Analysis Software

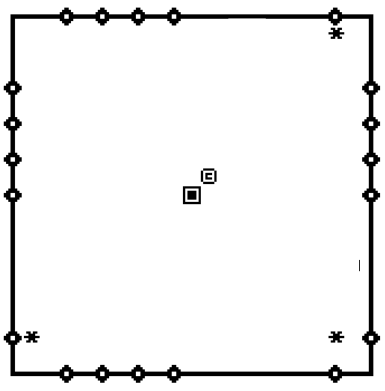
11



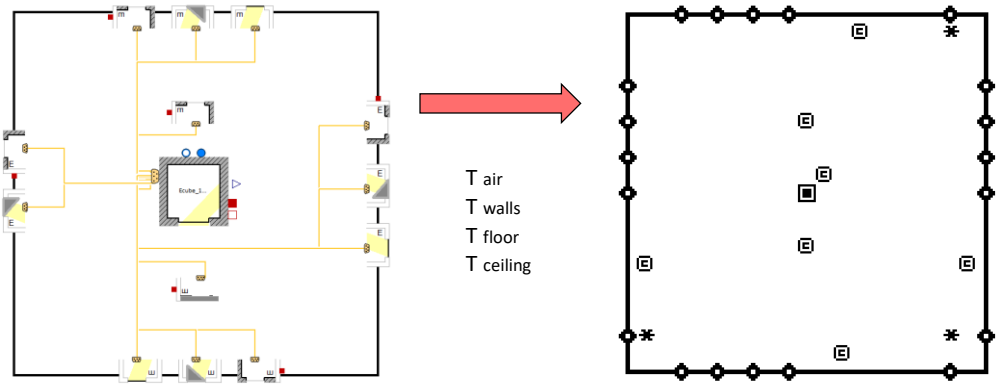
CONTAM
Multizone Airflow and Contaminant Transport Analysis Software



T air
T walls
T floor
T ceiling



12



13

$$E(t) = 2.1\frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right]\left[(1+C_1 AH) C_2 T^{-0.5} e^{\frac{-C_3}{T}}\right]}{\delta} e^{-2.36\frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right]}{\delta^2} t}$$

E(t)	[mg/m²/h]	Emission rate
T	[K]	Material temperature
AH	[g/kg]	Absolute humidity
δ	[m]	Material thickness
t	[h]	Time since start of emissions
d_1, d_2	[varies]	Diffusivity material constants for VOC-material system
C_1, C_2, C_3	[varies]	Initial concentration material constants for VOC-material system

14

$$E(t) = 2.1\frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right]\left[(1+C_1 AH) C_2 T^{-0.5} e^{\frac{-C_3}{T}}\right]}{\delta} e^{-2.36\frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right] t}{\delta^2}}$$

E(t) J. Xiong, W. Wei, S. Huang, and Y. Zhang, 2013.

15

Dm(T) Dm(T)

$$E(t) = 2.1\frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right]\left[(1+C_1 AH) C_2 T^{-0.5} e^{\frac{-C_3}{T}}\right]}{\delta} e^{-2.36\frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right] t}{\delta^2}}$$

E(t) J. Xiong, W. Wei, S. Huang, and Y. Zhang, 2013.

Dm(T) Q. Deng, X. Yang, and J. Zhang, 2009.

16

Dm(T) Co(T,AH) Dm(T)

$$E(t) = 2.1 \frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right]\left[(1+C_1 AH) C_2 T^{-0.5} e^{\frac{-C_3}{T}}\right]}{\delta} e^{-2.36 \frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right] t}{\delta^2}}$$

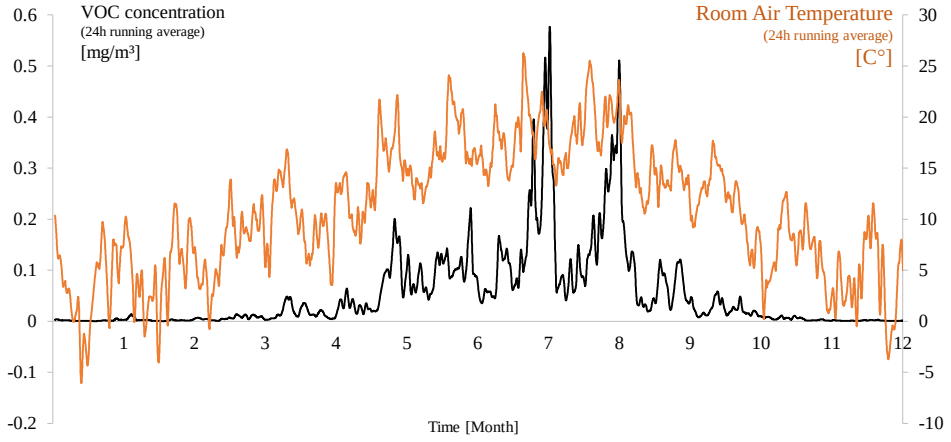
E(t)	J. Xiong, W. Wei, S. Huang, and Y. Zhang, 2013.
Dm(T)	Q. Deng, X. Yang, and J. Zhang, 2009.
Co(T,AH)	W. Liang, M. Lv, and X. Yang, 2016.

17

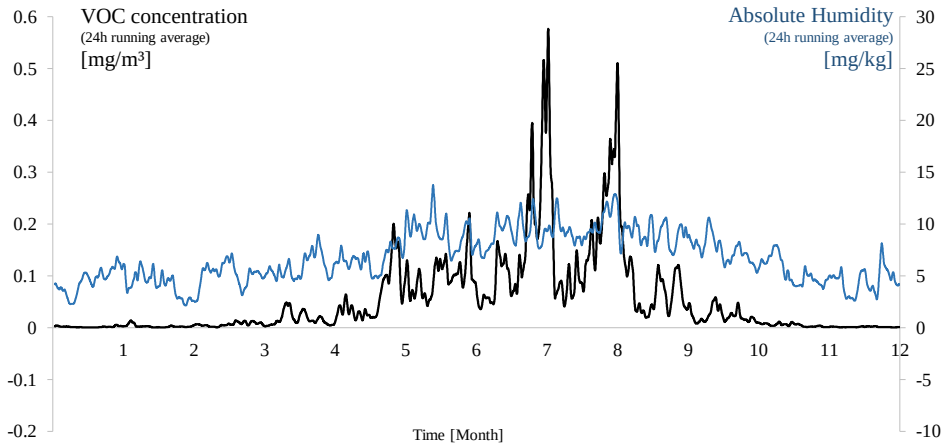
$$E(t) = 2.1 \frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right]\left[(1+C_1 AH) C_2 T^{-0.5} e^{\frac{-C_3}{T}}\right]}{\delta} e^{-2.36 \frac{\left[d_1 T^{1.25} e^{\frac{d_2}{T}} * 3.6 * 10^2\right] t}{\delta^2}}$$

E(t)	[mg/m²/h]	Emission rate
T	[K]	Material temperature
AH	[g/kg]	Absolute humidity
δ	[m]	Material thickness
t	[h]	Time since start of emissions
d_1, d_2	[varies]	Diffusivity material constants for VOC-material system
C_1, C_2, C_3	[varies]	Initial concentration material constants for VOC-material system

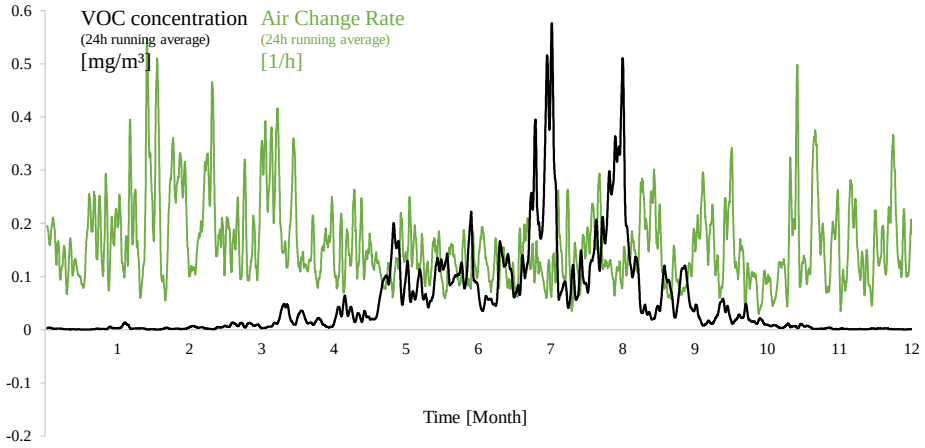
18


VOC concentration
(24h running average)
[mg/m³]
Room Air Temperature
(24h running average)
[C°]
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
30
25
20
15
10
5
0
-5
-10
1
2
3
4
5
6
7
8
9
10
11
12
Time [Month]

19


VOC concentration
(24h running average)
[mg/m³]
Absolute Humidity
(24h running average)
[mg/kg]
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
30
25
20
15
10
5
0
-5
-10
1
2
3
4
5
6
7
8
9
10
11
12
Time [Month]

20



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Conclusion

Validation Case

- Temperature expected to be a determining factor
- Humidity will be more challenging (addition of sources?)

Simulation

- Need for better understanding of the influence of the sun
- Internal walls
- Coupled thermal and pressure simulations

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FACULTY OF ENGINEERING AND ARCHITECTURE

Ir. Arch Klaas De Jonge

PhD student, FWO Strategic Basic Researcher

Promotor: Prof. Ir. Arch Jelle Laverge

RESEARCH GROUP OF BUILDING PHYSICS

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Project reference 1SA7619N

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1

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RETROFITTING CAN LEAD TO POOR AIR QUALITY EXAMPLE SOCIAL HOUSING IRELAND

IAP average concentrations before and after the retrofit in HB dwellings (n = 8) and significance levels.

Pollutant HB	Before		After		*p*- value*
	Mean	SD	Mean	SD	
$PM_{2.5}$ (µg/m^3)[a]	9.33	2.60	15.34	3.89	0.008*
CO_2 (ppm)[a]	565.69	66.28	671.94	58.59	0.003*
CO (ppm)[a]	0.21	0.16	0.43	0.45	0.269
Formaldehyde (ppb)[a]	14.33	2.52	18.3	4.23	0.089
TVOC (ppb)[a]	375.63	74.43	461.88	52.25	0.032*
Benzene (ppb)[b]	0.69	0.35	0.52	0.16	0.259
Toluene (ppb)[b]	3.69	2.09	2.08	1.02	0.134
Ethylbenzene (ppb)[b]	1.03	0.64	1.83	1.28	0.259
O- Xylene (ppb)[b]	0.85	0.49	1.72	1.06	0.113
MP-Xylene (ppb)[b]	1.01	0.27	1.09	0.87	0.804
NO_2 (ppb)[b]	6.84	7.42	5.96	3.57	0.534

After retrofit:
- More airtight
- Less ventilation flow

Broderick 2017

2

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SOURCES OF PM 2.5 IN DWELLINGS

Sources	Concentration (µg/m^3)
Cooking	2000
Hair spray	140
Deodorant spray	350
Outdoor fireworks	75
Candles	40
Children playing	35
Recoil of smoke from a stove	35
Fire pit in the back garden	50

Jacobs 2017

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ROLE OF VENTILATION TO IMPROVE IAQ

- avoid the emission of contaminants
- source control, encapsulate, local exhaust
- mixing, dilution ventilation
- stand-alone air purifiers

COMPLEXITY TO INSTALL MEASURES IS IMPORTANT ASPECT FOR SUCCES



versus





range hood with local exhaust

recirculation hood

REPORTED EFFECTS OF MEASURES

Contaminant	Type	Measure	Effect	Com-plexity	Literature ref.
PM2.5 by smoking	Elimination	Stop with smoking inside	100%	Low	
NO2 gas cooking	Elimination	Electric cooking	100%	Middle	
PM2.5	Elimination	LED candles and tea lights	100%	Low	
PM2.5, soot	Elimination	No use of fireplace or wood stove	100%	Low	
Phthalates	Elimination	Removal of PVC flooring in bedrooms	?	Middle	Shu 2014
PM2.5 due to frying	Local exhaust	Hood 95 dm3/s, cooking on front burners	75%	Middle	Singer 2012
		Hood 83 dm3/s, cooking of 4 Dutch meals	> 93%	Middle	O'Leary 2019
		Hood 83 dm3/s, not covering front burners	70%	Middle	VentKook
		Hood 21 dm3/s (Dutch Building Code)	50%	Low	2018
		Hood 21 dm3/s, not covering front burners	25%	Low	
NO2 gas cooking	Local exhaust ventilation	Hood with exhaust to ambient	67%	Middle	Logue 2014
PM2.5 frying	Local exhaust & Filtering	Recirculation hood	< 30%	Low	Jacobs, 2017
PM2.5	Filtering & local supply	HEPA filters in breathing zone asthmatic	99%	Low	Fisk 2013

TKI BE AWARE

- Goal: Sources of indoor air pollutants
- One year measurement campaign
- Optical particle sensors in 100 Dutch dwellings
- 50 percentile emissions patterns for $PM_{2.5}$ have been set up.





100 x



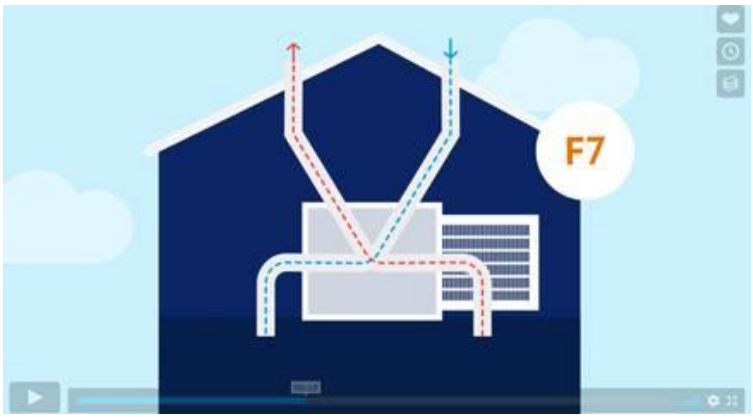








EFFECT OF RANGE HOOD COMBINED WITH FILTERING



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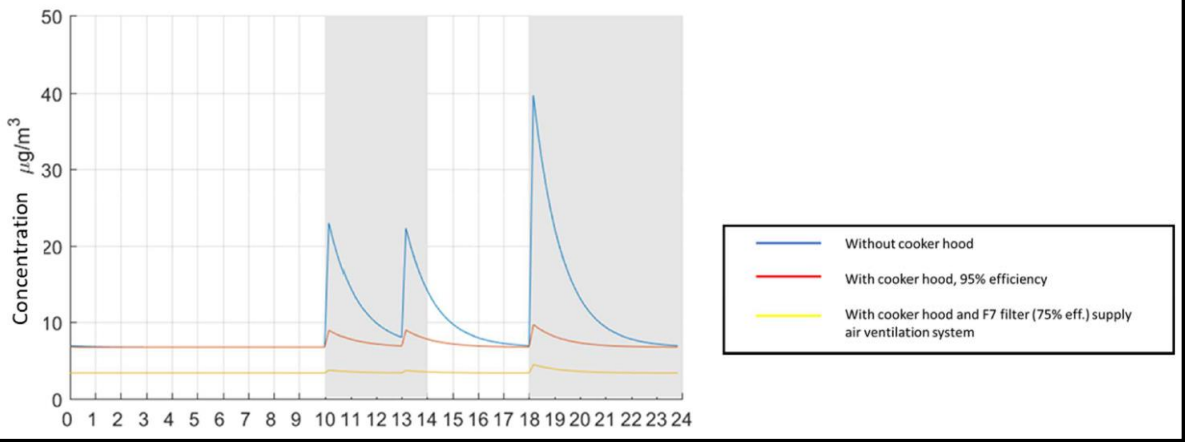
EFFECT OF COOKER HOOD COMBINED WITH FILTERING



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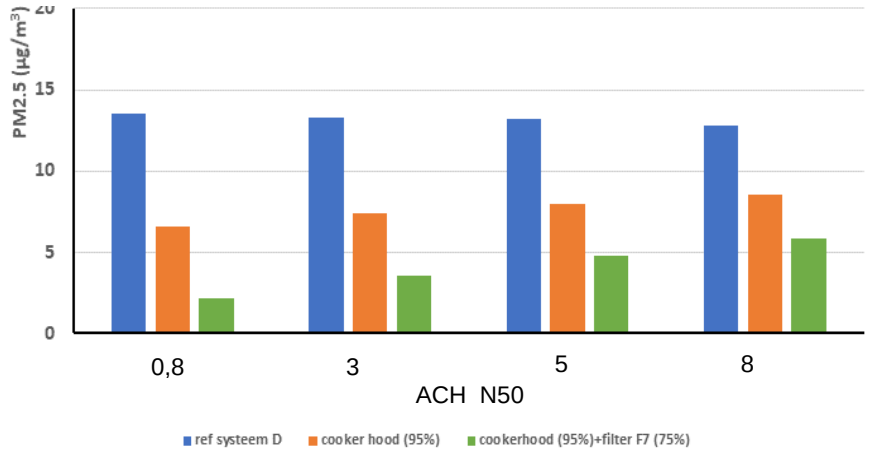
AVERAGE EXPOSURE TO $PM_{2.5}$ IN LIVING ROOM / KITCHEN WITH DIFFERENT MEASURES



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10

TYPICAL SCENARIO FOR A PERSON TO CALCULATE EXPOSURE

Day of the week	bedroom [hour]	livingroom [hour]	outdoor [hour]	work [hour]
Table content				
Monday	9	5	2	8
Tuesday	9	5	2	8
Wednesday	9	5	2	8
Thursday	9	5	2	8
Friday	9	5	2	8
Saturday	9	10	5	0
Sunday	9	10	5	0

AVERAGE YEARLY EXPOSURE AT THREE AMBIENT CONCENTRATIONS FOR DIFFERENT SCENARIOS

Ambient air concentration [µg/m^3]	1	1	11,5	11,5	22	22
Exposure according scenario	[µg/m^3]	reduction	[µg/m^3]	reduction	[µg/m^3]	reduction
C, no cooker hood (reference)	3,0		7,4		11,8	
C, with cooker hood	0,7	76%	5,3	29%	9,8	17%
C, with air cleaner	0,9	70%	3,2	57%	4,7	60%
C, with cooker hood & air cleaner	0,4	86%	2,6	65%	4,7	60%
D, no cooker hood (reference)	2,5		8,2		13,8	
D, with cooker hood	0,8	67%	6,6	20%	12,3	11%
D, cooker hood + F7 filter	0,6	75%	4,3	48%	8,0	43%
D, with air cleaner	1,0	58%	3,8	54%	6,5	53%
D, with cooker hood & air cleaner	0,5	80%	3,3	60%	6,0	56%
D, as previous + F7 filter	0,4	83%	2,5	69%	4,6	67%

STRATEGIES TO IMPROVE INDOOR AIR QUALITY

- STROOMVERSNELLING:
- Standardized API for monitoring dwellings
- Standardized data available for energy and indoor air quality
- Dutch housing corporations adapted this standard for billing and comparison

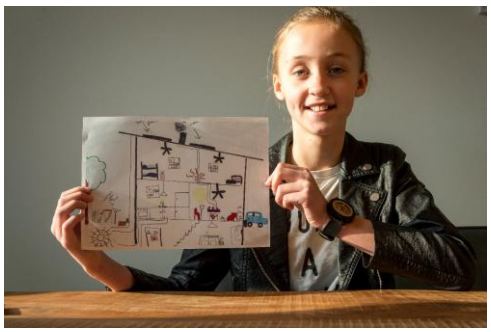




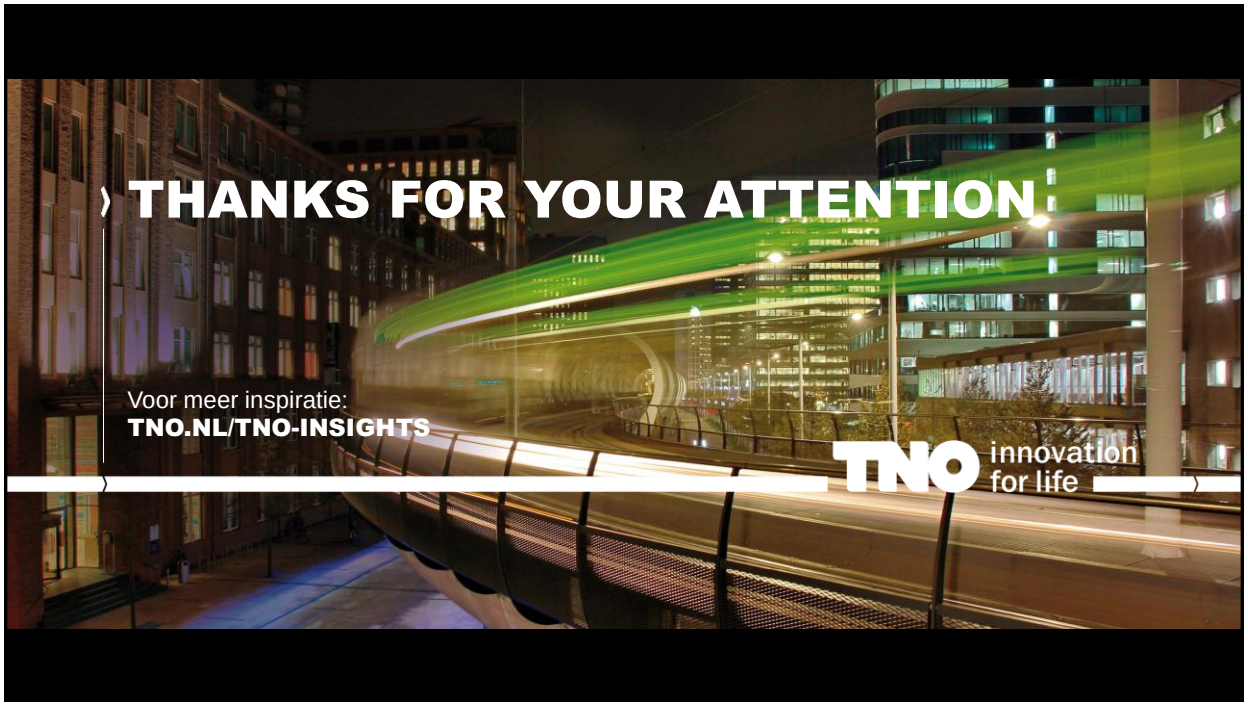
Application programming interface

"*BUILD TIGHT AND VENTILATE RIGHT*" AND....

- Eliminate avoidable harmful emissions from pollutants;
- Local extraction for indoor sources and filtering for outdoor sources;
- Smart control of the well-designed ventilation systems.
- Stand-alone filtering for unavoidable sources.



"gezond aardgasloos voor professionals"


THANKS FOR YOUR ATTENTION
Voor meer inspiratie:
TNO.NL/TNO-INSIGHTS
TNO innovation for life

Overall introduction on the EPBD article 19a with specific attention on inspection of stand-alone ventilation systems

P. Wouters

Manager INIVE EEIG

Agenda of this session

- **Overall introduction and context**
  - P. Wouters – INIVE-BBRI
- **Overview of existing experiences with relevance to the inspection of stand-alone ventilation systems**
  - F. Durier – INIVE-CETIAT
- **Selection of policy options for inspections of stand-alone ventilation systems and analysis of related potential impacts**
  - A. Janssens – UGent
- **Interactive voting**
  - P. Wouters – INIVE-BBRI

Article 4
Setting of minimum energy performance requirements

(already in 2003 edition of EPBD)

- …
- These requirements shall **take account of general indoor climate conditions**, in order to avoid possible negative effects such as **inadequate ventilation**, as well as local conditions and the designated function and the age of the building.
- …

What is happening in practice?
How is the IAQ?

Article 9a
Feasibility study

The Commission shall, before 2020, conclude **a feasibility study**, clarifying the **possibilities and timeline to introduce**

- **the inspection of stand-alone ventilation systems** and
- an optional **building renovation passport** that is complementary to the energy performance certificates, in order to provide a long-term, step-by-step renovation roadmap for a specific building based on quality criteria, following an energy audit, and outlining relevant measures and renovations that could improve the energy performance.'.


Feasibility
Funded by the
EPBD
Feasibility study 19a
Inspection of ventilation systems
Following Article 19a of the EPBD Directive 2018/844/EU, this study will assess the relevance and feasibility to introduce EU provisions for the inspection of stand-alone ventilation systems in buildings.
Home
About us
Stakeholders interaction & Meetings
Documents
Building renovation passport
Following Article 19a of the EPBD Directive 2018/844/EU, this study encompasses an assessment of the relevance and feasibility of introducing an EU approach (either voluntary or mandatory) to the concept of building renovation passport.
Home
About us
Stakeholders interaction & Meetings
Documents
1ST STAKEHOLDERS MEETING: BRUSSELS, 24 JUNE 2019
2ND STAKEHOLDERS MEETING: BRUSSELS, 28 NOVEMBER 2019

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Feasibility stu
EPBD
Feasibility study 19a
Funded by the
Inspection of ventilation systems
Building renovation passport
HOME
ABOUT US
STAKEHOLDERS INTERACTION & MEETINGS
DOCUMENTS
About Us
Who we are
The EPBD Article 19a feasibility study on the "inspection of stand-alone ventilation systems" is explored by a team of acknowledged collaborators under the lead of INIVE EEIG.
Funded by the
European Commission
This study is executed under the authority of the European Commission DG Energy
BCCA
REHVA
CETIAT
INIVE
bbri.be
Cerema
PB
UNIVERSITEIT GENT

6

Our scope

- Stand-alone ventilation systems, i.e. systems whose sole function is to ventilate a building;
  - combined heating and ventilation systems/combined air-conditioning and ventilation systems are covered by art. 14 and 15 of EPBD (amendment 2018)
- All types of stand-alone ventilation systems:
  - mechanical, natural, hybrid together with their controls
- All buildings except industrial buildings
- Newly-installed ventilation systems and systems already in operation

Agenda of this session

- Overall introduction and context
  - P. Wouters – INIVE-BBRI
- **Overview of existing experiences with relevance to the inspection of stand-alone ventilation systems**
  - F. Durier – INIVE-CETIAT
- Selection of policy options for inspections of stand-alone ventilation systems and analysis of related potential impacts
  - A. Janssens – UGent
- Interactive voting
  - P. Wouters – INIVE-BBRI

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Overview of existing experiences with relevance to the inspection of stand-alone ventilation systems

Francois Durier (INIVE-CETIAT)

ENER/C3/2018-447/05

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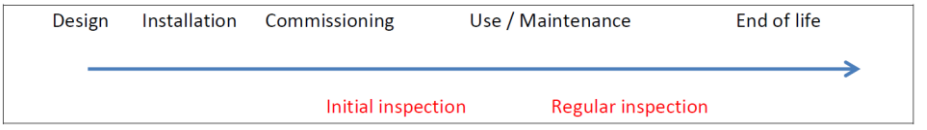
Contents

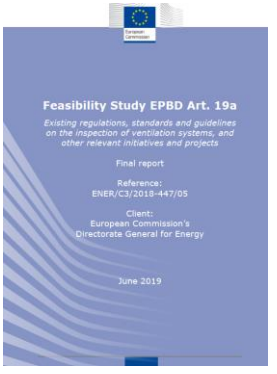
- Existing regulations, guidelines and standards on the inspection of stand-alone ventilation systems
- Stock and sales up to 2050
- Possible approaches for the inspection of stand-alone ventilation systems

Inspection

- Mandatory or voluntary, resulting from legislative measures or not
- Various possible operators:
  - installers, designers, maintenance staff, independent inspectors, others
- Various inspection objectives:
  - Good operation, ductwork airtightness, air flow rates, energy efficiency, indoor air quality, system cleanliness, thermal comfort, noise level, etc.
- Various levels of inspection: from simple visual check to detailed measurements



Existing regulations, guidelines and standards on the inspection of stand-alone ventilation systems



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Existing regulations, standards and guidelines

- Regulations
  - Mandatory inspection in Belgium (Region of Flanders), Finland, Ireland, Sweden
  - Checking of ventilation systems required in France, Poland, Portugal, U.K.
  - Regulations on inspection of ventilation systems in workplaces in several countries
- Standards
  - 11 EN standards (including 6 for ductwork)
  - Some national standards
- Guidelines
  - 47 guidelines
  - Austria, Belgium, Finland, France, Germany, Ireland, Netherlands, Poland, Sweden, United Kingdom, Switzerland, Turkey, USA

Few documents dedicated to inspection: mostly for installation, commissioning, maintenance, including inspection

Focus on guidelines (47)



- Mainly for initial inspection.
- Mostly for residential systems
- Cover whole ventilation system or ductwork alone
- Visual checks, limited measurements or a complete set of measurements
- Mainly measurements of airflow rates
  Some measurements of fan consumption and ductwork airtightness.
  Measuring indoor air quality and noise is rare.
- Most of the guidelines to be used by installers.
- Reporting of the inspection not always described.

Measures other than inspection that can support better performance of stand-alone ventilation systems

- Increasing awareness on ventilation (users, owners, professionals, policy makers)
- Easier access to product data, certification of product performances
- Education/training of professionals
- Qualification, certification, quality assurance for design, installation, commissioning and maintenance
- Regulations with requirements on the indoor environment (IAQ, noise, etc.), including measurements
- Stimulating the use of smart ventilation systems

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Stock and sales up to 2050

Feasibility Study EPBD19a

Stock of ventilation systems in EU buildings and foreseen evolution for 2030, 2040 and 2050

Final report

www.epbd19a.eu

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Current stock

(from consolidation of existing data - in thousands units)

	Residential								Non-residential	
Year 2020	Decentralised unidirectional units		Central unidirectional units		Residential central balanced units		Residential local balanced units		Non-resid. central unidir. units	Non-resid. central balanced units
Mean value for different sources	**92,032**		**32,868**		**4,052**		**958**		**4,726**	**4,329**
Min and max from different sources	61,053	124,547	14,441	50,631	1,111	8,646	51	2,294		
VHK 2019 +2014			37,438		7,492		2,439		4,726	4,329

Table 6: Stock 2020

+ stock of natural ventilation systems: in 2003, 37 million (source: FGK)

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Sales 2020

(from consolidation of existing data – in thousands units)

	Residential								Non-residential	
Year 2020	Decentralised unidirectional units		Central unidirectional units		Residential central balanced units		Residential local balanced units		Non-resid. central unidir. units	Non-resid. central balanced units
Mean value for different sources	**5,105**		**1,948**		**647**		**196**		**291**	**302**
Min and max from different sources	4,237	5,966	928	2,768	305	870	63	343		
VHK 2019 +2014			1,949		816		302		291	302

Table 7: Sales 2020

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Evolution of the stock

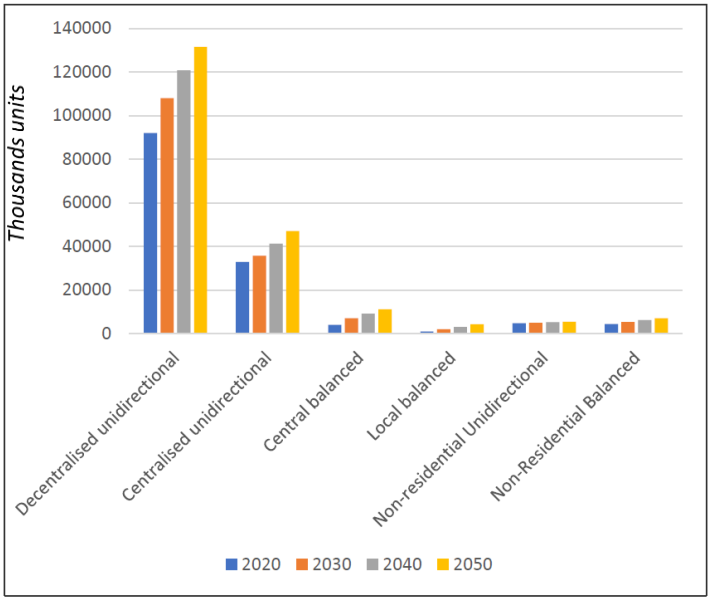

Figure 4: Evolution of the stock for mechanical ventilation systems

From 139 million in 2020

to 206 million in 2050

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Possible approaches for the inspection of stand-alone ventilation systems

Report available soon at www.epbd19a.eu

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Questions to build an inspection scheme

TECHNICAL ASPECTS	
Aim of inspection	Which performance to be inspected?
Targets of inspection	Who should benefit from inspection? What types of buildings should be covered? What types of ventilation systems should be inspected? Which climatic zones should be concerned? Which period of the year should be concerned?
Rules for inspection	What are the aspects covered by inspection (technical procedure)? What are the parts of ventilation system to be inspected? Is there a sampling of ventilation systems to be inspected?
In-situ measurements	What are the measured quantities? What are the measuring instruments? What is the measuring uncertainty? What is the calibration frequency of measuring instruments? What is the calibration procedure?
Reporting about inspection	What is the content of the report? What are the compliance criteria? What is the acceptable deviation for deciding on compliance? Who receives the report? Who keeps the report?

ORGANISATIONAL ASPECTS	
Periodicity of inspection	Does inspection occurs once or is it regular? When does inspection occur?
Inspectors	By who is inspection operated? Is there a need for quality assurance? Is there a need for training of inspectors? Is there a need for the qualification of inspectors? Is there a need for the certification of inspectors? Is there a surveillance of inspectors?
Non-compliance	What are the sanctions if inspection is not operated according to the defined rules?
Status	Is the inspection voluntary or mandatory?
Conformity to legislation	Is the inspection scheme in conformity with the legislations?
Economy	What is the cost of the inspection? Who is going to pay? What are the benefits?
Stakeholders	Who are the stakeholders involved in the implementation of the inspection scheme? Who are the stakeholders involved in the operation of the scheme? What is the role of public authorities? How is surveillance organised?
Other aspects	Does the inspection scheme create a market differentiation? Will the inspection scheme get societal support? Does the inspection scheme create barriers to innovation? Does the inspection scheme generate any risk?

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Answers to each question (= modules)

			TECHNICAL ASPECTS							
AIM	AIM	1-WHICH PERFORMANCE TO BE INSPECTED?	Energy performance	Air flow rates, air change	Indoor air quality	Hygiene of the ventilation system	Noise	Thermal comfort (draughts, temperature gradient)	Overall well-being of occupants	Overall well-being of neighborhood
TARGETS	TAR	1-TARGET POPULATION BENEFITING FROM INSPECTION	Occupants	Owners	Workers	Children	Elderly people	Persons with low revenues		
		2-TYPE OF BUILDING SUBMITTED TO INSPECTION	All residential	Single-family house	Multi-apartment buildings	All non-residential	Offices	Retail buildings	Educational buildings	Health care facities
		3-TYPE OF VENTILATION SYSTEM SUBMITTED TO INSPECTION	Natural	Hybrid	Mechanical decentralised unidirectional	Mechanical decentralised balanced without heat recovery	Mechanical decentralised balanced with heat recovery	Mechanical centralised unidirectional	Mechanical centralised balanced without heat recovery	Mechanical centralised balanced with heat recovery
		4-CLIMATIC ZONE FOR INSPECTION	All climatic zones	Average	Cold	Warm				
		5-PERIOD OF THE YEAR FOR INSPECTION	All year	Warm season	Cold season	Mid-season				
RULES	RUL	1-ASPECTS COVERED BY INSPECTION	Completeness	Adequacy between design and installation	Cleanliness and hygiene	General state	Good overall operation	Good operation of controls	Occupants satisfaction	Energy consumption (from energy invoices)
		2-PARTS OF VENTILATION SYSTEMS TO BE INSPECTED	Whole system	Ductwork	All system components	Ventilation unit	Air inlets	Air outlets	Air transfers	Controls
		3-SAMPLING RULES FOR INSPECTION	Each system	A sample of the systems	A sample of the buildings					
IN SITU MEASUREMENTS	MEA	1-MEASURED QUANTITIES	Air flow rates at fan level	Air flow rates at room level	Air pressures at fan level	Air pressures at room level	Ductwork airtightness	Electrical consumption	Performance of heat recovery	Indoor air quality parameters
		2-MEASURING INSTRUMENTS	Flow meter	Anemometer	Manometer	Wattmeter	Thermometer	Pollutant concentration analyser	Noise analyser	Hygrometer
		3-MEASURING UNCERTAINTY	No uncertainty	Fixed uncertainty	Uncertainty of the measurement method	Uncertainty of the measuring instrument				

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Description of a module (example)

Module's name	Description	Advantages / Drawbacks of the presence of this module in the inspection		Comments on the feasability (if any)
Completeness	This type of inspection consists in checking the completeness of the system, i.e. to verify that all components are present and that their assembly seems correct. Checking completeness relies on visual inspection, and ideally on a comparison between available documents describing the system and the actual installation. Checking completeness also includes a verification of the electrical connections and on the ductwork circuits: this can be checked for example by dismounting air inlets/outlets to check that they have been correctly connected to a duct.	Advantages:	This type of inspection can take place on the system out of operation.	
		Drawbacks:	If this inspection is made on a system out of operation, the correct direction of rotation of the fan and the detection of abnormal noise, vibrations or significant air leakage cannot take place. It can happen that parts of the system are not easily accessible to visual check: in such a case, the inspection report should mention which parts of the system have not been inspected.	

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Building an inspection scheme

			TECHNICAL ASPECTS							
AIM	AIM	1-WHICH PERFORMANCE TO BE INSPECTED?	Energy performance	Air flow rates, air change	Indoor air quality	Hygiene of the ventilation system	Noise	Thermal comfort (draughts, temperature gradient)	Overall well-being of occupants	Overall well-being of neighborhood
TARGETS	TAR	1-TARGET POPULATION BENEFITING FROM INSPECTION	Occupants	Owners	Workers	Children	Elderly people	Persons with low revenues		
		2-TYPE OF BUILDING SUBMITTED TO INSPECTION	All residential	Single-family house	Multi-apartment buildings	All non-residential	Offices	Retail buildings	Educational buildings	Health care facities
		3-TYPE OF VENTILATION SYSTEM SUBMITTED TO INSPECTION	Natural	Hybrid	Mechanical decentralised unidirectional	Mechanical decentralised balanced without heat recovery	Mechanical decentralised balanced with heat recovery	Mechanical centralised unidirectional	Mechanical centralised balanced without heat recovery	Mechanical centralised balanced with heat recovery
		4-CLIMATIC ZONE FOR INSPECTION	All climatic zones	Average	Cold	Warm				
		5-PERIOD OF THE YEAR FOR INSPECTION	All year	Warm season	Cold season	Mid-season				
RULES	RUL	1-ASPECTS COVERED BY INSPECTION	Completeness	Adequacy between design and installation	Cleanliness and hygiene	General state	Good overall operation	Good operation of controls	Occupants satisfaction	Energy consumption (from energy invoices)
		2-PARTS OF VENTILATION SYSTEMS TO BE INSPECTED	Whole system	Ductwork	All system components	Ventilation unit	Air inlets	Air outlets	Air transfers	Controls
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		2-MEASURING INSTRUMENTS	Flow meter	Anemometer	Manometer	Wattmeter	Thermometer	Pollutant concentration analyser	Noise analyser	Hygrometer
		3-MEASURING UNCERTAINTY	No uncertainty	Fixed uncertainty	Uncertainty of the measurement method	Uncertainty of the measuring instrument				

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Ongoing work: impact analysis of 6 options

1. Better knowledge about the status on the ground in combination with awareness raising of stakeholders
2. Professionals skills increase through training
3. Mandatory visual inspection of new residential systems
4. Mandatory inspection of new residential systems with air flow rates measurements at room level
5. Same as 4 + obligation to make the system compliant
6. IAQ measurements

Selection of policy options for inspections of stand-alone ventilation systems and analysis of related potential impacts

Arnold Janssens (UGent)

Yanaika Decorte (UGent), Francois Durier (INIVE-CETIAT), Peter Wouters (INIVE-BBRI)

ENER/C3/2018-447/05

Contents

- Possible approaches for the inspection of stand-alone ventilation systems
- Impact analysis specifications
- Proposed methodology
- Preliminary results

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Ongoing work: impact analysis of 6 options

1. Better knowledge about the status on the ground in combination with awareness raising of stakeholders
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5. Same as 4 + obligation to make the system compliant
6. IAQ measurements

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Impact analysis specifications

- Analysis of the potential impacts of each policy option until 2030, 2040 and 2050
- Account for different scenarios based on:
  - the evolution of the building stock,
  - the evolution of the use of ventilation systems in buildings,
  - possible additional supporting measures
- Quantify benefits or effects along these criteria:
  - Energy
  - CO_2 emissions
  - Wider benefits including comfort, indoor air quality, well-being and health

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Proposed methodology

BUILDING STOCK DATA (5 regions and EU)

MARKET SHARE OF VENTILATION SYSTEMS (5 regions and EU)

2020
2025 - … with estimation of impact of options

IMPACT OF OPTIONS ON VARIOUS PERFORMANCES

Energy and IAQ INDICATORS (results per m²)

ESTIMATION OF TOTAL ENERGY CONSUMPTION AND IAQ

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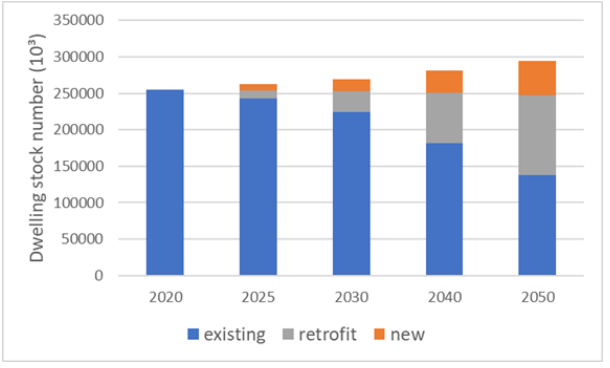
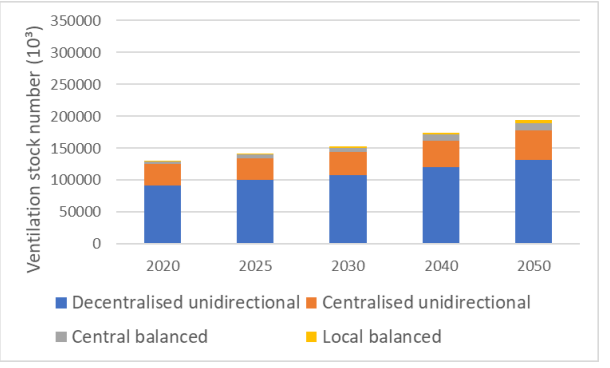
Assumed evolution of the use of ventilation systems in buildings (1)

- Evolution of dwelling stock
  - SRI-study (BEAM-model)



- Evolution of residential ventilation stock
  - Task 1 report



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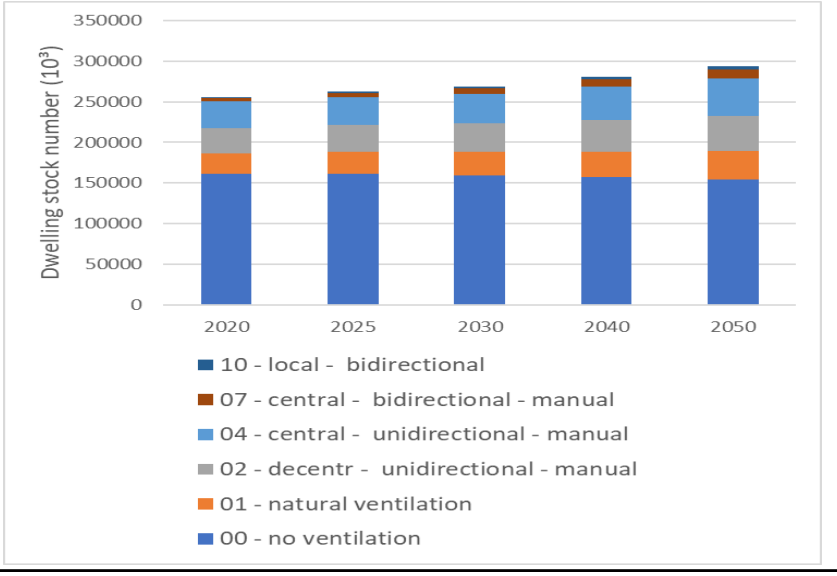
Assumed evolution of the use of ventilation systems in buildings (2)



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Assumed evolution of the use of ventilation systems in buildings (3)

ventilation types				
00 -	no	ventilation		00 - no ventilation
01 -	natural	ventilation		01 - natural ventilation
02 -	decentr -	unidirectional -	manual	02 - decentr - unidirectional - manual
03 -	decentr -	unidirectional -	DCV	03 - decentr - unidirectional - DCV
04 -	central -	unidirectional -	manual	04 - central - unidirectional - manual
05 -	central -	unidirectional -	DCV	05 - central - unidirectional - DCV
06 -	central -	unidirectional -	DCV smart	06 - central - unidirectional - DCV smart
07 -	central -	bidirectional -	manual	07 - central - bidirectional - manual
08 -	central -	bidirectional -	DCV	08 - central - bidirectional - DCV
09 -	central -	bidirectional -	smart	09 - central - bidirectional - smart
10 -	local -	bidirectional		10 - local - bidirectional

8

Assumed evolution of the use of ventilation systems in buildings (4)

- Reference evolution: within each system type, systems will shift from manually controlled systems to DC and smart systems, towards 2050
- Impact of 6 inspection options are reflected in 6 variations of the assumed evolution, considering e.g.:
  - With **increased awareness raising**, more builders might decide to **install ventilation** when renovating their house, even in countries where it is not mandatory. Also, more builders might decide to install **balanced ventilation** systems instead of natural or unidirectional systems
  - With **visual inspection** or inspection with measurements, builders who don't install a system even though it is mandatory, might be **forced to do so**
  - With **inspection with measurements**, the **shift towards smart systems** might be faster, because in these systems it is easier for installers to perform the required measurements

Calculation of ventilation related energy indicators

- Based on eco-design SEC calculation (Directive 2009/125/EC)
- Fan energy use (kWh/m²/a)

$$P_{f,p} = t_a . pef . q_{net} . f_{qual} . f_{ctr}^{x} . f_{use} . SFP$$

- Heating energy use (kWh/m²/a)

$$Q_{h,p} = t_h . \Delta T_h . \eta_h^{-1} . c_{air} . \left(q_{net} . f_{qual} . f_{ctr} . f_{use} . (1 - \eta_t) + n_{50} . H . 0.04 \right)$$

- Quality factor of design and installation f_{qual}
- Control factor of ventilation system f_{ctr}
- User impact on the air flow rate f_{use}
- Specific fan power SFP
- Heat recovery efficiency η_t

Performance parameters influenced by inspection options

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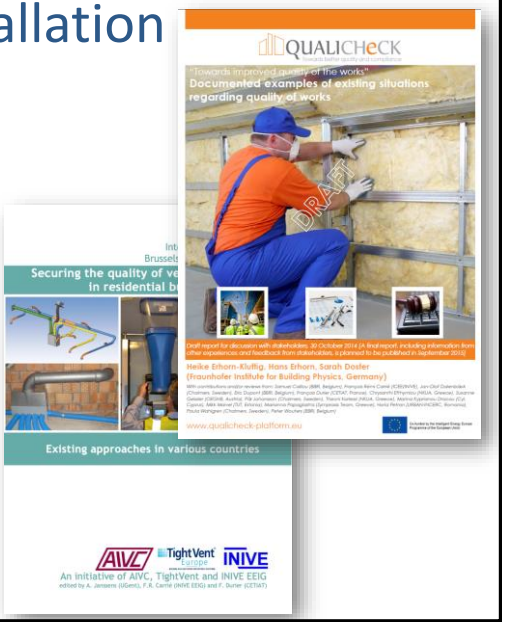
Assumptions on input data for quality of design and installation

- **AIVC-TightVent workshop** organised in 2013, where 13 countries have presented and discussed the status and perspectives with regard to the quality of residential ventilation systems
  - The vast majority of countries represented showed very poor experience with the quality of ventilation systems.
- **Qualicheck reports and fact sheets** on status on the ground about energy performance related quality and compliance



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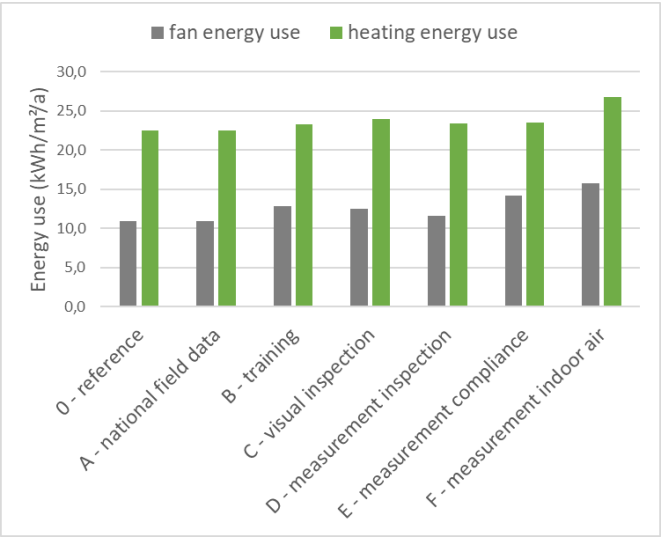
- Central-bidirectional ventilation
- Example of assumed variation of values for performance parameters
- Quality factor f_{qual}
- Heat recovery efficiency η_t

	07 - central - bidirectional - manual						
	0 - reference	A - national field data	B - training	C - visual inspection	D - measurement inspection	E - measurement compliance	F - measurement indoor air
150%	5%	5%	10%	5%	10%	20%	30%
100%	40%	40%	60%	50%	70%	80%	60%
66%	35%	35%	30%	30%	20%	0%	10%
33%	20%	20%	0%	15%	0%	0%	0%
CHECK	100%	100%	100%	100%	100%	100%	100%
[%]	77%	77%	95%	82%	98%	110%	112%
90%	10%	10%	25%	10%	10%	30%	10%
75%	40%	40%	50%	40%	60%	60%	40%
60%	30%	30%	25%	30%	30%	10%	30%
40%	20%	20%	0%	20%	0%	0%	20%
0%	0%	0%	0%	0%	0%	0%	0%
CHECK	100%	100%	100%	100%	100%	100%	100%
[%]	65%	65%	75%	65%	72%	78%	65%

Calculated energy indicators Central-bidirectional-manual control

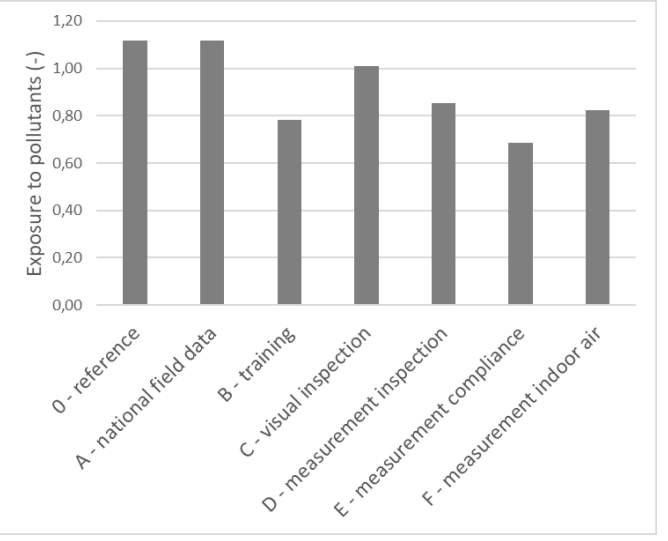


Calculation of health indicator

- Exposure dose

$$Dose_j \sim \frac{p_{qual} \cdot p_{use} \cdot p_{clim}}{q_j}$$

$$exposure\ indicator = \frac{Dose_{total}}{1/q_{net}}$$



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Proposed methodology

BUILDING STOCK DATA
(5 regions and EU)

MARKET SHARE OF VENTILATION SYSTEMS
(5 regions and EU)

2020
2025 - … with estimation of impact of scenario's

IMPACT OF SCENARIO's ON VARIOUS PERFORMANCES

Energy and IAQ INDICATORS
(results per m²)

ESTIMATION OF TOTAL ENERGY CONSUMPTION AND IAQ

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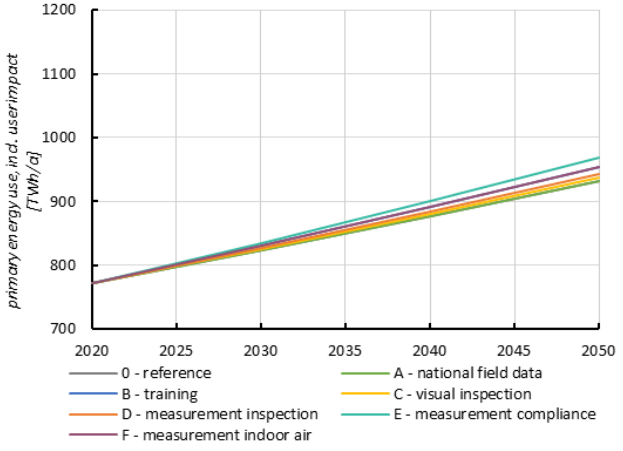
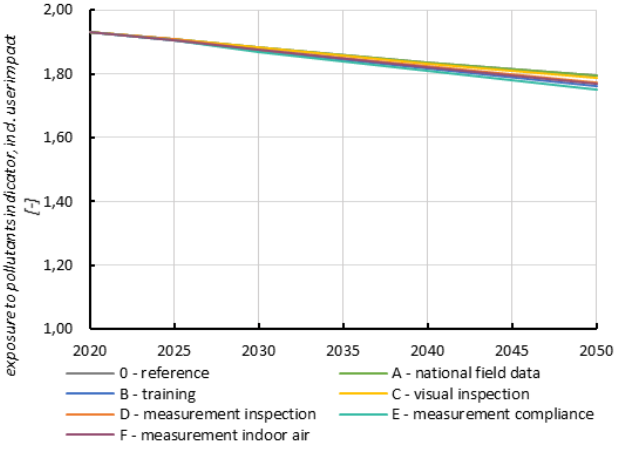
Preliminary results impact analysis at level of dwelling stock

- Primary energy use



- Mean exposure dose



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Conclusions

- Analysis of potential future impacts of policy options for inspections of stand-alone ventilation systems
  - Proposed policy options mainly directed towards new residential systems
- Impact is very sensitive to:
  - Assumed evolution of the use of ventilation systems in buildings
  - Assumptions on input data for calculation of energy and health indicators
- Preliminary results indicate that inspection schemes may reduce exposure to pollutants, not necessarily reduce energy used by stand-alond ventilation systems
- Feedback on methodology and assumptions is welcome!

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Interactive voting



1

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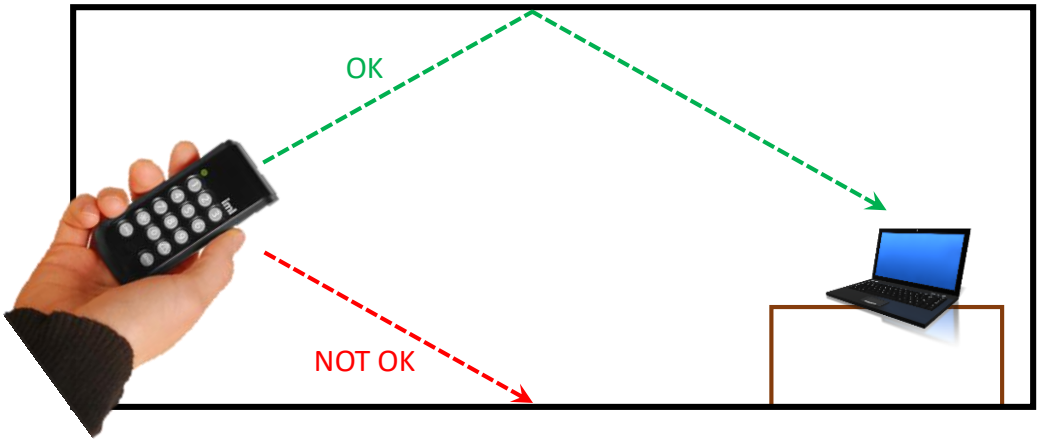
2

Wait for the green box

Please vote...

Click the button corresponding to your answer



3

OK



NOT OK



4

Vote Now

How many stars will be there in **the EU flag** in case of a hard Brexit?

1 9

2 12

3 18

4 28

5 29

6 No idea

5



6

In case of multiple answers …

OK



NOT OK



7

Which numbers are bigger than 10?

Enter Number(s) and Press Send

Vote for up to 5 choices

1. 7
2. 5
3. 12
4. 17
5. 224

OK



8



9

Vote Now

Do you believe that systematic inspections of newly installed ventilation systems should be considered?

1 Yes, mandatory

2 Yes, but as a voluntary system

3 No, it is more important to focus on other measures (training or qualification of professionals, increasing occupant awareness, etc.)

4 No, not necessary

5 No opinion

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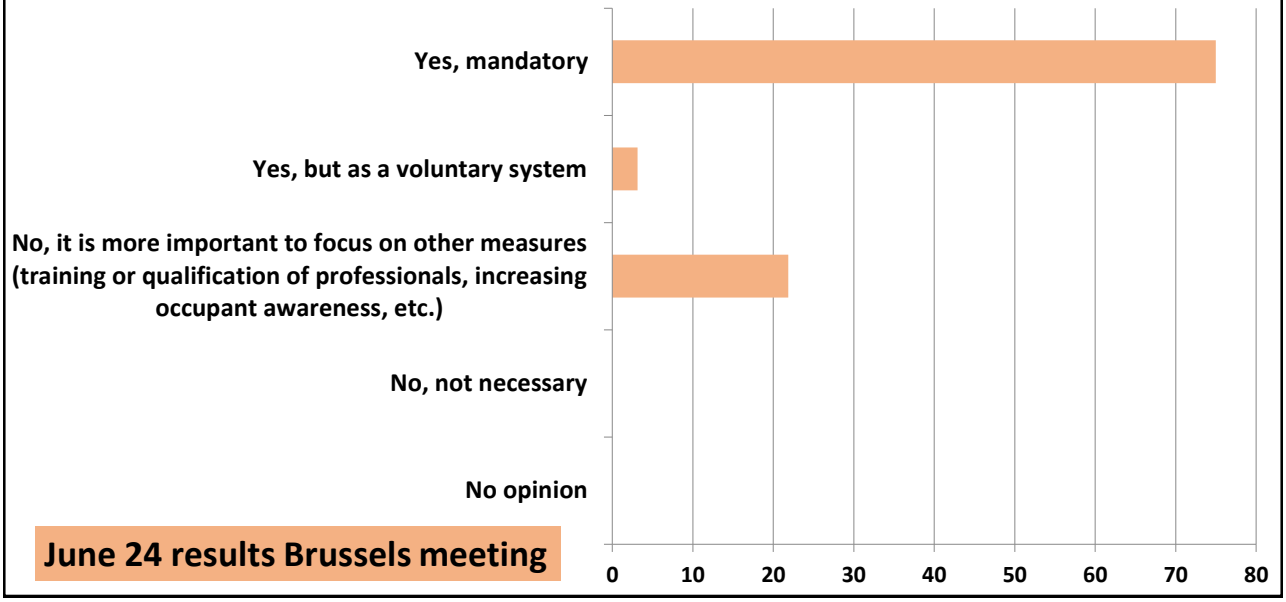
Do you believe that systematic inspections of newly installed ventilation systems should be considered?



June 24 results Brussels meeting

11

Vote Now

If there is an inspection, what should be its practical result?

1. Report - inspection has been done
2. Report with measured parameters
3. Report with results of visual inspection and measurements
4. Report with results of inspection and the target values
5. Report, as above, with recommendations for improvements
6. Report, as above, with obligation to make system IAQ compliant
7. Report, as above, with obligation to make system energy compliant
8. No opinion

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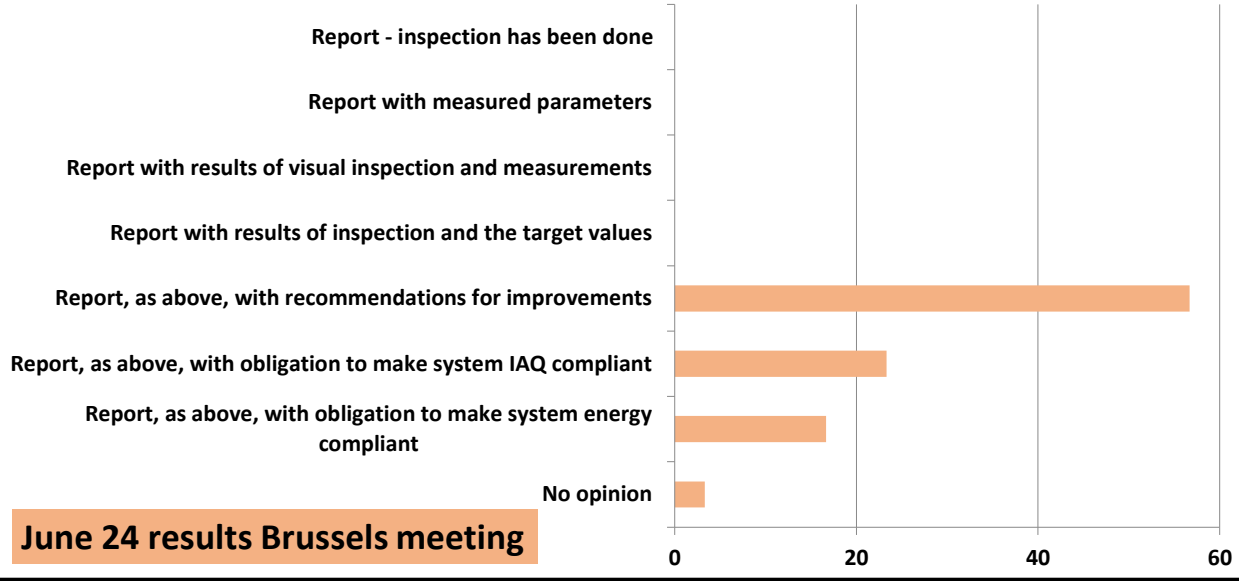
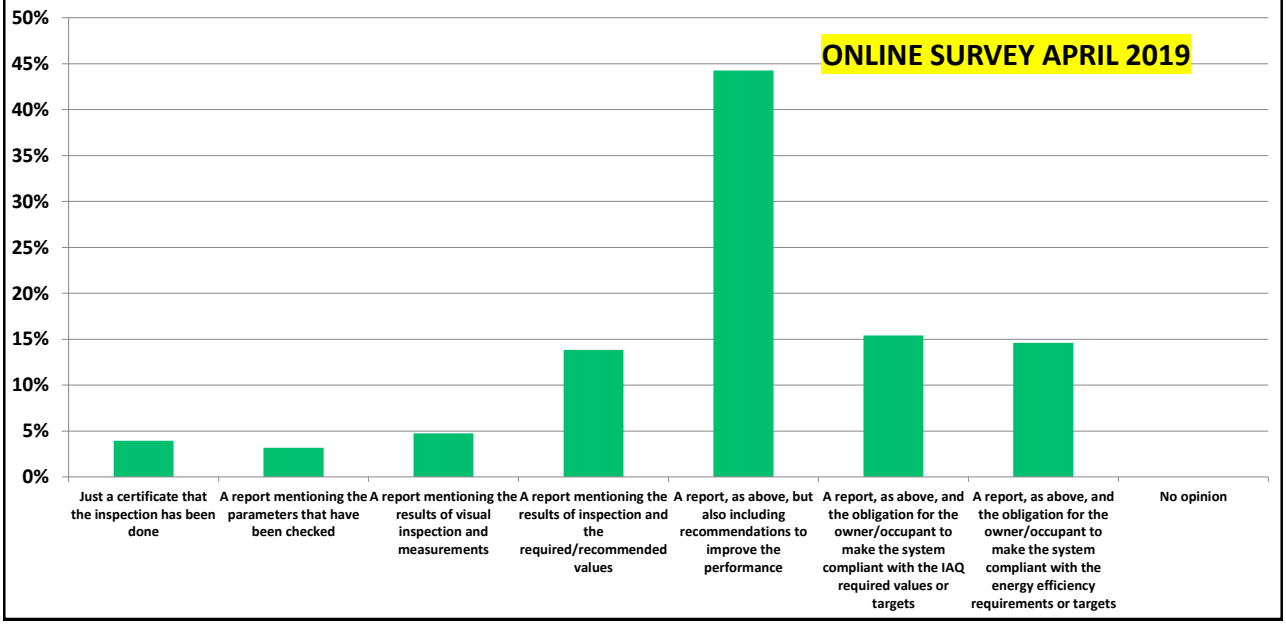
If there is an inspection, what should be its practical result?



June 24 results Brussels meeting

13

If there is an inspection, what should its practical result?



14

If there is an inspection, who should perform it?

Rank your top 5 choices in order, voting for your preferred choice first

Enter Number(s) and Press Send

1 Independent inspector

2 Designer of the installation

3 Installer

4 Maintenance staff

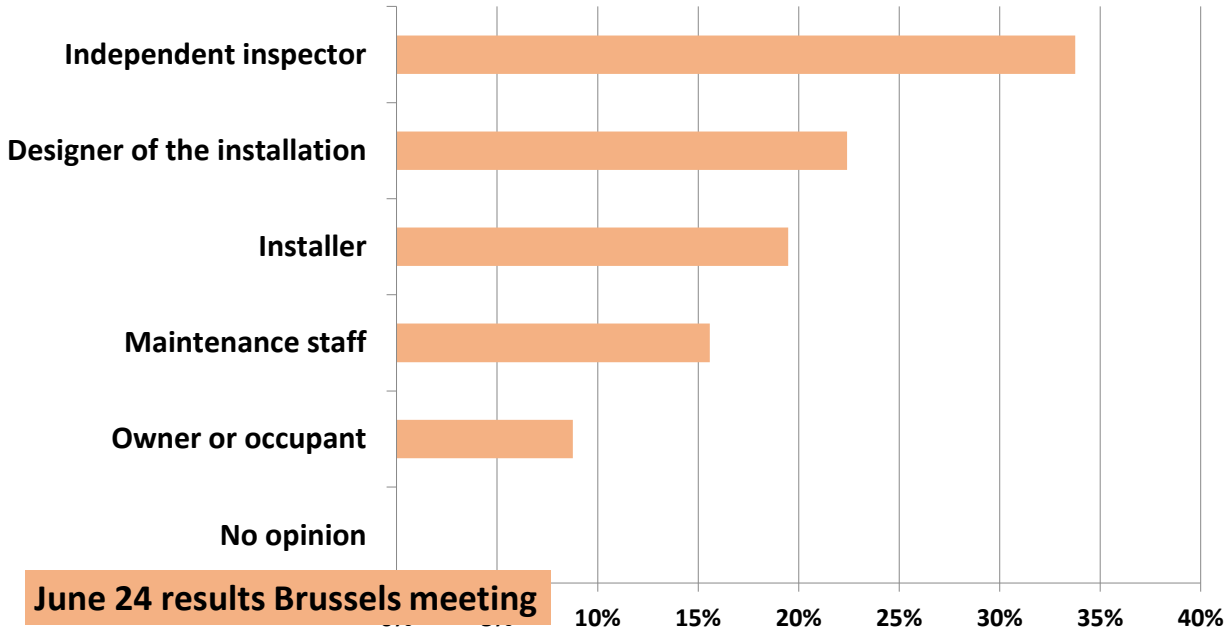
5 Owner or occupant

6 No opinion

Weighted Results: 1st Choice = 5 Points, 2nd Choice = 4 Points...

15

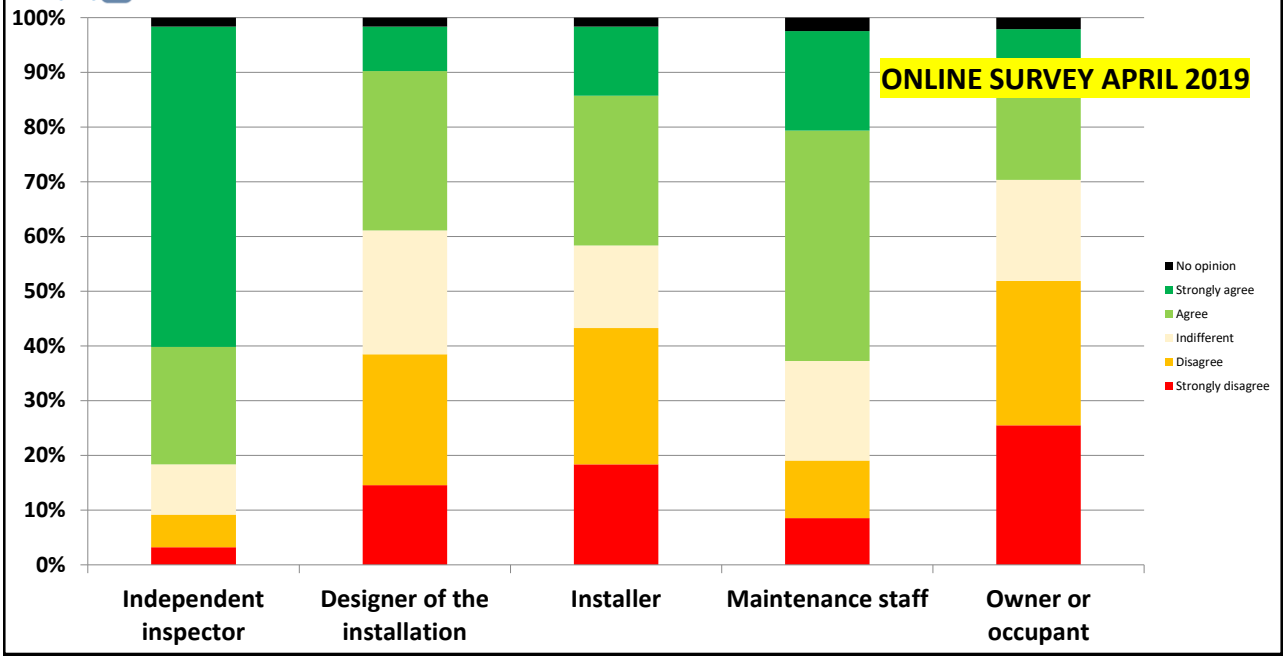
If there is an inspection, who should perform it?



June 24 results Brussels meeting

16

If there is an inspection, who should perform it?



17

What is the most efficient way to improve the performan installed ventilation systems?

Enter Number(s) and Press Send

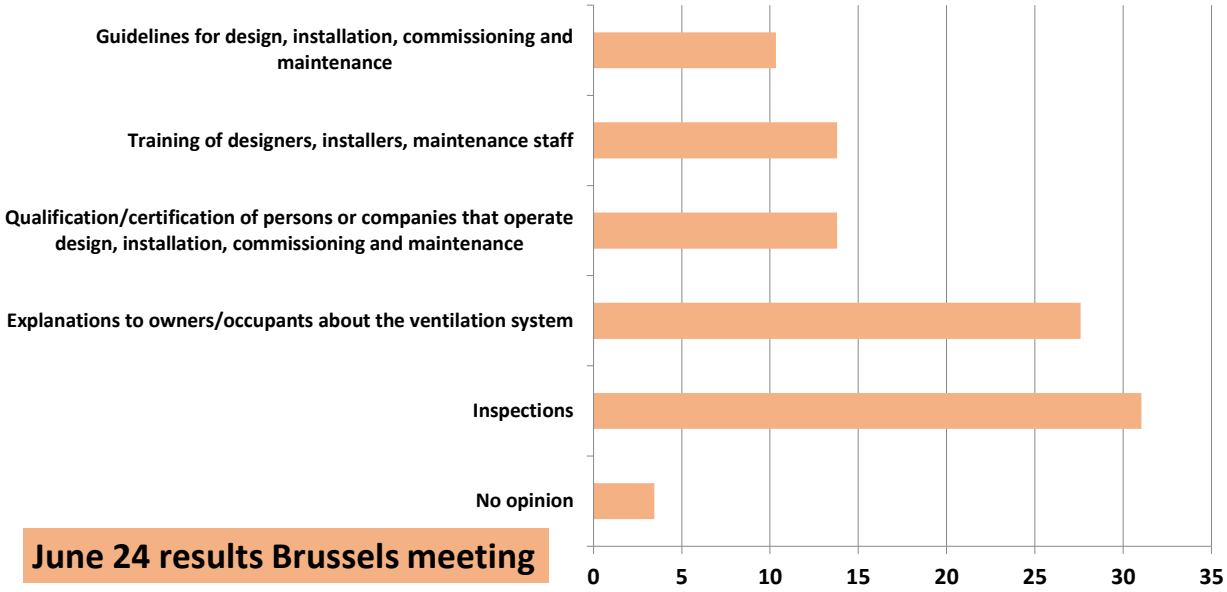
Rank your top 5 choices in order, voting for your preferred choice first

1. Guidelines for design, installation, commissioning and maintenance
2. Training of designers, installers, maintenance staff
3. Qualification/certification of persons or companies that operate design, installation, commissioning and maintenance
4. Explanations to owners/occupants about the ventilation system
5. Inspections
6. No opinion

Weighted Results: 1st Choice = 5 Points, 2nd Choice = 4 Points...

18

What is the most efficient way to improve the performance of installed ventilation systems?



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19

Vote Now

Do you think that smart ventilation systems could reduce inspection needs (e.g. by providing themselves information about their correct operation)?

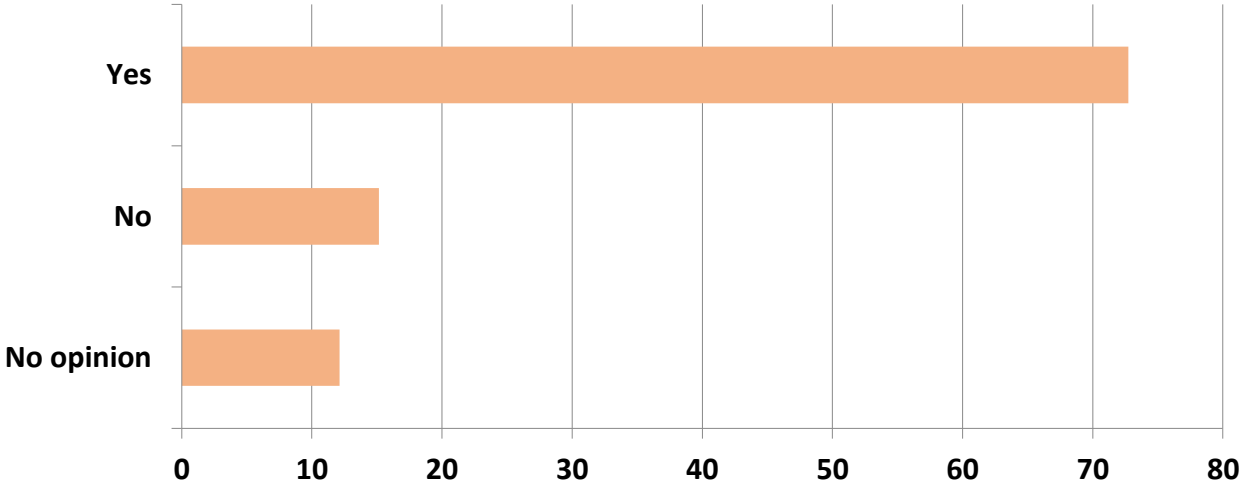
1 Yes

2 No

3 No opinion

20

Do you think that smart ventilation systems could reduce inspection needs (e.g. by providing themselves information about their correct operation)?



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Vote Now

Is there <u>in all EU countries enough awareness</u> about the performances of installed residential ventilation systems?

1. Yes, performances are known and decisions makers are aware
2. Yes, performances are known but not enough communicated
3. There are quite some countries where the performances are not known
4. The performances are not known in most countries
5. Overall, there is a lack of knowledge about the performances in practice
6. No opinion

Vote Now

To what extent can training alone improve the performances in practice of new ventilation systems?

1. Training of (designers AND installers) with examination/certification will result in good performances

17%
2. Training of installers with examination/certification will result in good performances

13%
3. Training alone does not guarantee good performances

23%
4. No opinion

47%

Sample Results

23

Vote Now

Is there in your country sufficient societal support for imposing visual inspection of new residential ventilation systems?

1. Yes

25.8%
2. There is support by most stakeholders but not by all

12.9%
3. Only a limited part of the stakeholders might support it

22.6%
4. There is no societal support

12.9%
5. No opinion

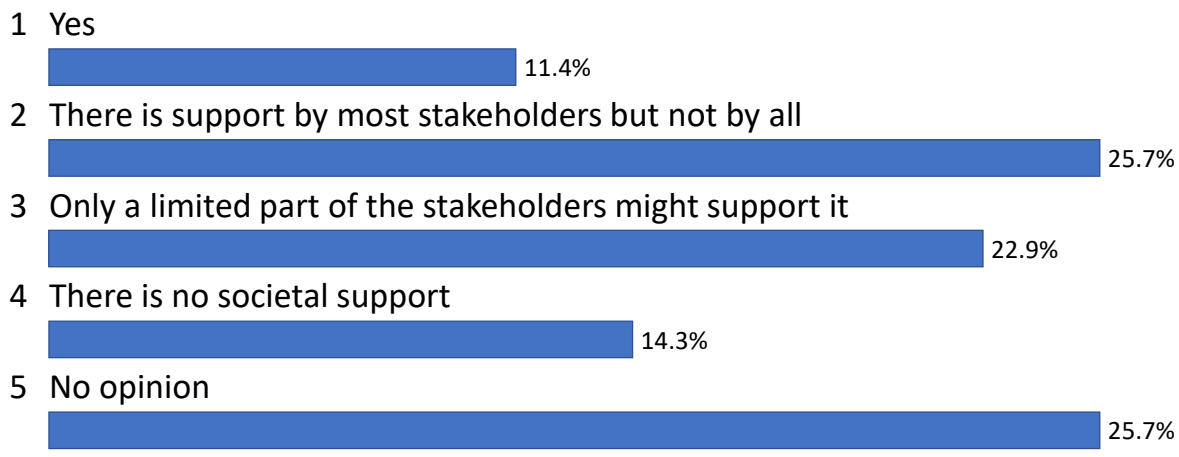
25.8%

Sample Results

24

Is there in your country sufficient societal support for imp… inspection with measurements of new residential ventilation systems?

Vote Now

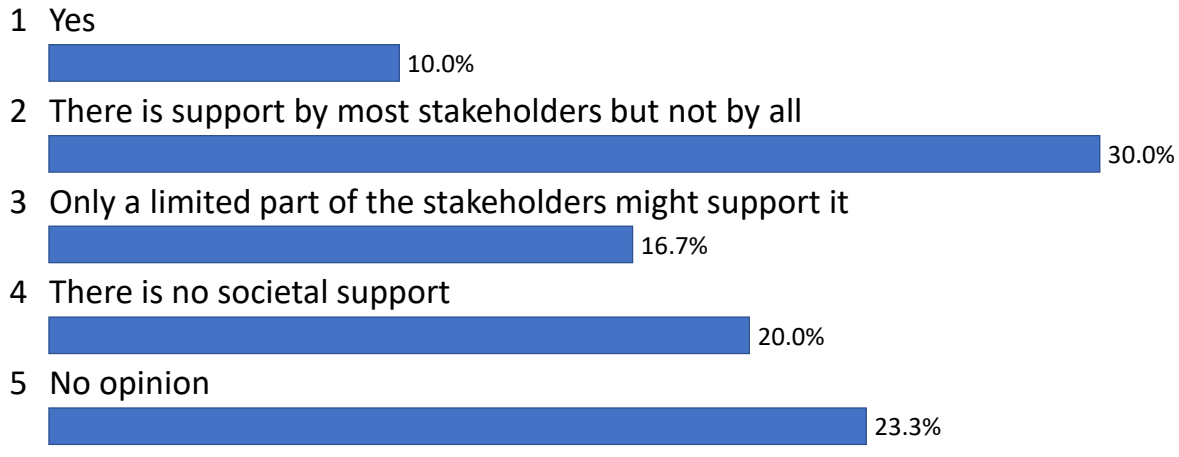


Sample Results

25

Is there in your country sufficient societal support for imp… **inspection with measurements** of new residential ventilation systems and obligation to make the system compliant?

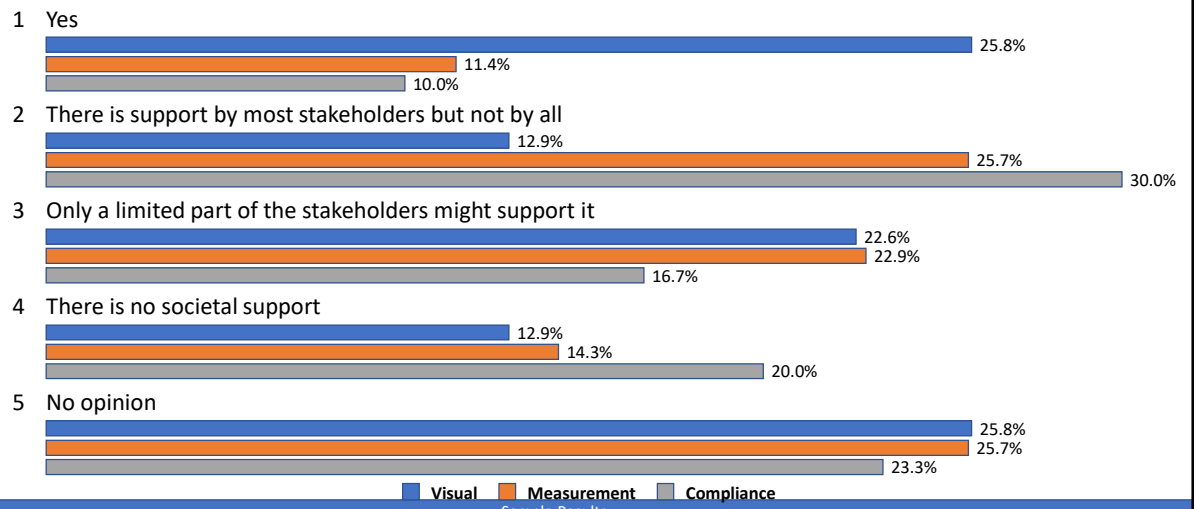
Vote Now



Sample Results

26

Is there in your country sufficient societal support for imposing inspection of new residential ventilation systems?



Sample Results

27



28

CHRISTOFFER PLESNER (VELUX A/S) / JANNICK K. ROTH (WINDOWMASTER INTERNATIONAL A/S)
OCTOBER 16, GHENT, BELGIUM

BETTER IMPLEMENTATION OF VENTILATIVE COOLING IN NATIONAL (BUILDING) STANDARDS, LEGISLATION AND COMPLIANCE TOOLS

Topical session #S3 @ AIVC conference, 2019

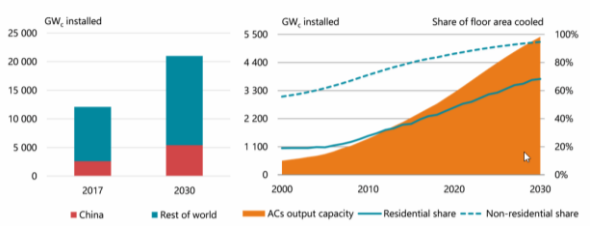
1

INTRODUCTION

Increasing energy consumption for space cooling

- Air conditioners use about 5% of all the electricity produced in the US, at an annual cost of more than $11 billion to homeowners [*]
- 50-100% increase estimate of installed output capacity for space cooling equipment from 2020 until 2030 in Rest of world/China! [**]
- Lower cooling electricity consumption leads to lower need for power generation and network capacity

- Passive cooling solutions could help on this...



(*) U.S. Department of Energy, Washington DC. 2013. http://energy.gov/energysaver/articles/air-conditioning]

(**) https://www.iea.org/publications/reports/TheFutureofCoolinginChina/

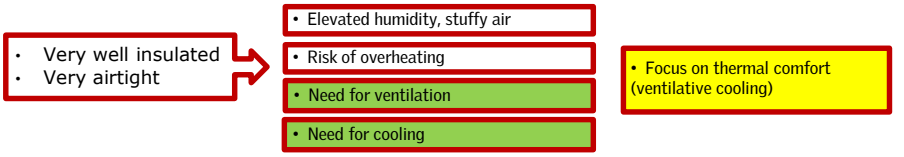
General - All

2

INTRODUCTION

High relevance for space cooling means:

- Increasingly stricter energy requirements in buildings have caused more airtight and well-insulated buildings
- Ventilative cooling of indoor spaces shows energy savings and comfort improvement potential



Focus in the past on reduction of space heating - not space cooling:

- Cooling is in many cases handled very simple

Challenges for space cooling:

- Standardisation
- Legislation
- Calculation methods

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INTRODUCTION TO VENTILATIVE COOLING

- Overheating **prevention** measures:
  - Solar shading
  - High thermal mass
- Overheating **removal** measures:
  - Active cooling
    - Air condition systems
  - **Ventilative cooling**
    - Natural ventilative cooling
      - Day ventilation
      - Night ventilation (e.g. night cooling) – combine w/thermal mass
    - Mechanical ventilative cooling
    - Hybrid ventilative cooling



"Ventilative cooling is an air system that cools a building taking ventilation air from outside at its actual temperature and humidity and should not have any mechanical pre-cooling. This may be done by natural, mechanical or hybrid means."

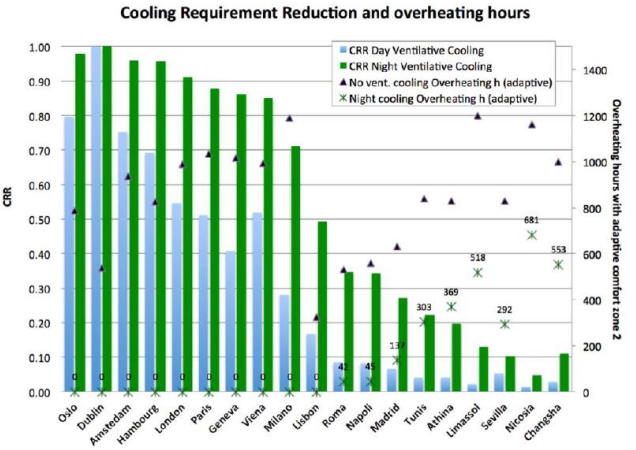
- ["Ventilative cooling systems", CEN/156/TS, 2019 (draft)]

General - All

INTRODUCTION

So what is the "ventilative cooling" potential?

- Energy saving evaluation (**CRR): [*]**
  - (% of reduction of the cooling demand of a scenario, compared to at reference scenario)
  - **0 to 1** = VC reduces the cooling need
- Very high night ventilation potential in:
  - Oslo, Dublin, Amsterdam and Hamburg → ~ 1
- Low day ventilation potential in:
  - Sevilla, Changsha (China) → ~ 0,1



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(*) IEA Annex 62 "Ventilative cooling design guide", 2018, https://venticool.eu/wp-content/uploads/2016/11/VC-Design-Guide-EBC-Annex-62-March-2018.pdf

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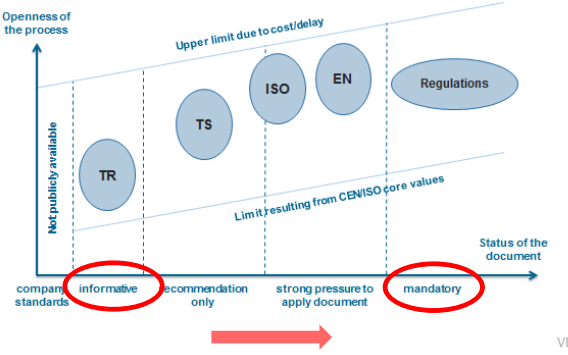
5

INTRODUCTION

- **Why talk about standards, legislation and compliance tools?**
- Standards are technical documents which can be adopted nationally
- Standards are non-binding, unless referred to in national legislation or being a harmonized standard
- Technical documents include:
  - Technical reports (informative)
  - Technical specifications (normative)
  - **Standards** (normative)
    - Strong pressure to apply document
  - Inspirations (@ different levels):
  - **National legislation/regulations**
  - **National compliance tools**



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6

PURPOSE OF WORKSHOP

- Give an insight into how "Ventilative cooling" currently is integrated into EN, ISO and national standards + in national legislation and compliance tools - with input given by national experts
- To describe the current status and future recommendations for better implementation of ventilative cooling in standards, legislation and compliance tools both in:
  - **Standards** level (National, EN and ISO)
  - **Legislation** level (National)
  - **Compliance too**l level (National) – also **known as EPC**
- To be inspired by e.g. the IEA Annex 62 report concerning "Recommendations to better implementation of ventilative cooling in standards, legislation and compliance tools" & beyond
- Help target groups (e.g. building designers) with concrete recommendations, for better future implementation of ventilative cooling, e.g.
  - How ventilative cooling is implemented
  - What can be done to improve the implementation nationally
- To make **you** join the discussion on how to improve the implementation of ventilative cooling in technical documents seen from **your** perspective

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WORKSHOP PROGRAMME

- Introduction. Christoffer Plesner, VELUX A/S, Denmark & Jannick Roth, WindowMaster International A/S, Denmark (*)
  - What is ventilative cooling and why is it important?
  - Introduction of the national experts
- Standardisation projects in CEN and ISO relevant to ventilative cooling systems. Christoffer Plesner & Jannick Roth, DK (*)

- Status & recommendations for better implementation of ventilative cooling in UK technical documents. Benjamin Jones, University of Nottingham, UK (*)
- Status & recommendations for better implementation of ventilative cooling in Belgium (Flanders). Hilde Breesch, KU Leuven, Belgium (*)
- Status & recommendations for better implementation of ventilative cooling in Switzerland. Flourentzou Flourentzos, ESTIA SA, Switzerland (*)
- Status & recommendations for better implementation of ventilative cooling in Denmark. Per Heiselberg, Aalborg University, Denmark (*)

- Findings and road ahead for better implementation of ventilative cooling. Per Heiselberg, Aalborg University, Denmark (*)
- Open Discussion. Facilitated by Per Heiselberg, Christoffer Plesner and Jannick Roth (~25 mins)
  - What common national barriers for implementation of Ventilative cooling do we all see?
  - Ideas to future recommendations of better implementation of Ventilative cooling both nationally and internationally

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STATUS OF EN AND ISO STANDARDS

NEW VENTILATION PROJECTS IN CEN & ISO

- New technical documents - Pre Work Items (PWI) in CEN/TC 156 and ISO/TC 205 have been approved, dealing with design of Ventilative cooling systems – underway since 2017
  - Planned to support content of CEN EPBD standards (indoor climate/energy performance)
  - Should guide designers on what to be aware of when designing these systems
  - Good development in these projects, with plan to coordinate strongly between CEN & ISO items
- **Overall purpose of PWI's:**
  - Make technical documents focusing on setting criteria and giving guidance to design and dimensioning of ventilative cooling systems in buildings
  - E.g. for "Ventilative cooling systems" – to reduce cooling loads and prevent/reduce overheating

NEW VENTILATION PROJECTS IN CEN & ISO

- **"Ventilative cooling systems (in all buildings)"**
  - Main focus: Thermal comfort (reduce cooling loads and prevent overheating)
  - Type: A CEN Technical specification
  - Work started up in: WG/21 in CEN/TC 156
- **"Design process of natural ventilative cooling for reducing cooling demand in non-residential buildings"**
  - Main focus: Thermal comfort (reduce cooling demand)
  - Type: An ISO standard
  - Work started up in: WG/2, SC/2 in ISO/TC 205
- **Other CEN work with similar topics…. (though main focus on IAQ – not thermal comfort)**
  - "Ventilation for buildings – Performance criteria, design and dimensioning of ventilation systems in residential buildings (Revision of EN 15665:2009 and CEN/TR 14788:2006), (CEN/TC 156/WG2)
  - "Natural and hybrid ventilation systems in non-residential buildings" (CEN/TC 156/WG20)

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NEW VENTILATION PROJECTS IN CEN & ISO

Main focus	Thermal Comfort for overheating prevention (TC)	Other related documents
Residential (R)		3. **CEN**; "Ventilation for buildings – Performance criteria, design and dimensioning of ventilation systems in residential buildings" - Revision of EN 15665 + "EN/TR 14788" (S)
Non-residential (NR)	1. **ISO**; "Design process of Natural ventilative cooling for reducing cooling demand in non-residential buildings" (S)	4. **CEN**; "Natural and hybrid ventilation systems in non-residential buildings" (CEN/TS)
R & NR	2. **CEN**; "Ventilative cooling systems" (CEN/TS)	

1. Thermal comfort (reduce cooling demand) - ISO/TC 205/WG 2/SC 2
2. Thermal comfort (reduce cooling loads and prevent overheating) - CEN/TC 156/WG 21
3. CEN/TC 156/WG 2
4. CEN/TC 156/WG 20

Expected publications: 2022-2023!!

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FINISHED & ONGOING TECHNICAL DOCUMENTS

- **EPBD standards (finished)**
  - EN 16798-7:2017 on "Calculation methods for the determination of air flow rates in buildings" (EPB standard)
    - Simplified calculation methods for single-sided natural ventilation + **cross-ventilation included**
    - Increases relevance of ventilative cooling:
      - Cross-ventilation now included in EN standard!
      - Increased stack effect by enhanced height difference (1 window → more windows)
- **International research studies ongoing to help integrate ventilative cooling better**
  - Guideline on design of "Ventilave cooling in residential buildings" (Denmark) - ongoing
  - IEA Annex 80 on resilient cooling (to include ventilative cooling) (International) - ongoing
  - FreeVent guide on ventilative cooling (France) - finished
- **National standardisation documents on ventilative cooling aspects (ongoing)**
  - "Natural ventilation standard for design from China" (National standard, China)
  - DS 447:2013 – Ventilation systems (National standard, Denmark)
  - CIBSE AM 10:2005 – NV in non-residential buildings (National guide, UK)

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CHALLENGES IN CEN & ISO STANDARDS

- **Ventilative cooling is a new standardisation area:**
  - Aim to formalize experience and knowledge on VC
    - New knowledge in IEA EBC Annex 62 publications
    - AIVC 2019 conference (e.g. topical sessions)
  - Adequately ensure sufficiently (correct) assessement methods for ventilative cooling systems
  - Difference in climates, building customs and typology in CEN and between CEN & ISO regions
- **Many technical documents ongoing abroad or starting up simultaniously on VC:**
  - Big task to coordinate among the "Ventilative cooling" documents, to limit overlaps and repetitions
  - Try to align methods, e.g. for calculation of air flow rates through windows for natural ventilative cooling; use EN 16798-7:2017:
    - New (simple) calculation methods of air flow rates (EN 16798-7) to hopefully be used in new documents
    - Relevance of ventilative cooling highly increased (e.g. by now including cross ventilation)
  - Work together and learn from each other in CEN & ISO; Liasions or workshops

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RECOMMENDATIONS TO CEN & ISO STANDARDS

- **Agreeing on terminology:**
  - Definitions not defined in EN 12792:2003, must be discussed and aligned on consensus basis in CEN WG's
  - Agreeing on terminology across different CEN standardisation bodies

- **Opportunities:**
  - New CEN & ISO projects give opportunities to increase the knowledge and explain how to utilize the ventilative cooling effects in buildings in upcoming standards
  - Enables e.g. architects & consulting engineers to better design and implement ventilative cooling systems
  - Increased focus on ventilative cooling, will also increase the relevance of hybrid ventilation, encompassing the best of both worlds; NV + MV
  - Content of new national/international documents & guidelines on VC to be "legislation-ready" (open to legislation)

RECOMMENDATIONS TO CEN & ISO STANDARDS

- **Less is more:**
  - Simple to use evaluation methods, to further increase the awareness and knowledge of NVC
  - The more difficult methods, the less general exposure of how to use ventilative cooling
  - The full effects of ventilative cooling which are evaluated should reflect the real conditions for the building, control, use and climate, e.g. the actual building physics and geometry

CONCLUSIONS

- Ventilative cooling is not well included in standards, legislation and compliance tools across the evaluated countries, ranging from:
  - Very simplified methods (e.g. pure monthly-based models)
  - Detailed methods (e.g. dynamic hourly-based models)
- Lack of "system design" standards on ventilative cooling - guidance on design and how to fulfil requirements are missing!
  - A lot of requirements for the ventilation systems, e.g. for natural ventilation systems, but how do designers/engineers achieve these and what to be aware of?
  - Focus is on requirements, not on any guidance (system design standards missing)
- Ensure that the full effects of ventilative cooling are evaluated – to reflect the real conditions for the building, control, use and climate:
  - Include the actual building physics and geometry, supporting a fair evaluation of natural ventilation (e.g. stack effects, cross ventilation), mechanical ventilation, control system, night/day ventilation and summer/winter ventilation.

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CONCLUSIONS

- The benefits of ventilative cooling are widely acknowledged, though its use by e.g. designers or architects strongly depend on:
  - The adequate modelling of natural ventilation and especially of air flows
  - The share of energy for cooling for summer comfort and overheating risk is to become equivalent to energy consumption for heating in winter
  - To adequately predict the expected "thermal comfort and cooling requirements", and the "energy performance" when using ventilative cooling in buildings, for:
    - Static models (e.g. Fanger PMV model)
    - Adaptive models (e.g. adaptive comfort model))
- To allow for ventilative cooling to be treated better in standards both at design stage, where initial calculations of e.g. the natural forces & at more detailed stages, it is important to include:
  - Assessment of overheating, e.g.:
    - Utilizing thermal comfort indicators, including adaptive temperature sensation
  - Assessment of night cooling

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Ventilative Cooling in UK technical documents

Dr Benjamin Jones
Associate Professor
University of Nottingham
benjamin.jones@nottingham.ac.uk

Overview

Documents considered:

- Statutory instruments
- Approved documents
- National standards and those used widely in the UK
- Guidance documents

Documents **not** considered:

- European standards
- International standards
- Non-UK organizations, such as AIVC or ASHRAE

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Working definition

Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces.

P. Heiselberg, M. Kolokotroni. Ventilative Cooling. State of the art review. Department of Civil Engineering. Aalborg University, Denmark. 2015

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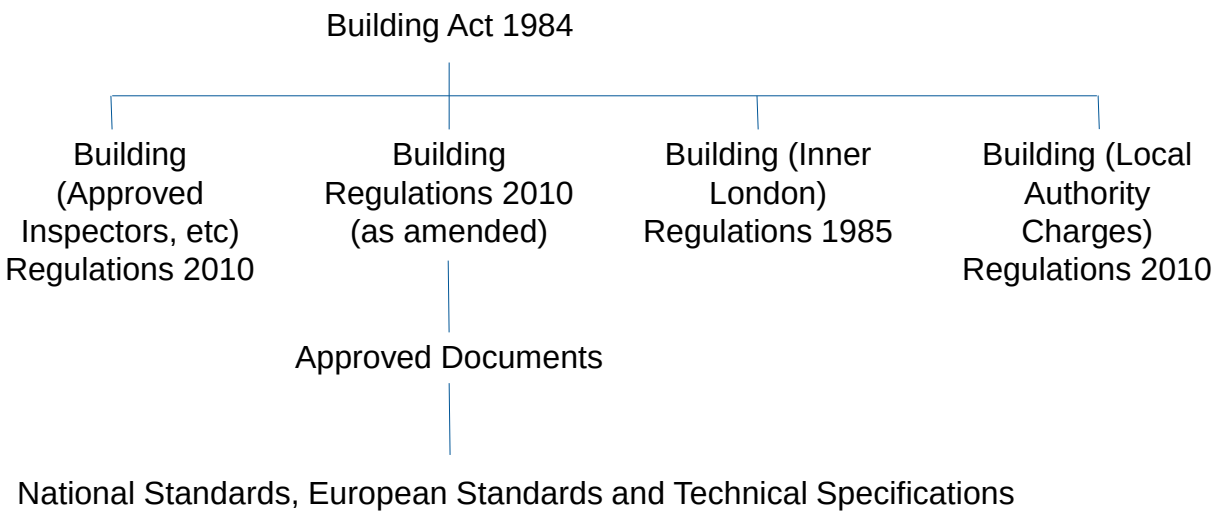
Statutory Instruments

Building Regulations

4

Building Regulations



Approved Documents

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Approved documents



7

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F1

Section 3: General guidance

Key terms

3.1 The following are key terms used in this document:

Air permeability is the physical property used to measure the airtightness of the building fabric. It is defined as air leakage rate per hour per square metre of envelope area at a test reference pressure differential across the building envelope of 50 Pascal (50 N/m²). The design air permeability is the target value set at the design stage.

Airtightness is a general descriptive term for the resistance of the building envelope to ***infiltration*** with ventilators closed. The greater the airtightness at a given pressure difference across the envelope, the lower the ***infiltration***.

Automatic control is where a ventilation device is opened and closed or switched on and off or its performance is adjusted by a mechanical or electronic controller which responds to a relevant stimulus. That stimulus is usually related to the humidity of the air in a room, pollutant levels (e.g. carbon dioxide concentration in a room), occupancy of the space (e.g. using a passive infra-red motion detector) or pressure difference across the device (e.g. due to the wind outside).

Background ventilator is a small ***ventilation opening*** designed to provide controllable ***whole building ventilation***. See Diagram 1.

Diagram 1 **Provisions for background ventilation**

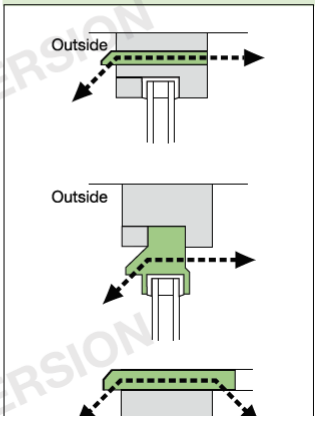

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Table 6.3: Ventilation of other buildings and spaces

Building/space/activity	Regulations and guidance (also see Section 8)
Hospitals and healthcare buildings	NHS Activity database Health Technical Memorandum (HTM) 03 Health Building Notes (HBN) – various CIBSE Guide B:2005, Section 2.3.13, and CIBSE AM10:2005 if naturally ventilated or CIBSE AM13:2000 if mixed mode
Hotels	CIBSE Guide B:2005, Section 2.3.14, and CIBSE AM10:2005 if naturally ventilated or CIBSE AM13:2000 if mixed mode
Industrial ventilation	*Industrial ventilation*, 24th Edition, *Manual of recommended practice*, American Conference of Government Industrial Hygienists HS(G) 37 *An introduction to local exhaust ventilation* HS(G) 54 *Maintenance, examination and testing of local exhaust ventilation* HS(G) 193 *COSHH essentials*
Laboratories	CIBSE Guide B:2005, Section 2.3.16
Museums, libraries and art galleries	BS 5454:2000 CIBSE Guide B:2005, Section 2.3.17, and CIBSE AM10:2005 if naturally ventilated or CIBSE AM13:2000 if mixed mode
Plant rooms	CIBSE Guide B:2005, Section 2.3.18
Prison cells	Refer to National Offender Management Service (NOMS). Home Office, NOMS Property, Technical Services, Room 401, Abell House, John Islip St., London SW1P 4LH
Sanitary accommodation	Same as for offices in Table 6.1a
Schools and educational buildings	Ventilation provisions in schools can be made in accordance with the guidance in Building Bulletin 101, *Ventilation of School Buildings* (see www.teachernet.gov.uk/iaq) and in the Education (School Premises) Regulations. Building Bulletin 101 can also be used as a guide to the ventilation required in other educational buildings such as further education establishments where the accommodation is similar to that found in schools, e.g. sixth form accommodation. However, the standards may not be appropriate for particular areas where more hazardous activities take place than are normally found in schools, e.g. some practical and vocational activities requiring containment or fume extraction. The Building Bulletin can also be used for children's centres and other early years settings, including day nurseries, playgroups, etc.
Shops and retail premises	CIBSE Guide B:2005, Section 2.3.20, and CIBSE AM10:2005 if naturally ventilated or CIBSE AM13:2000 if mixed mode
Sports centres (inc. swimming pools)	CIBSE Guide B:2005, Section 2.3.21
Standards rooms	CIBSE Guide B:2005, Section 2.3.24.7
Transportation buildings and facilities	CIBSE Guide B:2005, Section 2.3.23 and CIBSE AM10:2005 if naturally ventilated or CIBSE AM13:2000 if mixed mode

Section 8: Standards and other publications

Standards

BS EN 378-3:2008 *Refrigerating systems and heat pumps. Safety and environmental requirements. Installation site and personal protection.*

BSI PD CR 1752:1999 *Ventilation for buildings – design criteria for the indoor environment.*

BS 5502:2003 *Buildings and structures for agriculture. Various relevant parts including: Part 33:1991 Guide to the control of odour pollution, AMD 10014 1998. Part 52:1991 Code of practice for design of alarm systems, emergency ventilation and smoke ventilation for livestock housing*, AMD 10014 1998.

BS 5454:2000 *Recommendations for the storage and exhibition of archival documents.*

BS 5925:1991 *Code of practice for ventilation principles and designing for natural ventilation.* AMD 8930 1995.

BS 7913:1998 *Principles of the conservation of historic buildings.*

BS EN 13141-1:2004 *Ventilation for buildings. Performance testing of components/products for residential ventilation. Externally and internally mounted air transfer devices.*

BS EN 13141-3:2004 *Ventilation for buildings. Performance testing of components/products for residential ventilation. Range hoods for residential use.*

BS EN 13141-4:2004 *Ventilation for buildings. Performance testing of components/products for residential ventilation. Fans used in residential ventilation systems.*

BS EN 13141-6:2004 *Ventilation for buildings. Performance testing of components/products for residential ventilation. Exhaust ventilation system packages used in a single dwelling.*

BS EN 13141-7:2004 *Ventilation for buildings. Performance testing of components/products for residential ventilation. Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single family dwellings.*

BS EN 13141-8:2006 *Ventilation for buildings. Performance testing of components/products for residential ventilation. Performance testing of unducted mechanical supply and exhaust ventilation units [including heat recovery] for mechanical ventilation systems intended for a single room.*

BS EN 13986:2004 *Wood-based panels for use in construction. Characteristics, evaluation of conformity and marking.*

Other publications

American Conference of Government Industrial Hygienists (ACGIH)
Industrial ventilation 26th Edition, *Manual of recommended practice.*
Available from: www.acgih.org/store

BRE

BRE Digest 464, Part 1: *VOC amissions from building products. Sources, testing and emission data*, 2002. ISBN 978 1 86081 546 1.

BRE Digest 464, Part 2: *VOC emissions from building products. Control, evaluation and labelling schemes*, 2002. ISBN 978 1 86081 547 8.

BSRIA

Ventilation hygiene toolkit:
BSRIA Facilities Management Specification 1 *Guidance to the standard specification for ventilation hygiene*, 2002. ISBN 978 0 86022 454 9.

Chartered Institution of Building Services Engineers (CIBSE)

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National Standards

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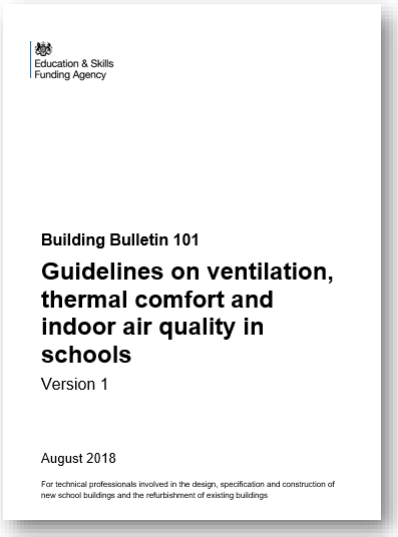
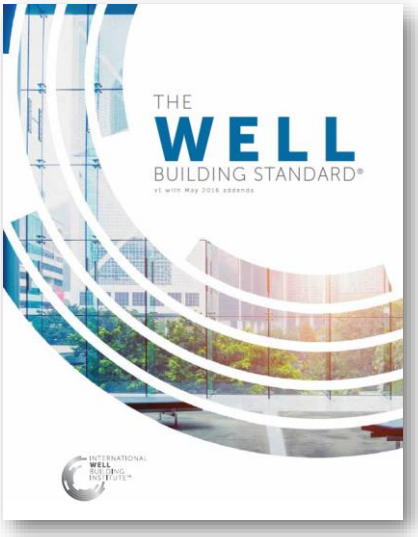
National Standards





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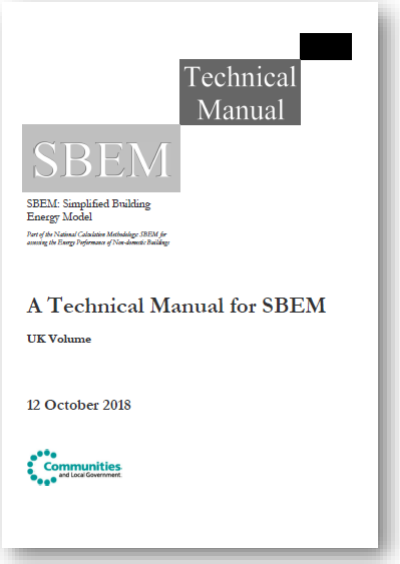
National Standards





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Technical Specifications

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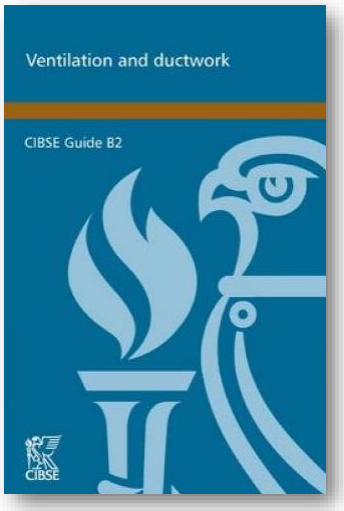
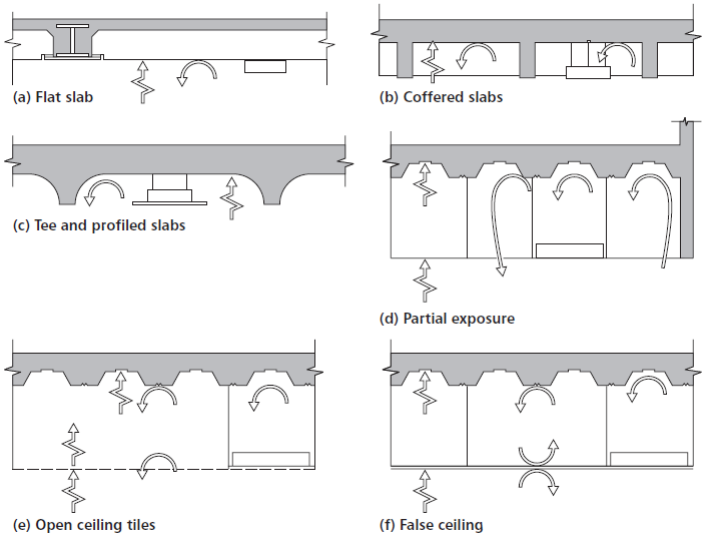
CIBSE Guides





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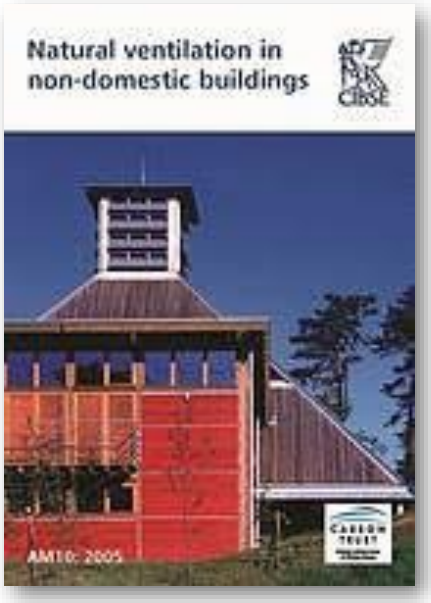
CIBSE AMs and TMs





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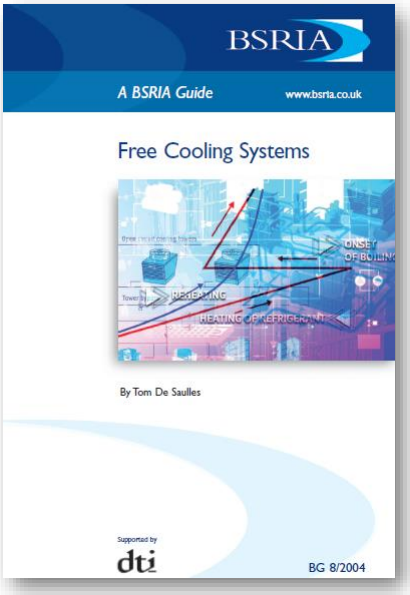
BSRIA



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What next?

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What next?

- Overheating is a growing problem in the UK so there is a need for low energy ventilative cooling
- Limited understanding of the term *ventilative cooling*
- Very limited implementation of ventilative cooling in UK technical documents
- CIBSE Guide B has the most information
- A need to define and unify terminology
- Documents need to communicate (e.g. ADF and ADL)
- A need to explain the mechanisms in appropriate documents
- Short term: Approved document F, CIBSE AM10
- Medium term: CIBSE KS, CIBSE B, SBEM, SAP etc.

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KU LEUVEN

Status & recommendations for better implementation of ventilative cooling in Flanders (BE)

Hilde Breesch

KU Leuven Ghent Technology Campus

1

Background compliance tool

- EPBD calculation method
  - Primary energy use
  - Residential <> non residential buildings
  - On monthly basis
  - On building level
- EPBD Requirements (new buildings)
  - Thermal insulation: max. U-values
  - Energy performance: primary energy use
  - Indoor climate
    - Min. ventilation requirements
    - Overheating risk -> only for residential
  - Renewable energy

2

4 questions

- Potential of including VC in national building legislation in Flanders (BE)?
- Needs for research?
- How is airflow rate determined in national legislation?
- National barriers for implementation of VC?

Potential & need for research

- Difficult question
- At this moment
  - Simulations to include VC in monthly based calculation method already done
  - Validation needed
- Future?



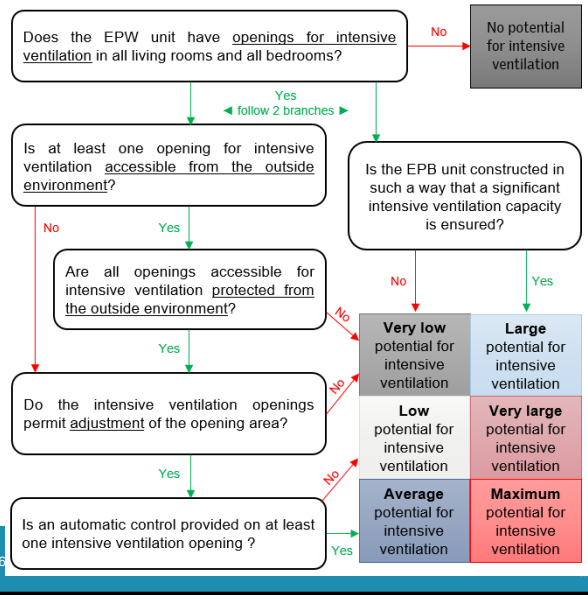
Airflow rate residential buildings

- Manual control of openable windows

Potential for intensive ventilation	Airflow rate (m³/h)
No	0
Very low	0.15 x V
low	0.20 x V
Average	0.40 x V
large	0.55 x V
Very large	0.70 x V
maximum	1.10 x V

5

Airflow rate residential buildings



Intensive ventilation if $A_{openings} > 6.4\% A_{floor}$

Significant capacity = cross or stack ventilation ($\Delta h > 3m$)

6

Airflow rate non-residential buildings

- Additional mechanical/natural ventilation by day/night
- Impact natural ventilation includes
  - Coefficient for thermal mass
  - Equation for time fraction
  - Equation for air flowrate

$$\dot{V}_{V,\text{add w,night,cool,fct f,m}} = \sum_{j} \left(3,6 \cdot 500 \cdot 0,163 \cdot c_{ow,night,j} \cdot A_{w,night,fctf,j}\right)$$

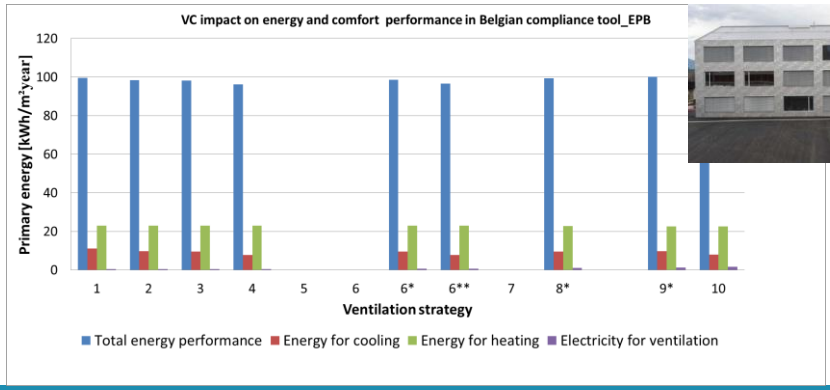
- $c_{ow,night,j}$ = coefficient reduced window opening area
  - Top/bottom hung window: 0.174
  - Side hung, sliding window: 0.9
- $A_{w,night,fct\ f,\ j}$ = window area (m²)

National barriers for implementation

- All type of buildings
  - No difference in use/no combination of VC day <> night
  - Only monthly calculation method on building level
- Residential buildings
  - Only included in thermal summer comfort indicator, no impact on energy need for cooling
  - Assumed airflow rate ventilative cooling is small

National barriers for implementation

- Non-residential buildings
  - Till now: no requirement nor calculation method for overheating risk
  - Impact ventilative cooling on energy performance too small



Status and recommendations for better implementation of ventilative cooling in Switzerland

Estia SA
Flourentzos Flourentzou

AIVC conference, October 2019

Do you see a clear potential of including ventilative cooling in your regulations?

- **SIA 180 edition 2014 – "thermal protection, humidity, interior climate in buildings" : definition of thermal comfort and air quality requirements and ways to achieve it, definitions of indicators for thermal comfort, architectural minimum requirements for thermal protection, and simulation methods to calculate interior air temperature.**
- **SIA 382/1 edition 2014 – "Installations of ventilation and cooling, general bases and performance requirements": this is the basic norm concerning ventilation and air conditioning.**
- **SIA 382/2– Model of calculation heating and cooling demand according to a dynamic model based on EN ISO 13 792. SIA technical note 2044 explaining how to use SIA 382/2 to calculate cooling demand and cooling load.**
- **SIA 2031 and CECB/GEAK/CECE – application of the EPBD in Switzerland. SIA 2031 explains the fundamentals and CECB-GEAK-CECE (Cantonal Energy Certificate for Buildings) is the organism defining how the regulation is applied and provides the software and logistics to produce energy certificates.**

SIA 180: Summer thermal protection

SIA 180 defines thermal comfort and sets the minimum requirements providing thermal comfort. SIA 180 defines a framework of obligations helping to answer to two questions:

A. Does the building conforms to minimum requirements for summer thermal protection?

B. Is the building comfortable?

- All buildings should answer YES to the first question. A building may conform to the minimum requirements, but even if all the minimum measures have been taken, it cannot provide summer comfort (for example due to high internal gains or due to impossibility to open windows).

- If a building answer YES to the first question and NO to the second, then it might be air conditioned or cooled mechanically.

Summer thermal protection 1: Simple rules

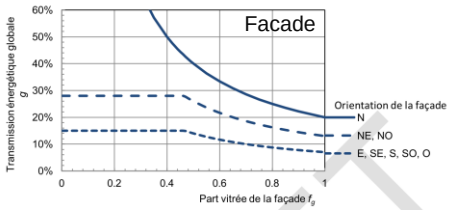
- **Insulated envelope, roof <0.2 W/m²K, with <5% glazed surface**
- **External solar protection g<0.1**
- **Room depth <3.5m or 7m with windows in both opposite facades**
- **At least medium apparent thermal mass (at least 1 heavy element)**
- **Glazed area**
  - **<40% for non residential heavy buildings <30% for non residential light buildings with automatic solar protection**
  - **<50% for residential heavy buildings, <40% for residential light buildings non automatic solar protection – <70% / 60% if automatic**
- **Possibility to provide 10 m³/m²h of night ventilation (3.6 ACH for 2.8 m room height)**
- **+ additional conditions providing sufficient night ventilation (next page)**

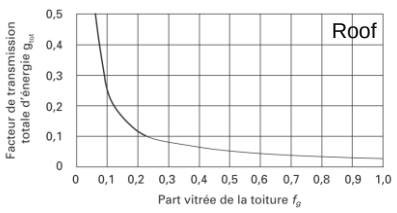
Summer thermal protection 1: additional conditions providing night ventilation

- **Mechanical system with 10 m^3/m^2h or**
- **Sufficient big openings well positioned able to remain open during night (façade and/or roof)**
- **At least one opening high in the volume able to evacuate hot air**
- **At least opening area 5% of the floor area and room depth <2.5 room height. If room depth between 2.5 and 5 times room height, necessity of opposite windows.**

Summer thermal protection 2: intermediate

- **Insulated roof <0.2 W/m^2K, with <5% glazed surface**
- **Specific thermal mass> 45 $Wh/(m^2K)$**
- **Possibility to provide 10 m^3/m^2h of night ventilation /cooling**
- **Solar protection:**





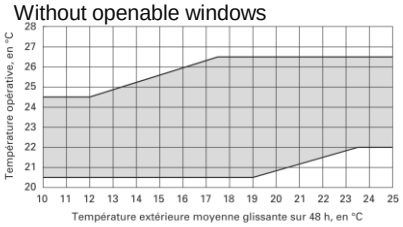
Summer thermal protection 3: Simulation conditions

- time step <=1h
- Operative temperature at 1m (or air temperature if they are equal)
- Standard meteorological year
- 16 April – 15 October (1 Jan =Saturday)
- Solar shading if I>200 W/m2 and U wind < U limit
- Solar gains 10% convective, 90% radiative
- Internal gains 120 Wh/m^2 24h/24, 50% convective
- Air change 3 m^3/m^{2}h or 10 m^3/m^{2}h when $T_i > T_e$ AND $T_i > T_{min}$

Summer thermal protection 3: simulation

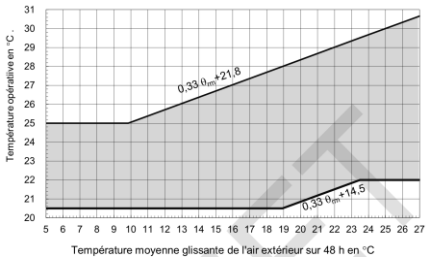
- All internal and external heat gains are taken into account
- Calculate the absorbed and resituated heat by the construction
- Calculate and indicate the evacuated heat through ventilation
- Calculation method validated according to EN ISO 13 791 or 13 792
- Internal temperature within

Without openable windows



+ EN ISO 7730 confort conditions

With openable windows



+ EN ISO 15251 adaptive confort

How is the air flow rate determined for ventilative cooling in your national regulations?

$$q_{V,w} = c_d \cdot h_w \cdot w_w \cdot \frac{1}{3} \cdot \left(\frac{g \cdot h_w \cdot (T_{i,t-1} - T_e)}{T_e} \right)^{0,5} \cdot 3600$$

$q_{V,w}$	débit d'aération par les fenêtres, en m^3/h
c_d	coefficient de décharge (≅ 0,6)
h_w	hauteur de l'ouverture, en m
w_w	largeur de l'ouverture, en m
g	accélération terrestre, en m/s^2
$T_{i,t-1}$	température de l'air intérieur du pas horaire précédent, en K
T_e	température de l'air extérieur, en K

- **Wind effect is neglected in the basic calculation but may be taken into account by an appropriate software.**
- **Multiple openings may be taken into account by appropriate soft.**
- **No indication for discharge coefficients or parasite air heating.**
- **No detailed indication about opening control**

Used to answer to the question 2: is by building comfortable

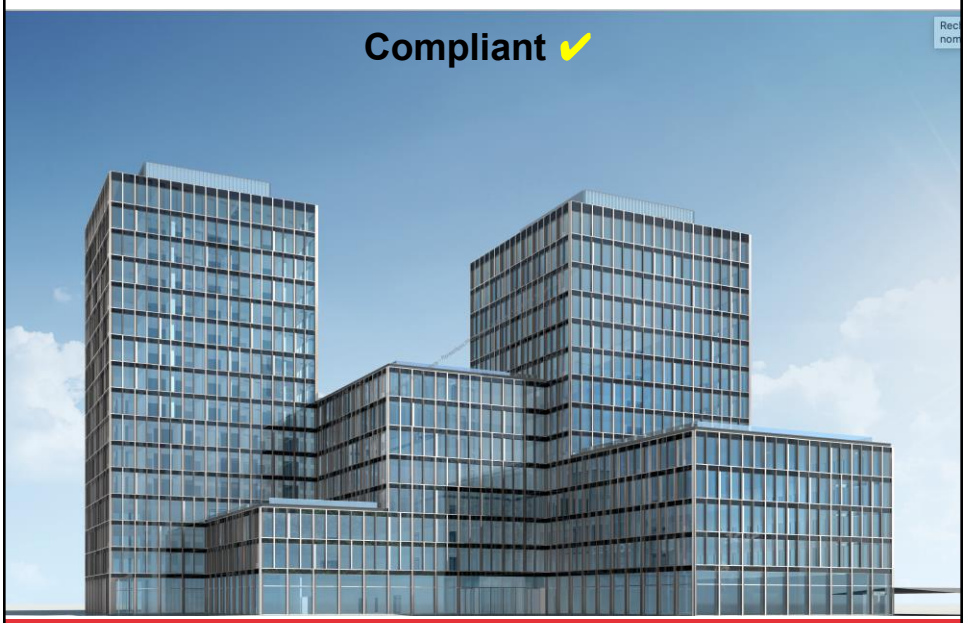
Open questions for boundary conditions

- **What is Tmin?**
- **How to justify higher internal gains**
- **How do we consider window openings?**
- **How to simulate opening obstacles (blinds, window geometry, nets, grids etc)?**
- **How to distinguish manual / automatic control**
- **How do we consider air preheating from blinds or air vents**
- **What are the conditions of openable windows during night?**
- **What is the risk of partial blind use and other risks?**

Other questions for discussion

- **Is new work/research (in your country) needed to reach a better implementation of ventilative cooling? NO (personal opinion ☺).**
- **Are there some national barriers for implementation of ventilative cooling? Yes but not normative.**
- **There is a need of design guidelines and education of engineers and architects to understand phenomena and implement correctly ventilative (and other forms of passive) cooling.**

Compliant ✔



STATUS AND RECOMMENDATIONS FOR BETTER IMPLEMENTATION OF VENTILATIVE COOLING IN DENMARK

PER HEISELBERG
DEPARTMENT OF CIVIL ENGINEERING



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DENMARK

1

VENTILATIVE COOLING IN A DANISH CONTEXT

APPLICATION OF VENTILATIVE COOLING FOR RESIDENTIAL BUILDINGS IS AT A LOW LEVEL

- It is considered difficult to design and evaluate
- Few technical solutions available – mainly manual window opening only very few automated

VENTILATIVE COOLING IS A STANDARD SOLUTION IN OFFICES WITH MECHANICAL VENTILATION

- Mainly designed for IAQ criteria
- Limited benefit due to fan energy use

VENTILATIVE COOLING BY NATURAL/HYBRID VENTILATION IS KNOWN

- But only used systematically in a few cases in offices



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2

VENTILATIVE COOLING IN DANISH VENTILATION STANDARD – DS447

THE DANISH STANDARD DS 447 SPECIFIES REQUIREMENTS FOR MECHANICAL, NATURAL AND HYBRID VENTILATION SYSTEMS – AND ALSO INCLUDES VENTILATIVE COOLING EXPRESSED AS

- Free cooling, night cooling, passive cooling
- Cooling by means of natural ventilation (single-sided, cross, stack)
- Effects of elevated air velocities included (informative annex)
- Refers to EN 16798-7:2017 for calculation of flow rates
- Refers to SBi Anvisning 202 (national Best Practice Guide for design of natural ventilation systems)

HOWEVER NO GUIDELINES ARE GIVEN:

- For system design
- For calculation of ventilative cooling performance
- On how elevated velocities can be achieved and documented



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VENTILATIVE COOLING IN DANISH BUILDING REGULATIONS

DANISH BUILDING REGULATION ALLOWS IN GENERAL TERMS TO TAKE INTO ACCOUNT THE EFFECT OF VENTILATIVE COOLING

- But does not give or refer to any guidelines or recommendations.

FOR THERMAL COMFORT BUILDING REGULATIONS REFER TO ISO 7730 AND DS 447

- But states that air velocities above 0,15 m/s is acceptable if indoor temperature exceeds 24ºC
- Indoor temperature levels in residences must not exceed 27ºC for more than 100 hours/year and 28ºC for more than 25 hours/year

A SIMPLIFIED METHOD IS AVAILABLE TO DOCUMENT COMPLIANCE

- A simplified hourly based method can be used to document thermal comfort compliancy. Energy use for cooling is based on a mean-monthly approach.



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VENTILATIVE COOLING IN DANISH EBPD COMPLIANCE TOOL – BE18

THE DANISH COMPLIANCE TOOL *BE18* IS BASED ON A SIMPLIFIED MEAN-MONTHLY CALCULATION

- Must be used to document compliance with Danish building regulation
- Prediction of cooling needs (mean monthly method) and overheating risk (simplified hourly method)

VENTILATIVE COOLING IS POSSIBLE ALSO FOR NATURAL VENTILATION. THE TOOL ALLOWS YOU TO INPUT VENTILATION RATE FOR VENTILATIVE COOLING SEPARATED IN DAY AND NIGHT VALUES

- Simple to use for mechanical systems
- When determining the airflow rate for natural ventilation the opening to floor area ratio and the ventilation principle is taken into account
- Air flow rates can be increased if window openings are controlled automatically

THE TOOL DOES ESTIMATE THE COOLING NEED (AVERAGE FOR WHOLE BUILDING)

- It is possible to calculate the risk of overheating for a critical room by an ad-on module
- It does not take into account effects of elevated air velocity

CALCULATION OF AIR FLOW RATES IN BE18 (COMPLIANCE TOOL)

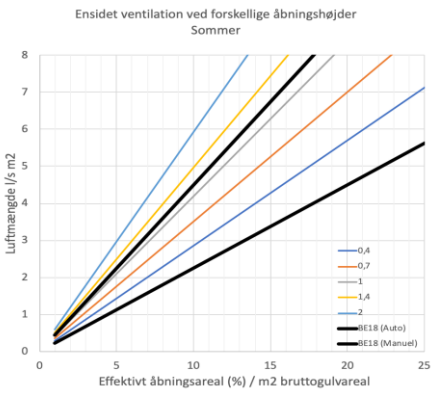
$$q_{n,s\ cross,stack} = \frac{A_{eff,v}}{1{,}5\%} * q_{n,s}$$

$$q_{n,s\ single\ sided} = \frac{A_{eff,e}}{4\%} * q_{n,s}$$

$q_{n,s}$ air flow rate for VC. 1,8 l/s m² floor area for openings with automatic control and 0,9 l/s m² for manually controlled openings.

$A_{eff,v}$ Effective opening area for cross/stack ventilation (% /m² floor area)

$A_{eff,e}$ Effective opening area for single sided ventilation (% /m² floor area)



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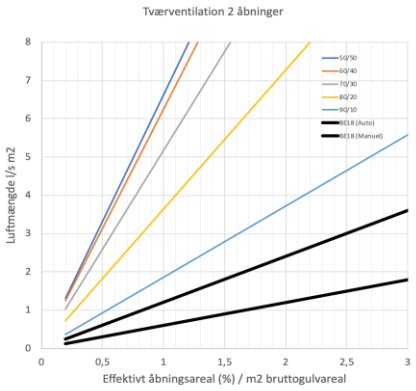

STATUS OF VENTILATIVE COOLING IN DANISH REGULATORY CONTEXT

BUILDING REGULATIONS AND STANDARDS SUPPORT THE USE OF VENTILATIVE COOLING

THE DANISH EPBD COMPLIANCE TOOL DOES NOT SUPPORT A FAIR EVALUATION OF VENTILATIVE COOLING AS PART OF THE CALCULATION PROCEDURE.

STATUS

(NATURAL) VENTILATIVE COOLING IS CONSIDERED SOMEWHAT DIFFICULT TO WORK WITH AS DESIGNER OR ENGINEER - TOO LITTLE GUIDANCE AND TOO LARGE RESPONSIBILITY.

THEREFORE (NATURAL) VENTILATIVE COOLING IS NOT WIDELY INCLUDED BY BUILDING DESIGNERS.

FUTURE OF VENTILATIVE COOLING IN DANISH REGULATORY CONTEXT

LOOKS PROMISING

- Increased legislative focus on summer comfort
- An easy to use design guide is under way for residential buildings, which do not require detailed calculation of thermal comfort and cooling need

FUTURE NEEDS

To avoid detailed performance simulation in the design phase:

- Simple tools for calculating air change rates during nighttime and daytime in buildings with increased ventilation rates (with the purpose of cooling the building).
- Simple tools for determining the cooling effect of increased ventilation rates.

Control strategies for ventilative cooling based on relevant thermal comfort criteria.

Standard off-the-shelves solutions for ventilative cooling to be used in typical residential and smaller office buildings



FINDINGS AND ROAD AHEAD FOR BETTER IMPLEMENTATION OF VENTILATIVE COOLING

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FINDINGS #1

THE POTENTIAL APPLICATION OF VENTILATIVE COOLING IS VERY DIFFERENTLY INCLUDED IN STANDARDS, LEGISLATION AND COMPLIANCE TOOLS ACROSS THE EVALUATED COUNTRIES.

- This includes cooling load prediction, ranging from very simplified to detailed methods, e.g. from pure monthly averaging models to more dynamic hourly-based models.
- This includes the estimation of flow rates and opening areas, ranging from qualitative estimation of the potential to fixed relations between flow rates and opening areas taking into account different aspects like driving principle, automation, opening type, etc. Standard calculation methods of flow rate is not used.
- This includes estimation of overheating risk and thermal comfort, ranging from simple rules and simplified calculations to hourly calculation during the summer season.



12

FINDINGS #2

THE FULL EFFECTS OF VENTILATIVE COOLING WHICH ARE EVALUATED SHOULD REFLECT THE REAL CONDITIONS FOR THE BUILDING, CONTROL, USE AND CLIMATE, E.G. THE ACTUAL BUILDING PHYSICS AND GEOMETRY.

THE BENEFITS OF VENTILATIVE COOLING ARE WIDELY ACKNOWLEDGED, THOUGH ITS USE BY E.G. DESIGNERS OR ARCHITECTS STRONGLY DEPEND ON A FEW INTERTWINED CHALLENGES:

- The adequate modelling of natural ventilation and especially of air flows
- The share of energy for cooling for summer comfort and overheating risk is to become equivalent to energy consumption for heating in winter
- To adequately predict the expected "thermal comfort and cooling requirements", and the "energy performance" when using ventilative cooling in buildings, e.g. using either static or adaptive comfort models



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FINDINGS #3

IT WOULD BE BENEFICIAL TO SHARE EXPERIENCES AND ALIGN PROCEDURES AND METHODS FOR VENTILATIVE COOLING, OVERHEATING RISK AND THERMAL COMFORT REQUIREMENTS IN CALCULATIONS AND PERFORMANCE EVALUATION AMONG COUNTRIES

THERE IS A STRONG NEED FOR DESIGN GUIDELINES AND STANDARD “OFF-THE-SHELVE” TECHNICAL SOLUTIONS TO APPLY IN RESIDENTIAL AND SMALL OFFICE BUILDINGS

FURTHER EDUCATION OF ENGINEERS AND ARCHITECTS TO ENSURE UNDERSTANDING OF THE PHENOMENA AND CORRECT IMPLEMENTATION OF VENTILATIVE (AND OTHER FORMS OF PASSIVE AND NATURAL) COOLING.



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QUESTIONS FOR DISCUSSION

DO YOU SEE A CLEAR POTENTIAL FOR INCLUDING VENTILATIVE COOLING IN YOUR NATIONAL BUILDING LEGISLATION/REGULATION?

- Is it already well implemented?
- Do you see a need for improvement?

DO YOU SEE IMPORTANT (NATIONAL) BARRIERS FOR IMPLEMENTATION OF VENTILATIVE COOLING?

- Are they related to standards, legislation or compliance tools?
- Are they related to lack of knowledge and experience?
- Are they related to lack of proper tools, methods and/or technologies?

IS NEW WORK/RESEARCH (IN YOUR COUNTRY) NEEDED TO REACH A BETTER IMPLEMENTATION OF VENTILATIVE COOLING?

- In relation to new simplified tools and methods for decision support?
- In relation to exchange of ideas in relation to development of calculation tools?
- In relation to new easy to use design guidelines?
- In relation to new technologies and solutions?

OPEN DISCUSSION

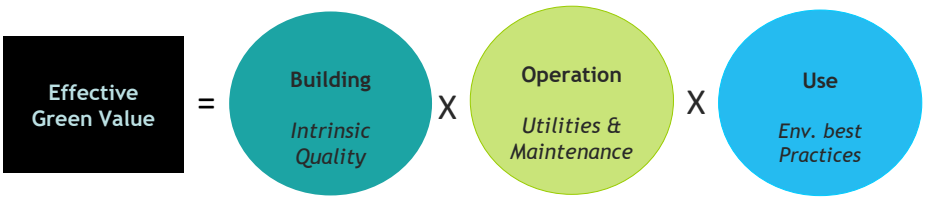


Data use in real Estate

indoor environmental quality and building performance : value trigger?

Frank Hovorka
French real estate develolper federation : technical director
RICS : member
REHVA : president

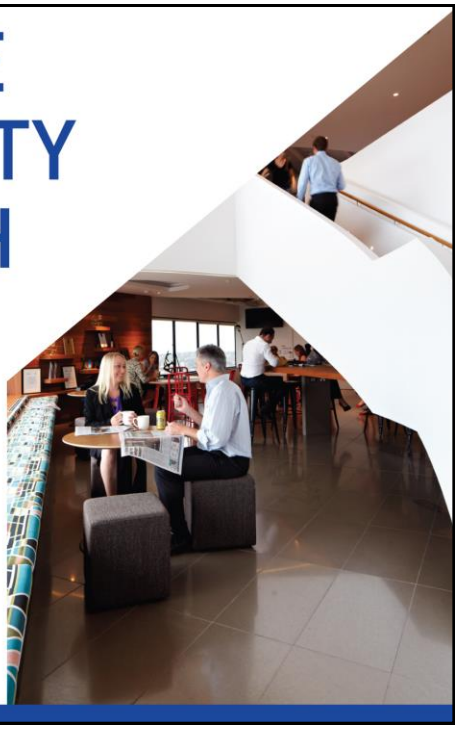
How to define environemental quality of buildings ?



Time dimension : Life span and flexibility

WORKPLACE PRODUCTIVITY AND HEALTH

- Evidence shows that green design attributes can improve occupant productivity, health and well-being.
- Investing in better indoor environments can lead to better returns on one of every company's greatest assets - its employees.



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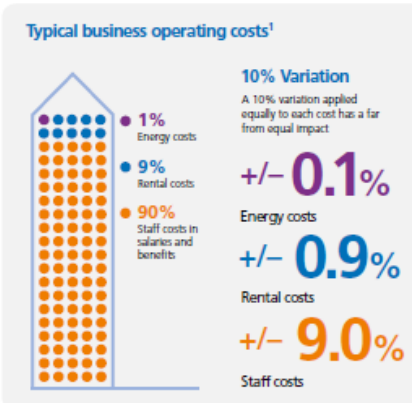
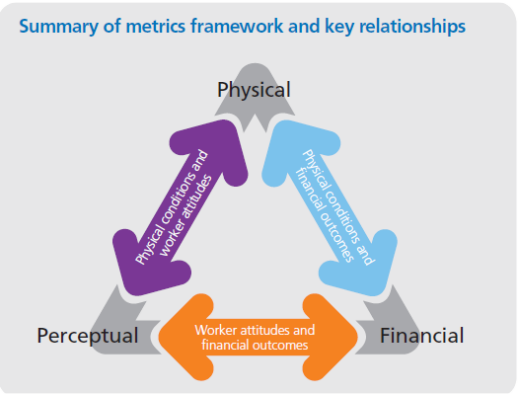
Staff costs, including salaries and benefits, typically account for about 90% of business operating costs.





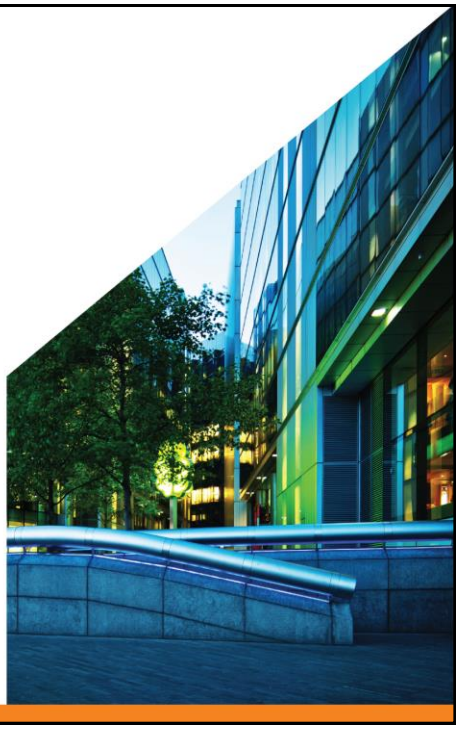
Source: **Health, Wellbeing & Productivity in Offices by WGBC**

4

4

RISK MITIGATION

- Sustainability risk factors can significantly affect rental income and the future value of real estate assets, in turn affecting their ROI
- Changing tenant preferences and investor risk screening may translate into risk of obsolescence for inefficient buildings



5

Energy linked to a building: 4 main blocks

Building energy

Actual new building:
130 to 250 $kWh_{ep}/m^2/an$

NZEB :
40 to 65 $kWh_{ep}/m^2/an$

Specific electricity

Housing :
10 à 50 $kWh_{ep}/m^2/an$

Office:
30 to 300 $kWh_{ep}/m^2/an$

Embodied energy

New building :
≈ 1200 kWh_{ep}/m^2

« As usual »NZEB:
≈ 1600 kWh_{ep}/m^2

Transport

French average daily distance:
16km

20 km :
by car : 6450 kWh_{ep}/an
bus: 630 kWh_{ep}/an

REHVA

Federation of European Heating, Ventilation and Air-conditioning Associations

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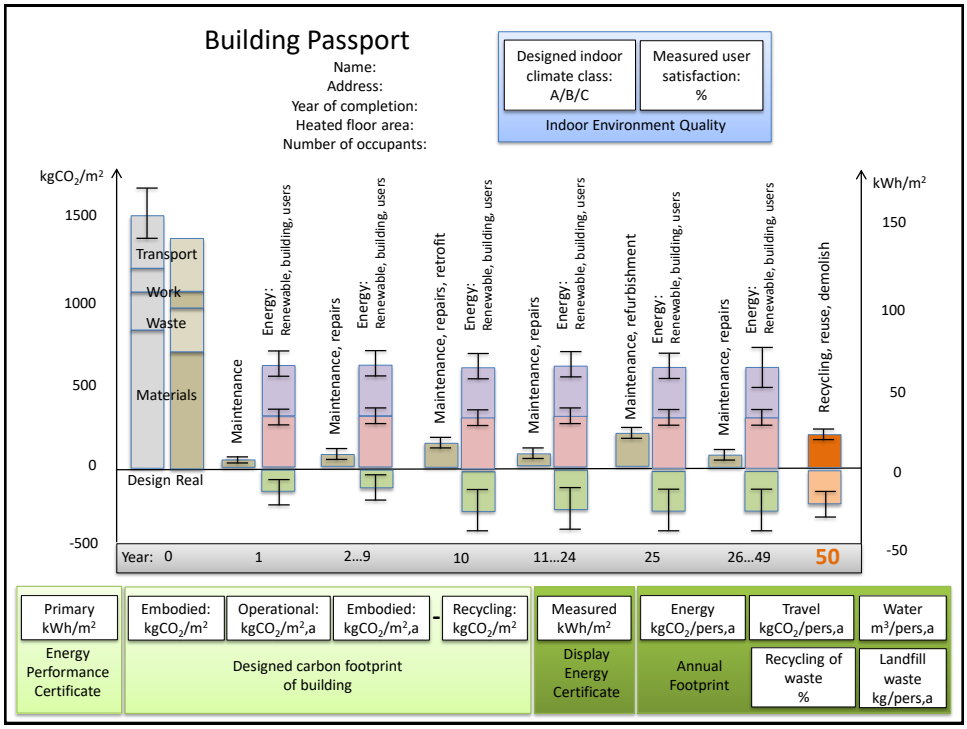
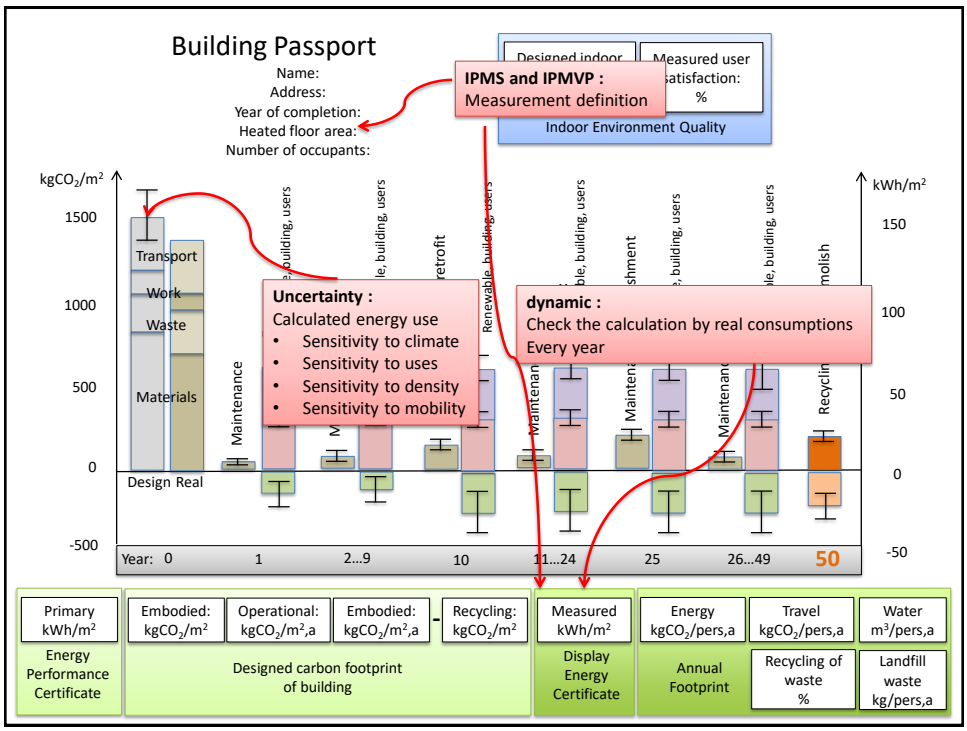
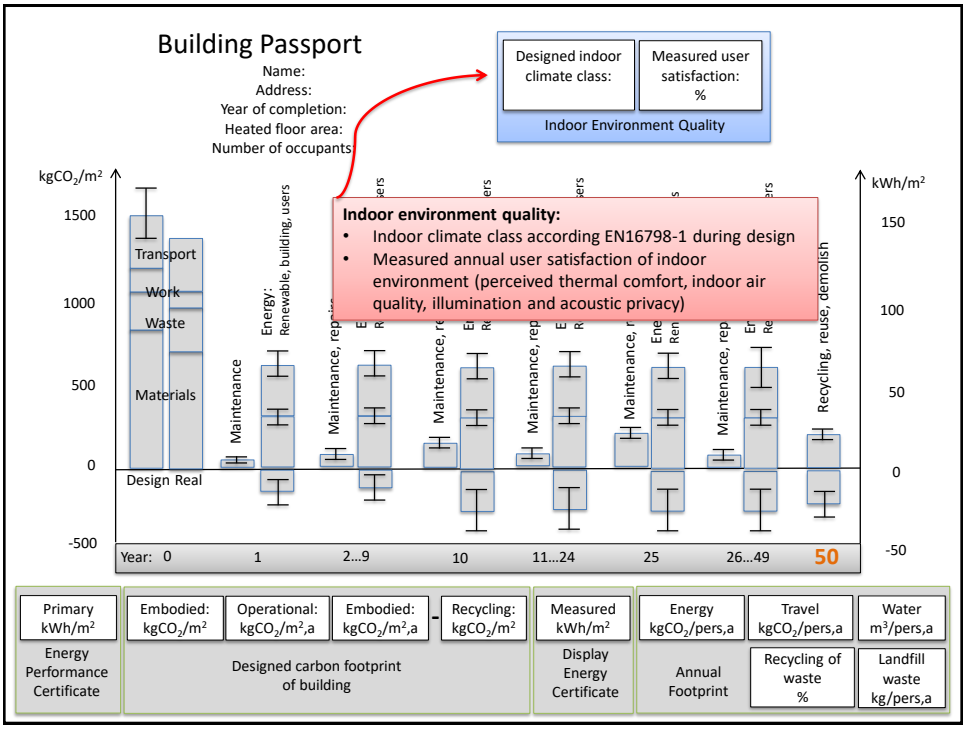

Building Passport
Name:
Address:
Year of completion:
Heated floor area:
Number of occupants:
Designed indoor climate class: A/B/C
Measured user satisfaction: %
Indoor Environment Quality
kgCO2/m²
kWh/m²
1500
1000
500
0
-500
150
100
50
0
-50
Transport
Work
Waste
Materials
Design Real
Maintenance
Energy: Renewable, building, users
Maintenance, repairs
Maintenance, repairs, retrofit
Maintenance, refurbishment
Recycling, reuse, demolish
Year: 0
1
2...9
10
11...24
25
26...49
50
Primary kWh/m²
Energy Performance Certificate
Embodied: kgCO2/m²
Operational: kgCO2/m²,a
Embodied: kgCO2/m²,a
Recycling: kgCO2/m²
Designed carbon footprint of building
Measured kWh/m²
Display Energy Certificate
Energy kgCO2/pers,a
Travel kgCO2/pers,a
Water m³/pers,a
Annual Footprint
Recycling of waste %
Landfill waste kg/pers,a

7


Building Passport
Name:
Address:
Year of completion:
Heated floor area:
Number of occupants:
IPMS and IPMVP : Measurement definition
Indoor Environment Quality
Uncertainty :
Calculated energy use
• Sensitivity to climate
• Sensitivity to uses
• Sensitivity to density
• Sensitivity to mobility
dynamic :
Check the calculation by real consumptions
Every year
kgCO2/m²
kWh/m²
Transport
Work
Waste
Materials
Design Real
Year: 0
1
2...9
10
11...24
25
26...49
50
Primary kWh/m²
Energy Performance Certificate
Embodied: kgCO2/m²
Operational: kgCO2/m²,a
Embodied: kgCO2/m²,a
Recycling: kgCO2/m²
Designed carbon footprint of building
Measured kWh/m²
Display Energy Certificate
Energy kgCO2/pers,a
Travel kgCO2/pers,a
Water m³/pers,a
Annual Footprint
Recycling of waste %
Landfill waste kg/pers,a

8



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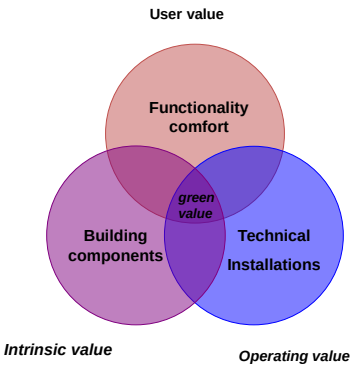
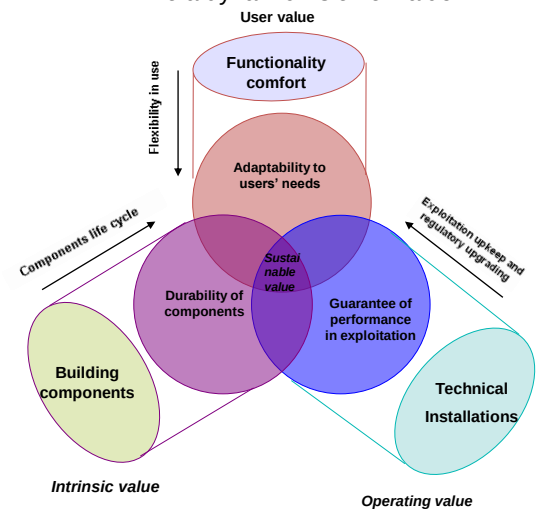
Quality, value, worth

From a static vision ….



To a dynamic vision of value



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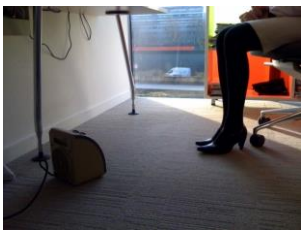
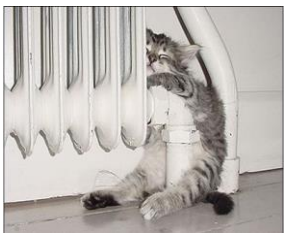
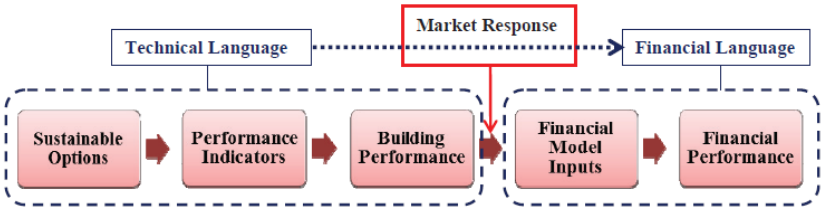
To avoid ….







Translation to achieve



KEY QUESTIONS



1. Is there something like a «HVAC benefits value» part of the building market value?
2. What is the correct way to quantify the HVAC benefits?
3. Are the conventional valuation approaches suitable for the quantification of HVAC benefits?

Source | Valentina Fabi

17

| TERMS OF VALUE EQUATION |



RENT OTHER INCOME

MARKET VALUE = (income - expenses) + residual value



OPERATING EXPENSES

OTHER EXPENSES

Source Valentina Fabi

18

| TECHNICAL SYSTEM IMPACT |



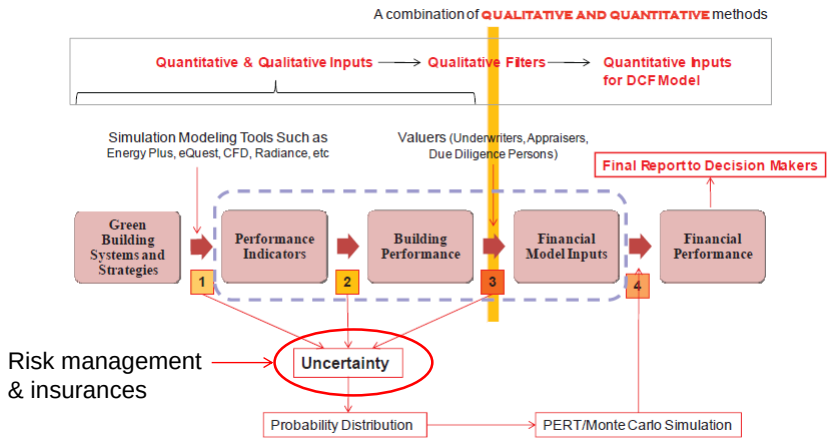
RISKS

Physical risk	Technology risk	Risk due regulation	Market risk
Occupant satisfaction	*Indoor flooding*	*Inability to compete with greener buildings*	*Change in discount rate*
Increasing of noise	*Fire*	*Inability to compete with buildings with a better energy label*	*Increased speed of depreciation*
HVAC inability to satisfy IEQ levels	*Losses of refrigerant*	*Inability to lease due to new regulation*	*Lower occupancy rates*
	Obsolescence of HVAC technology		*Shorter tenancies*
	Increasing of operating costs		

source| Valentina Fabi

19

The challenge



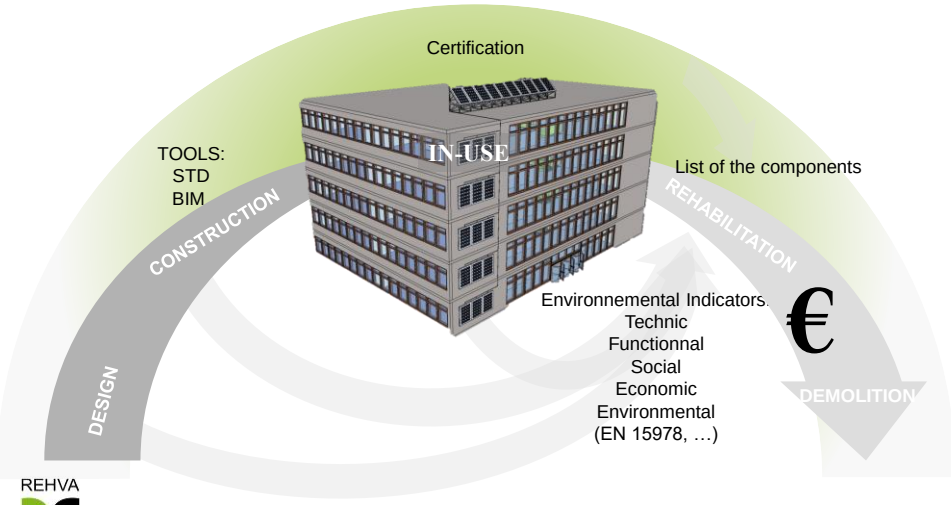
A FRAMEWORK FOR INTEGRATING VALUE AND UNCERTAINTY IN THE SUSTAINABLE OPTIONS ANALYSIS IN REAL ESTATE INVESTMENT

Alireza Bozorgi

21

21

DATA FLOW



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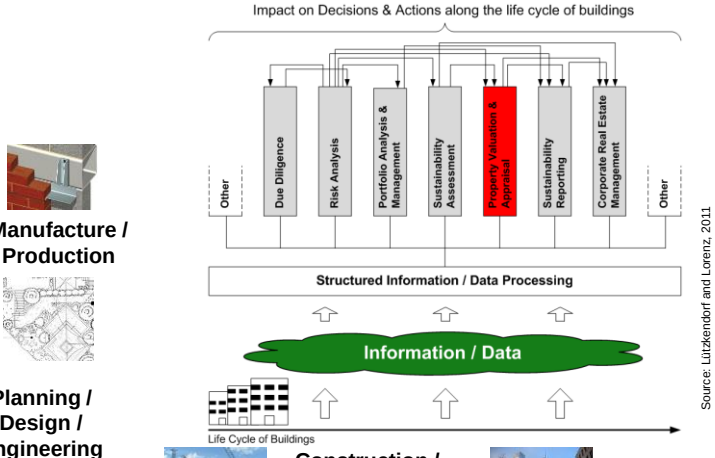
Data organisation and accuracy



Manufacture / Production

Planning / Design / Engineering



Construction / Commissioning / Modernisation



Facility Management

Disposal & Recycling



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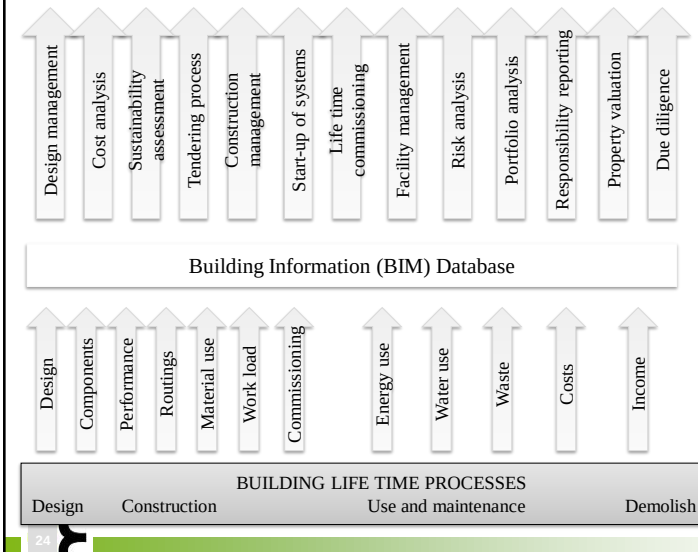
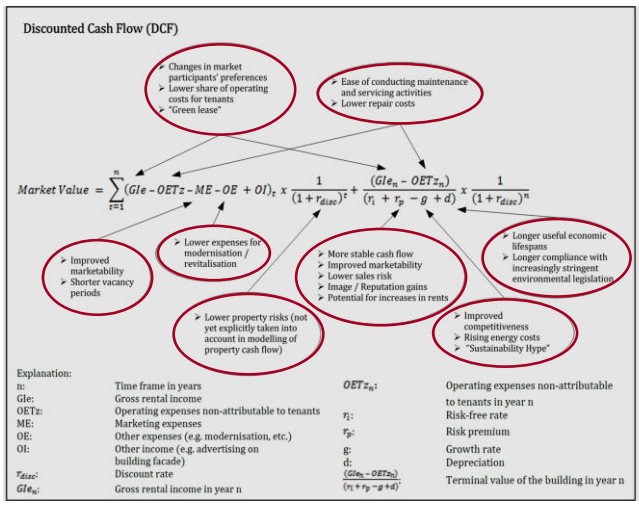
DATA FLOW



PERFORMANCE INDICATORS:
e.g.

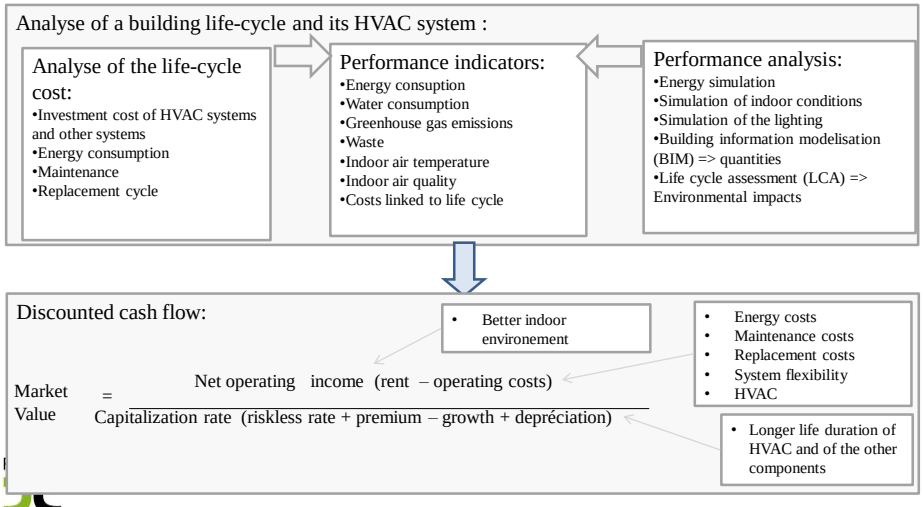
- Embodied carbon of building ($kgCO_2/m^2$)
- Carbon emission of energy use ($kgCO_2/m^2$)
- Carbon emission of travelling ($kgCO_2$/person)
- Primary energy consumption (kWh/m^2)
- Energy use (MJ)
- Water use (m^3/person)
- Landfill waste (kg/person)
- Indoor air temperature deviation (%)
- Particculates matter ($\mu g/m^3$)
- CO_2-level of indoor air (ppm)
- Maintenance cost (€/m^2)
- Energy costs(€/m^2)
- Rent income (€/m^2)

Integrating sustainability features into valuation methods: Example DCF-Method





Valuation



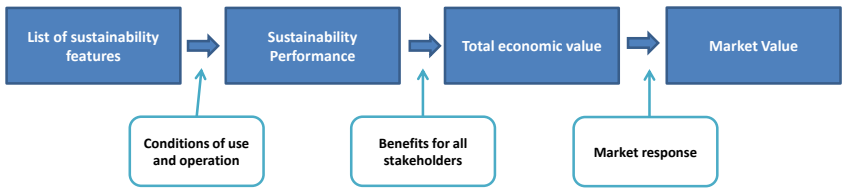
Source : REHVA guidebook 16

Federation of European Heating, Ventilation and Air-conditioning Associations

From data transparency to valuable information

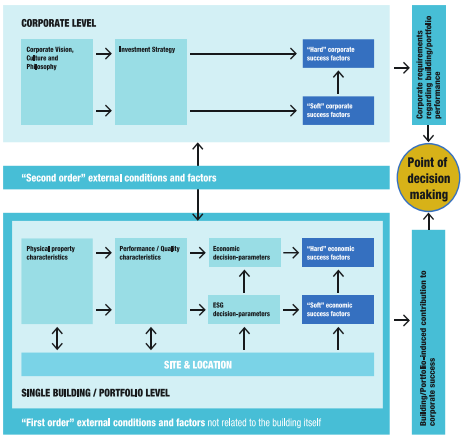
It is all about:

- data collection
- uncertainty management
- translation mechanisms through the market filters!



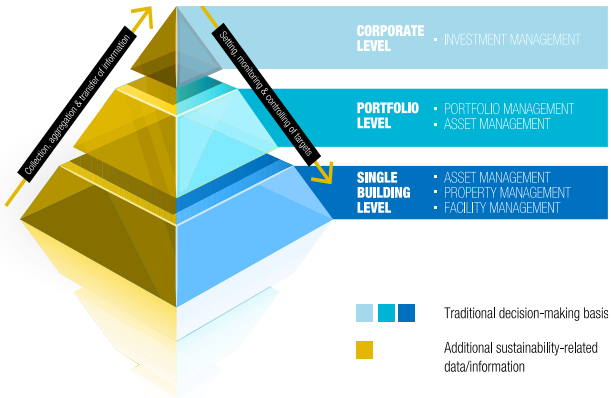
Translating information for decision-making

"From the boiler room to the board room.



How to get there: A selection of recommendations for best practice

Recommendations for Best Practices for Corporate Real Estate Sustainability Management (CRESM)



Building Long Term Value Assesment :

- Location
  - Connectivity infrastructure (grid & IT)
  - Local services and shops (positive impact density)
  - Security
  - Attractivity (image…)

- Quality
  - Indoor environemental quality
  - Energy performance
  - Lifespan
  - Flexibility / Mutability

VENTILATIVE COOLING

- TIME FOR LARGE SCALE IMPLEMENTATION

Per Heiselberg, Professor
Department of Civil Engineering

AALBORG UNIVERSITY
DENMARK

1

DEFINITION OF VENTILATIVE COOLING

- VENTILATIVE COOLING IS APPLICATION (DISTRIBUTION IN TIME AND SPACE) OF VENTILATION AIR FLOW TO REDUCE COOLING LOADS IN BUILDINGS
- VENTILATIVE COOLING UTILIZES THE COOLING AND THERMAL PERCEPTION POTENTIAL (HIGHER AIR VELOCITIES) OF OUTDOOR AIR
- IN VENTILATIVE COOLING THE AIR DRIVING FORCE CAN BE NATURAL, MECHANICAL OR A COMBINATION

2

VENTILATIVE COOLING

VENTILATIVE COOLING IS AN ATTRACTIVE AND ENERGY EFFICIENT PASSIVE SOLUTION TO COOL BUILDINGS AND AVOID OVERHEATING.

- Ventilation is already present in most buildings through mechanical and/or natural systems
- Ventilative cooling can both remove excess heat gains as well as increase air velocities and thereby widen the thermal comfort range.
- The possibilities of utilizing the free cooling potential of low temperature outdoor air increases considerably as cooling becomes a need not only in the summer period.



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IEA EBC Annex 62 Ventilative cooling 2012 - 2017

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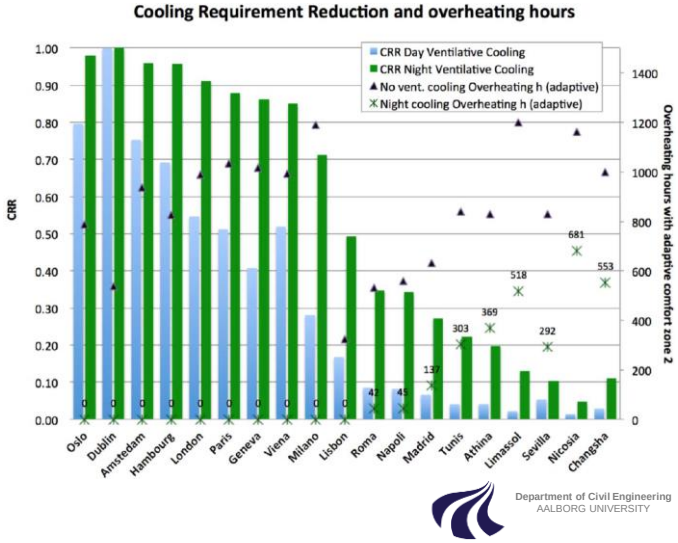
COOLING REQUIREMENTS REDUCTION (CRR)



$$CRR = \frac{Q_{t,c}^{ref} - Q_{t,c}^{scen}}{Q_{t,c}^{ref}}$$



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5

BOOK OF CASE STUDIES



6

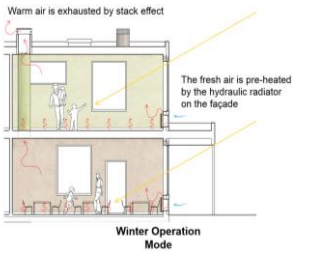
CML KINDERGARTEN
LISSABON, PORTUGAL

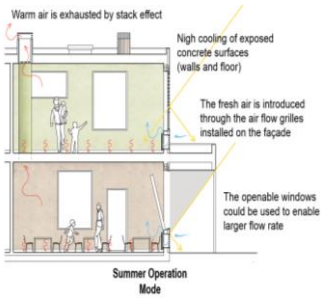


7

LESSONS LEARNED

- THE VC SYSTEM ELIMINATED THE ENERGY USE FOR COOLING OF THE BUILDING
- VC CREATED ACCEPTABLE THERMAL COMFORT AND IAQ CONDITIONS.
- THE INDOOR TEMPERATURE EXCEEDS 26 ^{O}C FOR LESS THAN 10% OF THE OCCUPIED HOURS.
- THE STACK DRIVEN NV PROVED TO BE VERY EFFECTIVE AND SELF REGULATING AND WAS ABLE TO MEET THE AIRFLOW RATE GOALS IN SPRING AND WINTER.
- THE MOST SIGNIFICANT PROBLEM ENCOUNTERED WAS RELATED TO CONTROL AND USER TRAINING.
- THE USERS WERE CONVINCED THAT THE CHIMNEYS WERE POORLY DESIGNED SKYLIGHTS





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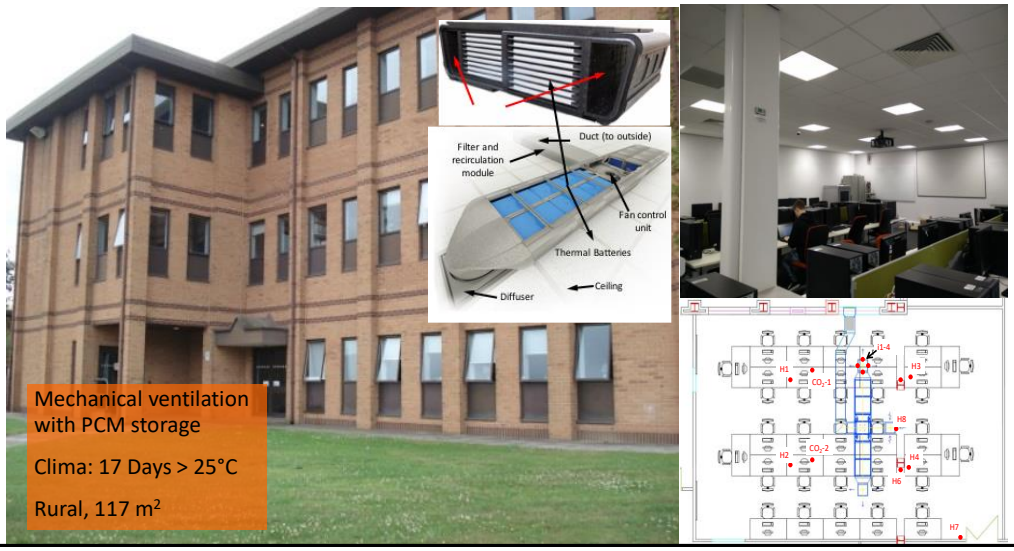
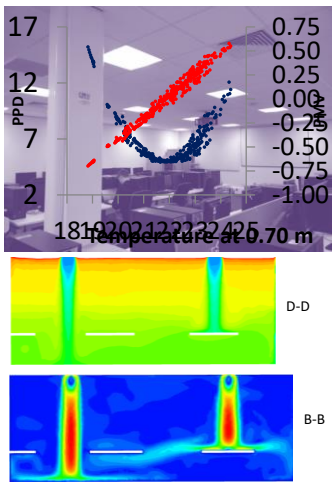


9

LESSONS LEARNED

- THE USE OF THE VENTILATIVE COOLING SYSTEM REDUCES THE ENERGY USE FOR COOLING OF THE BUILDING CONSIDERABLY.
- THE ELECTRICITY USE FOR AIR TRANSPORT WAS 0.78 KWH/M²/ANNUM IN 2014 AND 0.67 KWH/M²/ANNUM IN 2015, WHICH IS ONLY A FRACTION OF WHAT A NORMAL AC SYSTEM WOULD USE.
- ACCEPTABLE THERMAL COMFORT AND IAQ CONDITIONS WERE ACHIEVED.
- THE SYSTEM WAS ABLE TO COOL THE SPACE, SO NO OVERHEATING WAS MONITORED, BUT PERIODS WITH OVERCOOLING WAS IDENTIFIED.



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10

RENOVATED SINGLE FAMILY HOUSE









VENTILATION AND SHADING SYSTEMS COMPARISON

- 2015 SUMMER

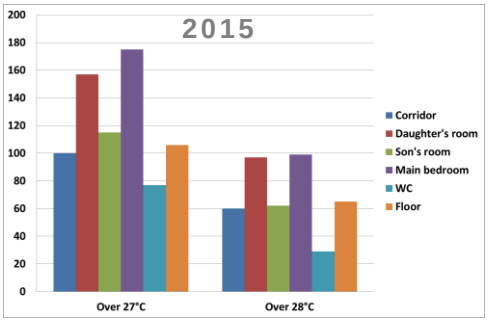
✓ MANUAL ROOF WINDOW OPENING AND SOLAR SHADING
✓ MANUAL USE OF FAÇADE-SHADING SYSTEMS
✓ CONSTANT MECHANICAL VENTILATION

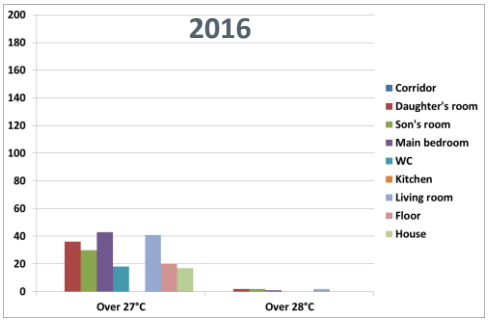
- 2016 SUMMER

✓ AUTOMATIC OPENING OF ROOF WINDOWS
✓ AUTOMATIC SOLAR SHADING ON ROOF WINDOWS
✓ NO (LIMITED) USE OF FAÇADE WINDOWS AND SHADING SYSTEMS
✓ NO MECHANICAL VENTILATION

LESSONS LEARNED

- AUTOMATIC CONTROL OF SOLAR SHADING AND WINDOW OPENING IMPROVED THERMAL CONDITIONS CONSIDERABLY
- MECHANICAL VENTILATION NOT NECESSARY IN THE SUMMER PERIOD (IAQ ALSO ACCEPTABLE)
- MOST REPORTED PROBLEMS WERE RELATED TO NOISE FROM MOTORS DURING NIGHT AND OVERCOOLING IN THE MORNING





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Next Step
- Large Scale Implementation

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WHAT ARE THE OBSTACLES AND STUMBLE STONES FOR LARGE SCALE IMPLEMENTATION?

VENTILATIVE COOLING IS HANDLED VERY DIFFERENTLY IN STANDARDS AND REGULATIONS IN DIFFERENT COUNTRIES

IT WOULD BE BENEFICIAL TO SHARE EXPERIENCES AND ALIGN PROCEDURES AND METHODS FOR VENTILATIVE COOLING, OVERHEATING RISK AND THERMAL COMFORT REQUIREMENTS IN CALCULATIONS AND PERFORMANCE EVALUATION AMONG COUNTRIES

THERE IS A STRONG NEED FOR EASY TO USE DESIGN GUIDELINES ESPECIALLY FOR RESIDENTIAL AND SMALL SCALE OFFICE BUILDINGS

THE USE OF CUSTOMIZED SOLUTIONS NEEDS TO BE REPLACED BY STANDARD "OFF-THE-SHELVE" TECHNICAL SOLUTIONS INCLUDING SOLUTIONS FOR CONTROL

FURTHER EDUCATION OF ENGINEERS AND ARCHITECTS TO ENSURE UNDERSTANDING OF THE PHENOMENA AND CORRECT IMPLEMENTATION OF VENTILATIVE (AND OTHER FORMS OF PASSIVE AND NATURAL) COOLING.

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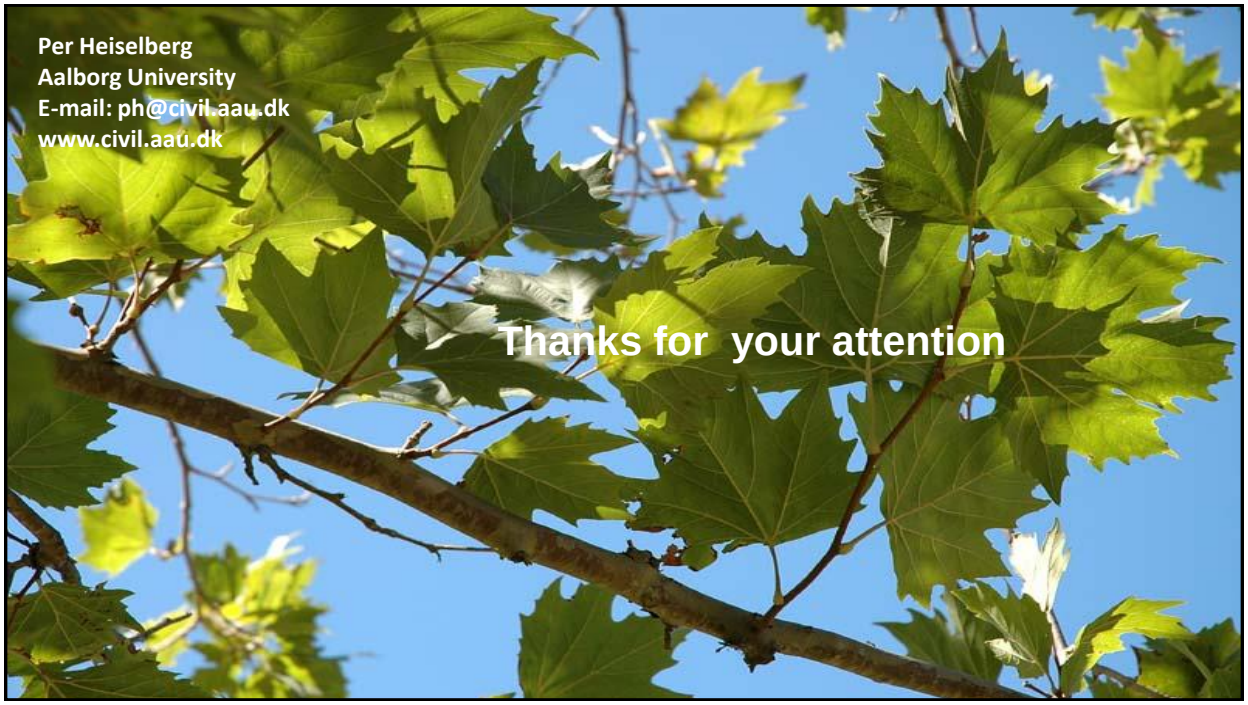

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AIVC 2019
Smart Ventilation, IAQ & Health

Benjamin Jones

On-Going AIVC Projects

1. Smart Ventilation
2. Air cleaning as an alternative to ventilation
3. Utilization of heat recovery
4. Rational behind ventilation requirements and regulations
5. Integrating uncertainties dues to wind and stack effect in declared airtightness results
6. Indoor Air Quality-IAQ Metrics
7. Residential cooker hoods
8. Competent tester schemes for building airtightness testing

University of Nottingham
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Smart Ventilation



Ventilation Information Paper n° 38
March 2018

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International Energy Agency's Energy in Buildings and Communities Programme

AIVC
Air Infiltration and Ventilation Centre

What is smart ventilation?

François Durier, CETIAT, France
Rémi Carré, ICEE, France
Max Sherman, LBNL, USA

1 Introduction

In March 2017, AIVC identified smart ventilation for buildings as a new and important topic to be addressed.

Several actions were defined by AIVC Board about this topic in order to exchange and disseminate information on this topic. A working group of AIVC experts from several countries was created. One of its tasks was to agree on a definition of smart ventilation.

The purpose of this paper is to present and illustrate this definition of "smart ventilation"

2 What is smart ventilation?

2.1 Definition

The definition given by AIVC for smart ventilation in buildings is:

"Smart ventilation is a process to continually adjust the ventilation system in time, and optimally by location, to provide the desired IAQ benefits while minimizing energy consumption, utility bills and other non-IAQ costs (such as thermal discomfort or noise).

A smart ventilation system adjusts ventilation rates in time or by location in a building to be responsive to one or more of the following: occupancy, outdoor thermal and air quality conditions, electricity grid needs, direct sensing of contaminants, operation of other air moving and air cleaning systems.

In addition, smart ventilation systems can provide information to building owners, occupants, and managers on operational energy consumption and indoor air quality as well as signal when systems need maintenance or repair.

Being responsive to occupancy means that a smart ventilation system can adjust ventilation depending on demand such as reducing ventilation if the building is unoccupied.

Smart ventilation can time-shift ventilation to periods when a) indoor-outdoor temperature differences are smaller (and away from peak outdoor temperatures and humidity), b) when indoor-outdoor temperatures are appropriate for ventilative cooling, or c) when outdoor air quality is acceptable.

Being responsive to electricity grid needs means providing flexibility to electricity demand (including direct signals from utilities) and integration with electric grid control strategies.

Smart ventilation systems can have sensors to detect air flow, systems pressures or fan energy use in such a way that systems failures can be detected and repaired, as well as when system components need maintenance, such as filter replacement."

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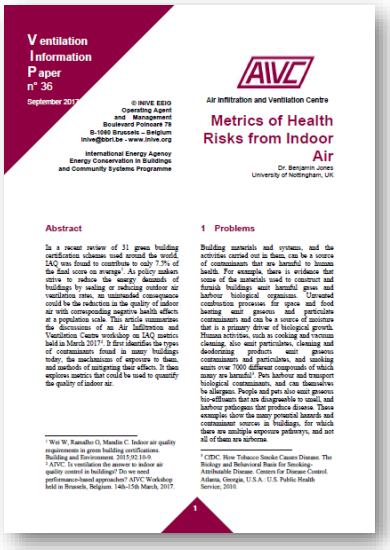

Ventilation Information Paper n° 36
September 2017

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International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

AIVC
Air Infiltration and Ventilation Centre

Metrics of Health Risks from Indoor Air

Dr. Benjamin Jones
University of Nottingham, UK

Abstract

In a recent review of 31 green building certification schemes used around the world, IAQ was found to contribute to only 7.5% of the final score on average[1]. As policy makers strive to reduce the energy demands of buildings by sealing or reducing outdoor air ventilation rates, an unintended consequence could be the reduction in the quality of indoor air with corresponding negative health effects at a population scale. This article summarizes the discussions of an Air Infiltration and Ventilation Centre workshop on IAQ metrics held in March 2017[2]. It first identifies the types of contaminants found in many buildings today, the mechanisms of exposure to them, and methods of mitigating their effects. It then explores metrics that could be used to quantify the quality of indoor air.

1 Problems

Building materials and systems, and the activities carried out in them, can be a source of contaminants that are harmful to human health. For example, there is evidence that some of the materials used to construct and furnish buildings emit harmful gases and harbour biological organisms. Unwanted combustion processes for space and food heating emit gaseous and particulate contaminants and can be a source of moisture that is a primary driver of biological growth. Human activities, such as cooking and vacuum cleaning, also emit particulates, cleaning and deodorizing products emit gaseous contaminants and particulates, and smoking emits over 7000 different compounds of which many are harmful[3]. Pets harbour and transport biological contaminants, and can themselves be allergens. People and pets also emit gaseous bio-effluents that are disagreeable to smell, and harbour pathogens that produce disease. These examples show the many potential hazards and contaminant sources in buildings, for which there are multiple exposure pathways, and not all of them are airborne.

[1] Wei W, Ramalho O, Mandin C. Indoor air quality requirements in green building certifications. Building and Environment. 2015;92:10-9.
[2] AIVC. Is ventilation the answer to indoor air quality control in buildings? Do we need performance-based approaches? AIVC Workshop held in Brussels, Belgium. 14th-15th March, 2017.

[3] CDC. How Tobacco Smoke Causes Disease. The Biology and Behavioral Basis for Smoking-Attributable Disease. Centers for Disease Control. Atlanta, Georgia, U.S.A.: U.S. Public Health Service; 2010.

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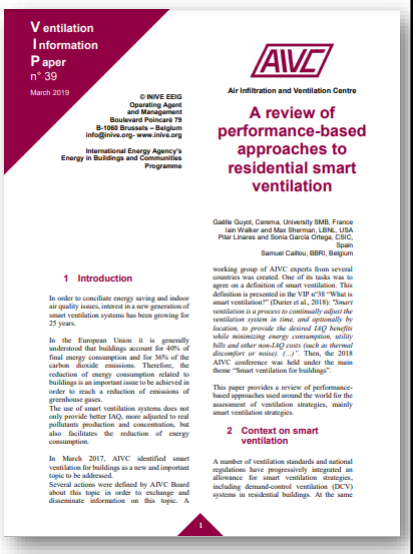

Ventilation Information Paper n° 39
March 2019

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International Energy Agency's Energy in Buildings and Communities Programme

AIVC
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A review of performance-based approaches to residential smart ventilation

Gaëlle Guyot, Cerema, University SMB, France
Iain Walker and Max Sherman, LBNL, USA
Pilar Linares and Sonia Garcia Ortega, CSIC, Spain
Samuel Caillou, BBRI, Belgium

1 Introduction

In order to conciliate energy saving and indoor air quality issues, interest in a new generation of smart ventilation systems has been growing for 25 years.

In the European Union it is generally understood that buildings account for 40% of final energy consumption and for 36% of the carbon dioxide emissions. Therefore, the reduction of energy consumption related to buildings is an important issue to be achieved in order to reach a reduction of emissions of greenhouse gases.
The use of smart ventilation systems does not only provide better IAQ, more adjusted to real pollutants production and concentration, but also facilitates the reduction of energy consumption.

In March 2017, AIVC identified smart ventilation for buildings as a new and important topic to be addressed.
Several actions were defined by AIVC Board about this topic in order to exchange and disseminate information on this topic. A working group of AIVC experts from several countries was created. One of its tasks was to agree on a definition of smart ventilation. This definition is presented in the VIP n°38 "What is smart ventilation?" (Dunier et al., 2018): *"Smart ventilation is a process to continually adjust the ventilation system in time, and optionally by location, to provide the desired IAQ benefits while minimizing energy consumption, utility bills and other non-IAQ costs (such as thermal discomfort or noise). (…)"*. Then, the 2018 AIVC conference was held under the main theme "Smart ventilation for buildings".

This paper provides a review of performance-based approaches used around the world for the assessment of ventilation strategies, mainly smart ventilation strategies.

2 Context on smart ventilation

A number of ventilation standards and national regulations have progressively integrated an allowance for smart ventilation strategies, including demand-control ventilation (DCV) systems in residential buildings. At the same

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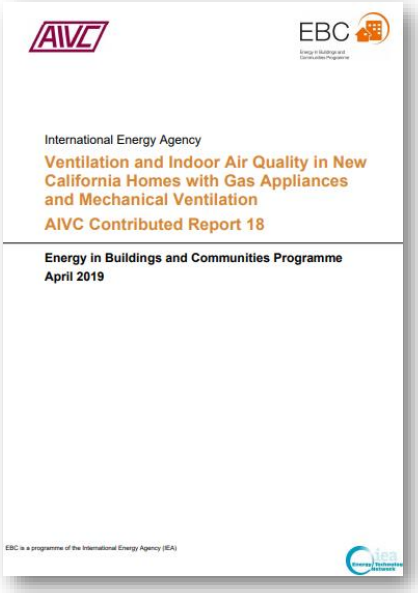
Annex 68



AIVC

EBC
Energy in Buildings and Communities Programme

International Energy Agency

Ventilation and Indoor Air Quality in New California Homes with Gas Appliances and Mechanical Ventilation

AIVC Contributed Report 18

Energy in Buildings and Communities Programme
April 2019

EBC is a programme of the International Energy Agency (IEA)

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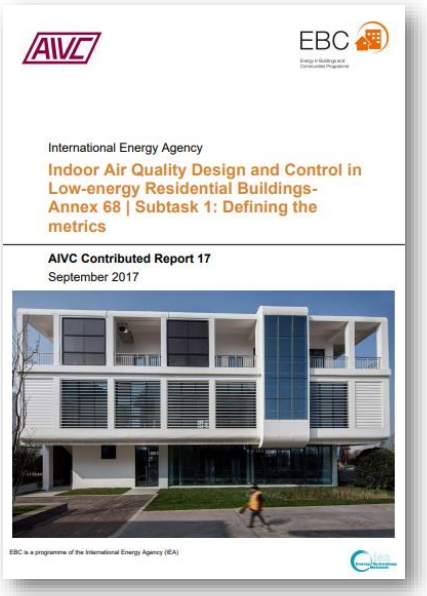
Field studies



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Performance assessment

"Turn left at the next traffic lights, then take the fourth street to the right, go right ahead at the first roundabout, turn to the right at the second roundabout and keep the left lane, then turn ....."



"To the airport!"



Figure 1. Illustration of (a) a prescriptive approach; (b) a performance-based approach. Source : (Spekkink, 2005)

6

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Moisture

Moisture in indoor air: findings of 40 years

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Building Technology
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paula.wahlgren@chalmers.se

SUMMARY

This extended summary is a part of a more extensive summary (technote to be published) that compiles a number of AIVC publications that deal with ventilation and health in relation to moisture in air, and the development over time.

FUKTSÄKERT ByggaF

7

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Sleep



8


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The End

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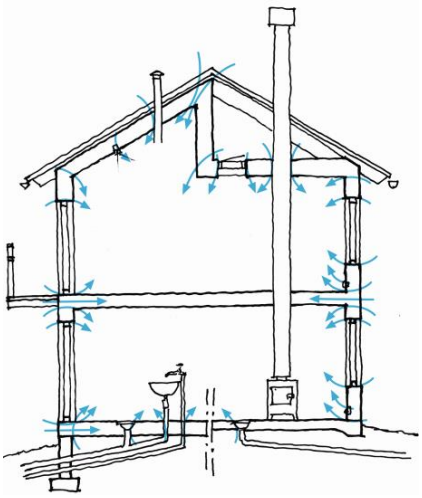
Summary of the airtightness track

40th AIVC, 8th TightVent & 6th Venticool conference



Paula Wahlgren
Chalmers University of Technology
Sweden

1

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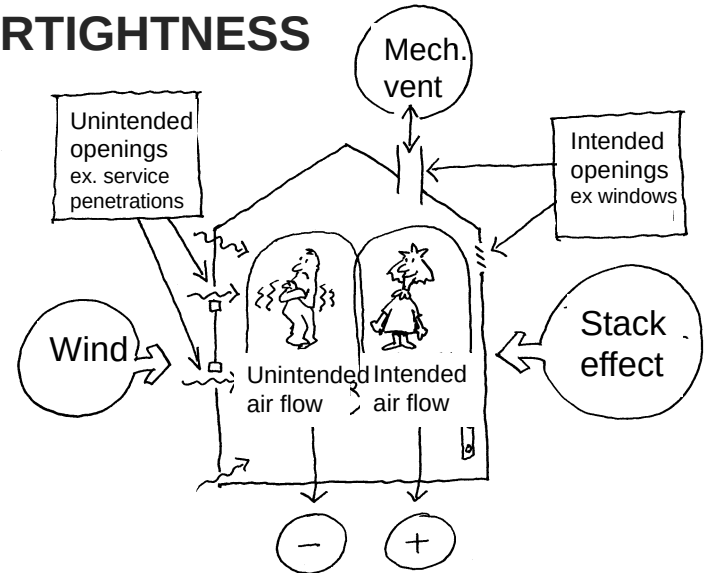
AIRTIGHTNESS



Evaluation



Consequences: moisture problems, energy use, comfort etc.

2

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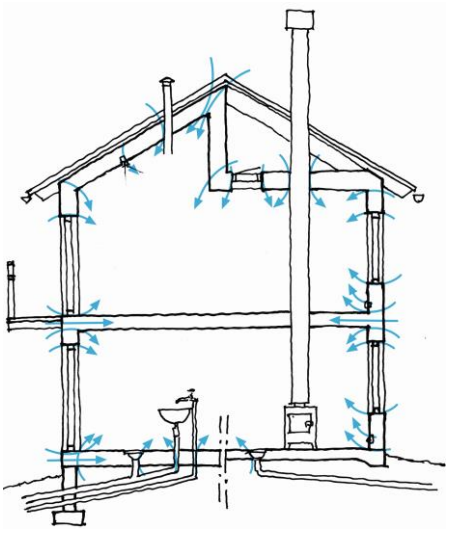
Airtightness



Building air permeability, q50, and leakages
How do we measure it?
What levels are acceptable?
What requirements should we have?
How is the durability?

Infiltration
What is affecting it?
How do we measure it?
How do we modell it?

3

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Airtightness topics

- Measurement of airtightness- alternative methods and wind impact
- Durability of airtightness
- Modelling of infiltration

4

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Sessions relating to airtightness TUESDAY

1B Test methods for building airtightness (6 pres)

2C 40 years on AIVC

- **History of modelling infiltration**

3B Energy performance of ventilation systems

- **Duct leakage**

4B Short oral presentations (6 pres)

- **Airtightness measurements of larger building stocks- how does the airtightness vary with different properties**
- **Measuring very airtight buildings is time consuming**
- **How to calculate/model infiltration the best way**

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Sessions relating to airtightness WEDNESDAY

5B Integrating uncertainties due to wind and stack effect in declared airtightness results (5 pres)

6B Durability of building airtightness (3 pres)

7B Modelling of infiltration and ventilation

- **Commercial building infiltration rate**
- **Probabilistic modelling of wind induced air exchange**

Measurement of airtightness

Alternative methods for measuring airtightness

- The Pulse Method compared to Blower Door measurements
- The performance of the Pulse Method
- Acoustical technique for measuring the airtightness

Pulse method

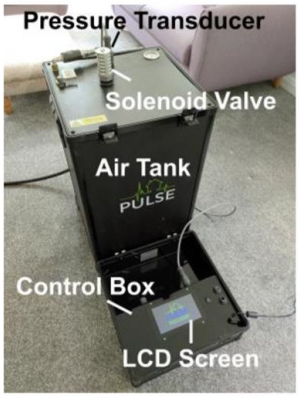


Figure 1: PULSE-60 unit with control box

Blower door



Figure 2: Energy Conservatory duct blaster series B

From paper by Yun-Sheng Hsu

Acoustical technique

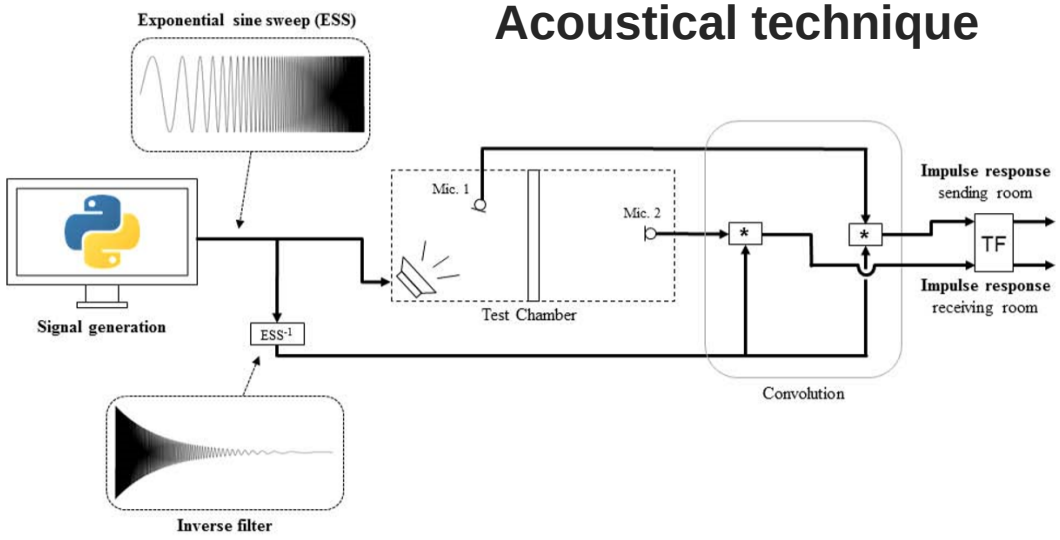


Figure 1: Measurement procedure

Airtightness

Measurement of airtightness

Alternative methods for measuring airtightness

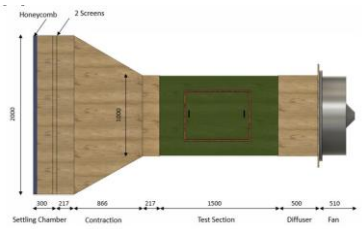
- The Pulse Method compared to Blower Door measurements
- The performance of the Pulse Method
- Acoustical technique for measuring the airtightness

Change in performance of blower-door fans

Measurement of airtightness

Impact of wind on measurement results

- Location of pressure taps
- Uncertainty of zero-flow pressure
- CFD simulations to prepare for measurements
- Wind tunnel measurements



From Adeline Bailly Méloi

Durability of airtightness

Field measurements mid term and long term
- airtightness decrease/increase depends on the construction

Laboratory measurements





From Fredrik Domhagen

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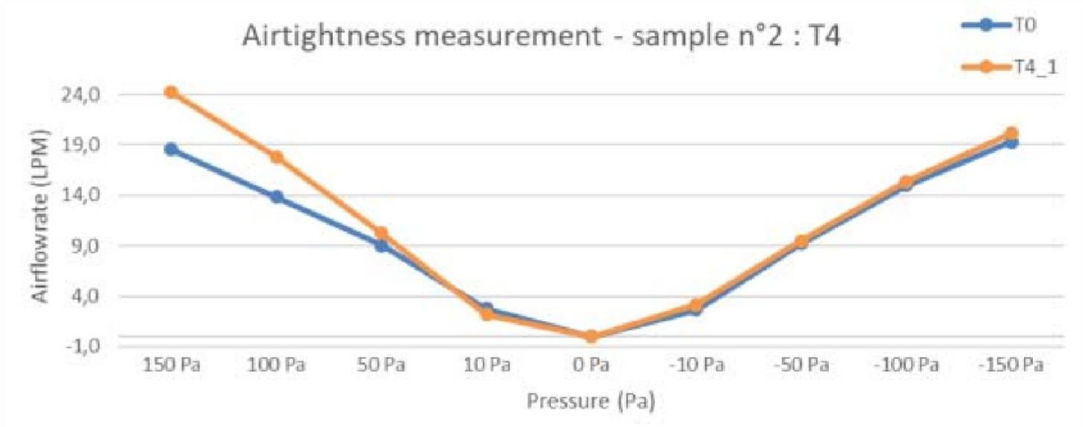
Laboratory test on durability



From Andrés Litvak

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Airtightness topics

Measurement of airtightness- alternative methods and wind impact

Durability of airtightness

Modelling of infiltration

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16

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Sessions relating to airtightness

1B Test methods for building airtightness

5B Integrating uncertainties due to wind and stack effect in declared airtightness results

6B Durability of building airtightness

7B Modelling of infiltration and ventilation

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Sessions relating to airtightness WEDNESDAY

5B Integrating uncertainties due to wind and stack effect in declared airtightness results (5 pres)

- **Pressure measurements (location, type and zero pressure)**
- **Model-scale experiment**
- **CFD modelling**

6B Durability of building airtightness (3 pres)

- **Field measurements mid term and long term**
- **Laboratory measurements**

7B Modelling of infiltration and ventilation

- **Commercial building infiltration rate**
- **Probabilistic modelling of wind induced air exchange**

40th AIVC - 8th TightVent & 6th venticool Conference

From energy crisis to sustainable indoor climate - 40 years of AIVC

Summing up
Ventilative Cooling & HVAC track

Hilde Breesch

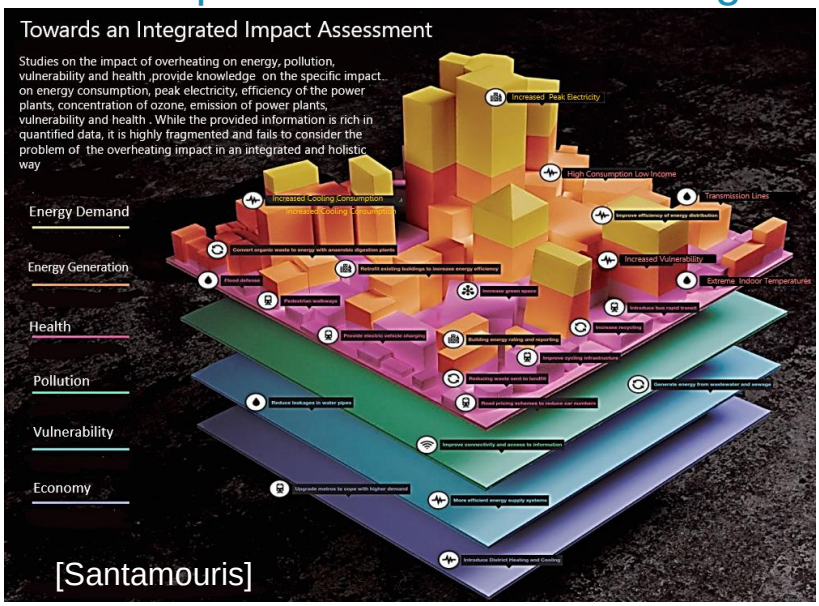
1

Overview Ventilative Cooling & HVAC

15 October	16 October
1C: Topical session Annex 79: what information do we need for occupant-centric building design & operation?	5C: Topical session: model based control and concepts for ventilation systems
3C: optimized HVAC design and operation	6C: Topical session: Annex 80: resilient cooling
	7C: Measurement and commissioning of ventilation systems and ductwork
	8B: Topical session: When the EPR hits the fan
	9C: Topical session: implementation of Ventilative Cooling in national building standards

2

Holistic aproach urban overheating



Annex 80: resilient cooling

- Requirements/definition resilient cooling [Holzer]
  - Reliability & Failure Safety
  - Affordability & Accessibility
  - Energy Efficiency & Carbon Neutrality
  - Social Inclusiveness

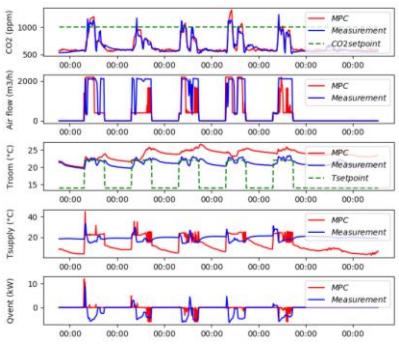


Ventilative cooling in standards

- ISO and EN [Plesner and Roth]
  - New technical documents
    - ISO/TC 205: standard: design process natural VC non-residential buildings
    - CEN/TC 156: technical specification: VC in all buildings
  - Focus on thermal comfort
  - Expected publication: 2022-23
- National standards/legislation/compliance tools [UK, BE, CH, DK]
  - Potential very differently included
  - Strong need for system design guidelines & education of designers

Ventilation control

- Discussion about potential & barriers of model predictive control
  - Do you think that MPC has potential in control of ventilation? *Yes, a little bit*
  - Barriers:
    - Cost
    - Potential not clear
    - Lack of knowledge of designer
    - Lack of experience of installer
    - Difficult to convince building owner/user



[Merema et al.]

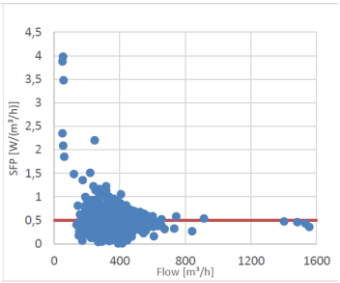
Commissioning is important

- Quality framework
  - BE (Flanders): inspection ventilation system [De Strycker et al.]
  - NL: performance contract: Simplified measurement tools for ventilation air flows & noise [Borsboom et al.]
- Development/refinement of test procedures for measuring airflow rates [Remion et al.], [Berhault et al.], [Paralovo et al.], [Few et al.]



Inspections performed in 2018

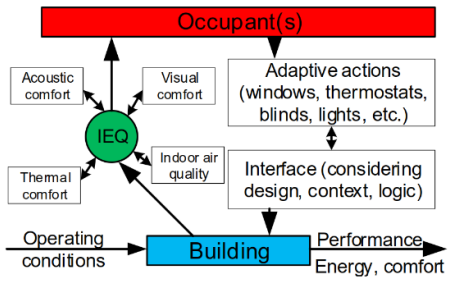
[De Strycker et al.]



Mechanical ventilation with heat recovery

User/occupant is important

- Annex 79: Occupant-Centric Building Design and Operation [Wagner, Mahdavi]



Advanced modelling of occupant behaviour in buildings assumes that occupants are active decision-making agents who respond to indoor environmental conditions.
Source: EBC Annex 79

- Annex 80: resilient cooling technologies [Olesen]
  - Occupants
  - Personal control
- Also in [Belmans et al.]: test robustness ventilation system towards users by a semi-probabilistic virtual user panel



IAQ 2020: Indoor Environmental Quality Performance Approaches

Transitioning from IAQ to IEQ

September 14-16, 2020 | Athens, Greece

ASHRAE® AIVC

1

Overview

- Established in 1986, 19th in series
- Co-organized with AIVC, IAQ 2020 also serves as the 41st AIVC Annual Conference
- Expand focus from Indoor *Air* Quality to Indoor *Environmental* Quality (IAQ, thermal comfort, acoustics, and illumination and their interactions)
- International, multidisciplinary participation, researchers and practitioners
- Co-chaired by Bill Bahnfleth (Penn State) and Max Sherman (Lawrence Berkeley National Laboratory)

2

Topics

- **Health and Well-being:** Appropriate technical and operational definitions
- **Performance Metrics:** For all aspects of IEQ
- **Interactions:** Interactions between IEQ parameters
- **Occupant Behavior**: How behavior impacts IEQ and how IEQ impacts behavior - psychological dimensions of IEQ
- **Smart Sensors and Big Data**: Sensor properties, data management, cybersecurity, applications
- **Smart Controls**: Equipment properties, commissioning, equivalence
- **Resilience and IEQ**: Responding to climate change and disasters
- **Ventilation**: Mechanical, passive, natural and hybrid systems
- **Air Tightness:** Trends, methods and impacts
- **Thermal Comfort**: Dynamic approaches, health impacts and trends
- **Policy and Standards**: Trends, impacts, implications

Keynote Speakers

- Philomena Bluyssen, TU Delft, Netherlands
- Richard de Dear, University of Sydney, Australia
- Mariana Figueiro, Lighting Research Center, RPI, USA
- Benjamin Jones, PhD, University of Nottingham, UK
- Catherine Noakes, PhD University of Leeds, UK
- Stephanie Taylor, Taylor Healthcare Consulting, US

Call for Papers/Schedule

- Conference papers (6 pages) or extended abstracts https://www.conftool.org/IAQ2020/
- Submit 300 max word abstract, December 9, 2019
- Notify of decision on abstract, February 12, 2020
- Submit complete manuscript, April 17, 2020
- Final acceptance, June 12, 2020

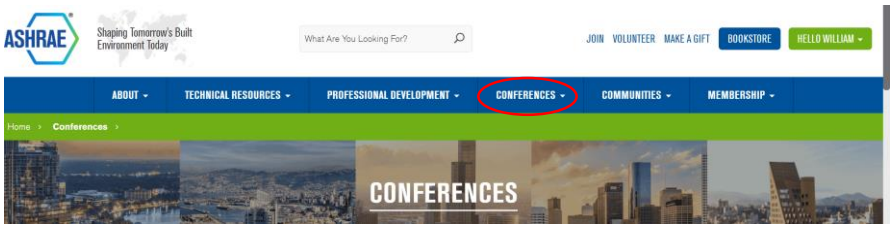
Special Issue of STBE

- Papers with potential archival value will be selected for publication as full length articles in a special issue of *Science and Technology for the Built Environment*
- Guest editors
  - Chandra Sekhar, National University of Singapore
  - William Bahnfleth, Penn State



Conference Web Page

www.ashrae.org/conferences/topical-conferences/indoor-environmental-quality-performance-approaches



Please considering submitting an abstract and joining us in Athens!