43rd AIVC
11th TightVent & 9th venticool Conference

Ventilation, IEQ and health in sustainable buildings

CONFERENCE ORGANIZERS

INIVE

AIVC

venticool
the platform for resilient ventilative cooling

TightVent Europe
BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

BUILD DEPARTMENT OF THE BUILT ENVIRONMENT
AALBORG UNIVERSITY

October 4-5 2023

Copenhagen Denmark

PRESENTATIONS

www.aivc2023conference.org

SUPPORTING ORGANIZERS

EBC

IEQ-GA

REHVA

Sponsors / Exhibitors

TightVent Partners

Lindab
retrotec
meztechnik AIR SYSTEM PRODUCTS
ACIN instrumenten
BCCA
BlowerDoor GmbH MessSysteme für Luftdichtheit
doopApp
SOUDAL
eurima
gonal driving air
SIGA
BPIE

Venticool Partners

DUCO Ventilation & Sun Control
RENSON Creating healthy spaces
NAVENTA NATURAL VENTILATION ASSOCIATION
Reynaers Aluminium
VELUX
WindowMaster Fresh Air. Fresh People.
activehouse
EuroWindoor
CIBSE Natural Ventilation
REHVA

Other Sponsors

TSI Knowledge Beyond Measure.
aranet
BUILD TEST SOLUTIONS

Congress Venue

Aalborg University A. C. Meyers Vænge 15, 2450 København -Denmark

Registration Desk Hours

Registration Desk will be open during the following dates and times:

Tuesday 3 October, 2023 / 19:00 – 20:00

Wednesday 4 October, 2023 / 08:00 – 19:00

Thursday 5 October, 2023 / 08:30 – 18:00

Poster display information

- Posters should be set up on Wednesday 4 October, 2023 from 09:00
- Dismantling of posters should be finished by **Thursday 5 October 2023 at 16:30**

Professional Congress Organizer and Organizers have no liability for posters left behind

Poster dimensions

A0) size, 120CM Height x 80CM Width

Poster presentation session

Wednesday October 4, 2023 at 19.00 – 21.00

Authors are kindly requested to be in front of their poster
to be able to reply to any questions

Long & Short Oral Presentation 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

Tuesday 3 October, 2023

19:00 – 20:00

Aalborg University,
Kantine Area

Poster Presentations & Student Competition – Industry stands – Cocktail Reception

Wednesday 4 October, 2023

18:30 – 20:00

Aalborg University,
Poster Area

Gala Dinner

Thursday 5 October, 2023

20:00 – 22:30

Kosmopol ApS
(Fiolstræde 44 DK-1171
København)

Tuesday October 3th, 2023

19:00–20:00	Registration & Welcome reception

ROOM D (1.042)

Wednesday October 4th, 2023

08:00-09:00	Registration
09:00-10:30	**Opening - Plenary session** *Chairs:* Alireza Afshari, Arnold Janssens **Welcome on behalf of AIVC, venticool, TightVent** Arnold Janssens, *INIVE/AIVC/Ghent University* **Welcome on behalf of Aalborg University Copenhagen** Alireza Afshari, *Aalborg University Copenhagen, Denmark* **Tomorrow's Ventilation Solutions for Future Hospital Demands** Trond Thorgeir Harsem, *Nordconsult, Norway* **Users and practices in heating and ventilating homes – why do they behave different than we think?** Kirsten Gram-Hanssen, *Aalborg University, Denmark* **What we know about smart ventilation** Gaëlle Guyot, *Cerema, France* **Dallying with DALYs: Why acceptable IAQ should consider harm** Benjamin Jones, *University of Nottingham, United Kingdom*
10:30-11:00	Coffee Break

ROOM A (1.008)

11:00-12:30

Session 1A - Topical Session
(Airborne cross infection and engineering solutions)

Chairs: **Peter V. Nielsen, Chen Zhang**

The COVID-19 pandemic raises the publics' attention on cross infections in the indoor environment. WHO has identified airborne transmission as a principal route for SARS-CoV-2, especially in crowded and poorly ventilated indoor environments. In fact, airborne transmission is one of the primary routes for many infectious diseases, such as anthrax, chickenpox, and influenza. The airborne cross-infection risk between people is influenced by many parameters, such as distance, relative position, respiratory activities, room ventilation, face mask, or other protection equipment. Effective control of these influencing factors can be important to mitigate airborne transmission risk between people. Many prevention measures were recommended by authorities during COVID-19, but their protective effects regarding airborne transmission are still under discussion.
The main objective of this workshop is to discuss the mechanism of airborne transmission and the engineering control solutions. Through the discussion, the workshop will find out some effective and efficient control measures to reduce airborne cross-infection risk. Discussion topics include:
1. What are the parameters influencing the cross-infection risk?
2. What are the challenges to reduce infection risk indoors?
3. How to design indoor airflow distribution to reduce the indoor exposure?
4. Are there any other engineering control solutions and what are their efficiency?
5. Where these engineering control solutions may be applied

Opening
Alireza Afshari, *Aalborg University, Denmark*

Human exposure against airborne pathogens in an office environment
Risto Kosonen, *Aalto University, Finland*

Discussion on minimum ventilation rates for infection control
Yuguo Li, *University of Hong Kong, Hong Kong*

Mitigation of airborne transmission of respiratory viruses by ventilation – past, present and future
Arsen Krikor Melikov, *Technical University of Denmark, Denmark*

Point source ventilation effectiveness in infection risk-based post-COVID ventilation design
Jarek Kurnitski, *Tallinn University of Technology, Estonia*

Airborne transmission of disease in stratified and non-stratified flow
Peter V. Nielsen, *Aalborg University, Denmark*

Discussion with the audience

ROOM B (1.001)

11:00-12:30	Session 1B - Long Oral Presentation Session (Building airtightness testing & prediction)

Chairs: **Laure Mouradian, Iain Walker**

Acoustic method for measurement of airtightness – field testing on three different existing office buildings in Germany
Bjorn Schiricke, *DLR (German Aerospace Center), Germany*

Pulse tests in highly airtight Passivhaus standard buildings
Xiaofeng Zheng, *University of Nottingham, United Kingdom*

Correlation analysis between ACH50 and Air permeability considering the floor area of a residential buildings
Suji Choi, *Inha University, Republic of Korea*

Airtightness predictive model from measured data of residential buildings in Spain
Irene Poza Casado, *University of Valladolid, Spain*

Bridging The Mechanical / Enclosure Gap
David de Sola, *3iVE LLC, United States of America*

ROOM C (2.1.042)

11:00-12:30	Session 1C - Topical Session (Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback)

Chairs: **Maxime Boulinguez, Gwénaëlle Haese, Arnaud Jay**

This session explores combined passive, soft and active cooling solutions, some occupant feedback and performance indicators. The presentation will be based on case studies in different climate conditions. The first part of the session will focus on windows and ceiling fan occupant behaviour model coupling methodology with Building Energy Models. This presentation will rely on a tropical case study. Then, an innovative approach to better understand hot discomfort will be highlighted based on the measurement of global human responses. This presentation will lie on an application to end users of mixed-mode cooled buildings under tropical climate conditions. Thirdly, a Windows coach for office workers will be introduced. The coach's objective is to advise occupants on the proper action to take on their windows (open or close) to optimise their thermal comfort, IAQ and energy efficiency. Feedback on two summers' experimental campaigns for occupant thermal comfort in a naturally ventilated building in a continental climate has been used to design the coach. This feedback will be presented. Finally, these works led to a new research project, CoolDown, funded by the French National Research Agency (ANR). It aims to develop new tools and methodologies to target energy and comfort performance in mixed-mode cooled buildings from early design to on-site performance. COOL-DOWN methodology will be introduced in the last presentation and will serve as a starting point for the discussion of this session.

Wednesday October 4th, 2023

11:00-12:30	**Windows and ceiling fan occupant behaviour model coupling methodology with building energy models, a tropical case study** **Maxime Boulinguez,** *Université La Réunion - PIMENT, France* **An innovative approach to better understand hot discomfort, based on the measurement of global human responses, including physiological and sensory indicators - application to end users of mixed mode cooled buildings under tropical climate conditions** **Gwénaëlle Haese,** *CSTB, France* **An IAQ and thermal comfort coach prototype to improve comfort and energy consumption thanks to adequate management of natural ventilation: development and first feedback results** **Arnaud Jay,** *CEA Liten - INES, France* **Towards an alternative cooling: Optimisation of the successive use of the cooling systems from passive to active - Development of design and control strategies of the hybrid cooling** **Arnaud Jay,** *CEA Liten - INES, France*
12:30-13:30	Lunch Break

ROOM C (2.1.042)

13:30-14:45	Session 2A - Topical Session (Energy Performance of Gas Phase Air Cleaning) *Chairs:* **Bjarne W. Olesen, Sasan Sadrizadeh** *The session will focus on the energy performance of gas phase air cleaning. Standalone air cleaners may improve air quality by delivering a certain Clean Air Delivery Rate (CADR). For the same level of air quality, the ventilation rate can be reduced by a similar amount. However, standalone air cleaners are also using energy. Air cleaners built into the ventilation system may increase pressure drop and using some power, which both increase the energy use. A couple of studies based on models and dynamic building simulations on energy use for heating, cooling, and ventilation have been used to study the overall energy implications of using gas phase air cleaners. The results will be presented and discussed in this session.*
13:30-14:45	**Introduction to IEA EBC Annex 78** **Bjarne W. Olesen,** *Technical University of Denmark, Denmark* **Air cleaner as an alternative to increased ventilation rates in buildings: a simulation study for an office** **Alireza Afshari,** *Aalborg University Copenhagen, Denmark* **Exploring the Energy-Saving Benefits of Gas-Phase Air Cleaning in Nordic Buildings** **Sasan Sadrizadeh,** *KTH Royal Institute of Technology, Sweden* **Gas phase air cleaning effects on ventilation energy use and indicators for energy performance** **Dragos-Ioan Bogatu,** *Technical University of Denmark, Denmark*

ROOM B (1.001)

13:30-14:45	Session 2B - Topical Session (Revision of ISO 9972: Improvements in the reliability of airtightness measurements) *Chairs:* **Valérie Leprince, Gary Nelson** *ISO 9972 is an international standard describing the measurement procedure and calculation methods for determining the air permeability of buildings using the fan pressurisation method. Given the impact of airtightness on building energy use, more and more tests are performed, a lot of them required by regulations. Indeed, environmental conditions during the test, and more specifically wind and temperature differences, may cause significant errors and thus increase the result uncertainty. However, when a target value must be reached in a mandatory context, knowing the test uncertainty is crucial. Recent works have underlined the need to improve the reliability of the method to measure a building's air leakage rate as described in ISO 9972.* *To address these challenges, Cerema has launched a project to review ISO 9972 and has set up a working group of international experts in the field of building airtightness testing to identify the relevant issues with the current standard and propose improvements. This project aims to lay a foundation for a thorough review and revision of the current ISO 9972 standard and this session will present the first results towards this revision.*
13:30-14:45	**Introduction to the project of ISO 9972 revision** **Valérie Leprince,** *Cerema, France* **On the integration of envelope pressure inhomogeneity and autocorrelation in fan pressurization uncertainty analysis** **Martin Prignon,** *Buildwise, Belgium* **Statistical analysis of the correlations between buildings air permeability indicators** **Bassam Moujalled,** *Cerema, France* **Proposal for new implementations in ISO 9972** **Benedikt Kölsch,** *Cerema, France* **Discussion with the audience**

ROOM C (2.1.042)

13:30-14:45	Session 2C - Long & Short Oral Presentation Session (Climate change & Resilient cooling) *Chairs:* **Yun Gyu Lee, Pilar Linares** **Which design parameters impact the resilience to overheating in a typical apartment building?** (Long Oral Presentation) **Abantika Sengupta,** *KU Leuven, Belgium* **Renewable ventilative cooling? Insights from an Irish perspective** (Long Oral Presentation) **Adam O' Donovan,** *Munster Technological University, Ireland* **Urban context and climate change impact on the thermal performance and ventilation of residential buildings: a case-study in Athens** (Long Oral Presentation) **Maria Kolokotroni,** *Brunel University London, United Kingdom* **Thermography-based assessment of mean radiant temperature and occupancy in healthcare facilities** (Long Oral Presentation) **Paul Seiwert,** *RWTH Aachen University, Germany* **Analyzing natural ventilation and cooling potential in a communal space building in Belgium under future climate conditions** (Short Oral Presentation) **Shiva Khosravi,** *Archipelago Leuven, Belgium* **A study of indoor environment and window use in French dwellings monitored during a summer with heatwaves** (Short Oral Presentation) **Mathilde Hostein,** *Cerema/ENTPE, France* **Importance of thermal stack effect in ventilative cooling concepts for residential buildings** (Short Oral Presentation) **Diederik Verscheure,** *Vero Duco NV, Belgium*
14:45-15:00	Room Change

ROOM A (1.008)

15:00-16:30

Session 3A - Topical Session
(Real performance of (smart) residential ventilation - performance assurance, fault detection, continuous commissioning)

Chairs: **Gaëlle Guyot, Jakub Kolarik**

This topical session is organized by the fourth subtask of the IEA EBC Annex 86 Energy Efficient IAQ Management in residential buildings entitled "Ensuring performance of smart ventilation". One of our focus points is the quality assurance of implemented residential ventilation systems & strategies, whether they can be called "smart" or not.

In this topical session, we want to present and discuss results and experiences from different stakeholders representing both industry and academia, regarding real performance of residential ventilation. Furthermore, we want to discuss how doe their data stand against existing quality management approaches and inspection protocols for residential ventilation. Can we identify the crucial issues specific to "smart systems"? We aim to discuss examples of approaches to ensure reliable operation beyond the commissioning phase.

15:00-16:30

Welcome and introduction
Gaelle Guyot, *Cerema, France*

Performance 2 project - Winter IAQ campaigns in 13 dwellings equipped with Humidity-based DCV systems: analyses of the ventilation performance after 15 years of use
Adeline Melois, *Cerema, France & Juan Rios, Aereco, France*

Checking and assuring real IAQ and energy performances through demand control and cloud connectivity
Ivan Pollet, *Renson, Belgium*

Data driven models for fault detection - Combining thermal and indoor air quality grey box models
Gabriel Rojas, *University of Innsbruck, Austria*

Evaluation of supply temperature set-points and airflow imbalance using smart ventilation data
Kevin Smith, *Technical University of Denmark, Denmark*

Technologies in balanced ventilation systems to maintain optimal performance in energy and comfort
Bart Cremers, *Zehnder Group, The Netherlands*

Discussion

ROOM B (1.001)

15:00-16:30	**Session 3B - Topical Session (Building and ductwork airtightness regulations in various countries)** *Chairs:* **Irene Poza Casado, Nolwenn Hurel** *In 2008 a series of Ventilation Information Papers (VIP)s (from VIP 17 to VIP 27) were published by the AIVC, detailing the "Trends in the building ventilation market and drivers for changes" for 10 countries. Regulations have however evolved a lot in most countries since then. A new series of VIPs is being developed to get an update on the current regulations in European countries regarding building and ductwork airtightness. They include for both, when relevant, information on: national requirements and drivers: airtightness indicator, requirements in the regulation, energy programs, airtightness justifications, sanctions, etc.; if it is included in the energy calculations and how; the airtightness test protocol: qualification for the testers, guidelines, requirements on measuring devices; tests performed: tested buildings/ductworks, database, evolution with time; guidelines to build airtight buildings/ductworks.* *Eight VIPs have been already published in this new series, and most of them have already been presented at the last AIVC Conference in Rotterdam (for Belgium, Czech Republic, Estonia, France and Greece). Contributions from other countries are in preparation, and a total of about 15 publications is expected to give an overview of the building and ductwork airtightness trends in various countries. Some of them are presented in this Topical Session.*
15:00-16:30	**Introduction: Presentation of the series of AIVC VIPs on building and ductwork airtightness regulations** **Nolwenn Hurel,** *PLEIAQ, France* **Building and ductwork airtightness in Norway: national trends and requirements** **Tormod Aurlien,** *NMBU, Norway* **Building and ductwork airtightness in The Netherlands: national trends and requirements** **Niek-Jan Bink,** *ACIN Instrumenten, The Netherlands* **Building and ductwork airtightness in Spain: national trends and requirements** **Irene Poza Casado,** *University of Valladolid, Spain* **Building and ductwork airtightness in Latvia: national trends and requirements** **Andrejs Nitijevskis,** *IRBEST Ltd, Latvia* **Air tightness and its impact on energy consumption in multi-family residential buildings in Montenegro** (Short Oral Presentation) **Esad Tombarevic,** *University of Montenegro, Montenegro*

ROOM C (2.1.042)

15:00-16:30	Session 3C - Topical Session (Resilient Cooling of Buildings meets Resilient Cooling in Cities) *Chairs:* **Hilde Breesch, Patryck Czarnecki** *In this interactive session the challenges of resilient cooling of buildings and their relation to their urban surroundings will be addressed. After a short presentation of main outcomes of EBC Annex 80 Resilient Cooling of Buildings, the audience will work in small groups on a prepared set of building cases and challenges. With the Technology Profiles from Annex 80 and the Resilient Cooling Guidelines at hand different solutions shall be discussed and most suitable ones identified. The discussion of these different approaches in the plenum shall foster peer learning and create a better understanding of the nexus of resilient cooling of buildings and resilient cooling in cities.*
15:00-16:30	**Resilient Cooling Technology Profiles from the EBC Annex 80** **Peter Holzer,** *Institute of Building Research & Innovation, Austria* **Resilient Cooling Guidelines from the EBC Annex 80** **Vincenco Corrado,** *Politecnico di Torino, Italy* **Work in small Design Groups** **Open discussion and collective conclusion in plenum**
16:30-17:00	Coffee Break

ROOM A (1.008)

17:00–18:15 **Session 4A - Short Oral Presentation Session (Indoor Air Quality & Health)**

Chairs: **Max Sherman, Pawel Wargocki**

Health risks of residential indoor and outdoor exposure to fine particle-bound phthalates
Jiayao Chen, *University College Dublin, Ireland*

HEPA filters to improve vehicle cabin air quality – advantages and limitations
Dixin Wei, *Volvo Cars, Sweden*

Experimental study of an innovative wet scrubber concept in regards to particle filtration and pressure loss
Nhat Nguyen, *RWTH Aachen University, Germany*

An evaluation of CO2 emission rates by Chilean school children
Nicolas Carrasco, *Pontificia Universidad Catolica de Chile, Chile*

The Effects of Bedroom Mechanical Ventilation on Health and Sleep Quality
Jeongwon Kim, *Dankook University, Republic of Korea*

Analysis of PM2.5 indoor-outdoor ratio in lobby floor according to configurations of entrance
Soyi Park, *Inha University, Republic of Korea*

Proposal of an effort-benefit diagram to compare unit and room air-change rates applied to a literature review
Sven Auerswald, *Fraunhofer ISE, Germany*

Experimental Investigation of Indoor Air Quality in an Open Office Environment
Mustafa Zeki Yilmazoglu, *Untes Heating Air Conditioning Corp., Turkey*

Hygienic Air Handling Unit Certification Program: the new necessity for a guaranteed indoor air quality
Ali Nour Eddine, *Eurovent Certita Certification, France*

Car traffic or emissions from heating sources: What is responsible for IAQ?
Katarzyna Ratajczak, *Poznan University of Technology, Poland*

Monitoring VOCs' concentrations in a circular biobased residential building using low-cost sensors (Student Competition)
Yannick Thienpont, *KU Leuven, Belgium*

Smart & Predictive Air Quality Solution
Paul Brasser, *Prometech, The Netherlands*

Energy Implications of Increased Ventilation in Commercial Buildings to Mitigate Airborne Pathogen Transmission
David Artigas & Sean M. O'Brien, *Simpson Gumpertz & Heger Inc., United States of America*

ROOM B (1.001)

17:00-18:15 **Session 4B - Short Oral Presentation Session (Ventilation strategies & thermal comfort)**

Chairs: **Jaap Hogeling, Maria Kolokotroni**

Reflections on alternative modelling approaches regarding occupants' window operation behaviour
Christiane Berger, *Aalborg University, Denmark*

Development of air supplied ceiling radiant air conditioning system using the Coanda effect (Student Competition)
Satoshi Noguchi, *the University of Kitakyusyu, Japan*

Wind Tunnel Experiment of Wind-Induced Single-sided Ventilation under Generic Sheltered Urban Area
Zitao Jiang, *Osaka University, Japan*

A study on desiccant system regenerated by waste heat from home-use solid oxide fuel cell cogeneration system
Keita Mizuno, *Misawa Homes Institute of Research & Development Co., Ltd., Japan*

Method for Evaluating an Air-Conditioning System with Natural Ventilation by Coupled Analysis of a Building Energy Simulation Tool and Computational Fluid Dynamics (Student Competition)
Ryuichi Yasunaga, *the University of Kitakyushu, Japan*

Performance comparison of different ventilation strategies in elderly care homes in Belgium
Hilde Breesch, *KU Leuven, Belgium*

Sea Water Air Conditioning (SWAC): A Resilient and Sustainable Cooling Solution for hot and humid climates - Energy Performance and Numerical Modeling
Kanhan Sanjivy, *University of French Polynesia, French Polynesia*

The Effects of Lowering Temperature Setpoints on Perceived Thermal Comfort –An experimental study in office buildings (Student Competition)
Beatriz Coutinho, *University of Coimbra - ADAI, Portugal*

Long-term energy performance of dew-point indirect evaporative cooler under the climate change world scenario (Student Competition)
Maria Jesus Romero-Lara, *University of Cordoba, Spain*

On the assessment of the pressure coefficient on the mixed ventilation modeling
Marcos Batistella Lopes, *Associacao Paranaense de Cultura – APC – PUCPR, Brazil*

Construction of operational control rules for an earth-to-air heat exchanger through transfer reinforcement learning (Student Competition)
Yuki Adachi, *the University of Kitakyusyu, Japan*

Ventilation and Thermal Performance Examination of Slot Line Diffuser for Perimeter Usage by CFD Simulation
Shaoyu Sheng, *Osaka University, Japan*

Wednesday October 4th, 2023

ROOM A (1.008)

18:15-19:00	Industry Presentations **Acin Instrumenten, BCCA, Blowerdoor, DooApp, Lindab, Mez-Technik, Renson, Retrotec, Soudal, Velux, WindowMaster**
19:00-21:00	Poster presentations & Student Competition – Industry stands – Cocktail reception with snacks

ROOM A (1.008)

09:00-10:30	Session 5A - Topical Session (The Role of Building Ventilation on Building Decarbonization) *Chairs:* **Núria Casquero-Modrego, Iain Walker** *Decarbonization of buildings leads to a significant reduction of CO2 emissions, which is essential in order to meet climate goals. However, this is a complex undertaking, especially when decarbonization is an emergent topic for the construction sector and households. Building ventilation is connected with many factors related to building decarbonization. Considering building ventilation requirements is essential when improving the energy efficiency of buildings (for example when improving the airtightness of existing buildings). Appliance electrification aspects of building decarbonization may also provide opportunities for better IAQ for the occupants and consequently decreasing the possibility of health issues. Furthermore, designing and proposing better building ventilation strategies can help us to meet climate goals. This session aims to bring people with expertise in building ventilation and IAQ, who are working on assessing building ventilation and IAQ strategies for building decarbonization. The goal is to generate a dialogue that addresses the relationship between building ventilation and climate change and promote awareness of the need to integrate ventilation and building decarbonization research.*
09:00-10:30	**Quantifying the Potential Health Impacts of Unvented Combustion in Homes - A Meta-Analysis** **Nuria Casquero-Modrego,** *LBNL, United States of America* **How to create a performance-based regulation on ventilation – the French Experience** **Valérie Leprince,** *Cerema, France* **Comparative Analysis Between Indoor Temperatures of Dwellings at Urban Scale During a Typical and Extreme Summers in a Temperate Climate** **Ainhoa Arriazu-Ramos,** *University of Navarra, Spain* **Decarbonization and IAQ in Spain: a roadmap** **Marta Sorribes Gil,** *IETCC-CSIC, Spain* **Discussion Time: The Role of Building Ventilation on Building Decarbonization**

ROOM B (1.001)

09:00-10:30

Session 5B - Long Oral/Topical Presentation Session (Indoor Air Quality & ventilation)

Chairs: Simon Jones, James McGrath

Ventilation behaviour of occupants driven by outdoor temperature: 12 case studies
Sonia Garcia-Ortega, *IETCC-CSIC, Spain*

Indoor air quality in Austrian classrooms – Assessing different ventilation strategies with a citizen science approach
Simon Beck, *University of Innsbruck, Austria*

Measurement of ventilation effectiveness and indoor air quality in toilets at mass gathering events
Filipa Adzic, *University College London, United Kingdom*

Impact of the building airtightness and natural driving forces on the operation of an exhaust ventilation system in social housing in Chile
Gilles Flamant, *Pontificia Universidad Catolica de Chile, Chile*

Metal Oxide Semiconductor sensors (MOS) for measuring Volatile Organic Compounds (VOC) - performance evaluation in residential settings
Jakub Kolarik, *Technical University of Denmark, Denmark*

Towards performance-based approaches for smart residential ventilation: a robust methodology for ranking the systems and decision-making
Baptiste Poirier, *Cerema, France*

ROOM C (2.1.042)

09:00-10:30 Session 5C - Topical Session
(Importance of good resilient building design and standards to ensure good ventilative cooling performance to reduce overheating and environmental impact)

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

The purpose of this session is to discuss and showcase how ventilative cooling can be part of the following three key elements, in which the building sector are facing:

Resiliency: Robustness and resilience are key indicators when designing future buildings in terms of ventilative cooling.

Indoor climate: The focus on the indoor climate including limiting overheating is a main point due to rapid changes in the outdoor environment, fx. climate change.

Environmental impact: Sustainability will be, and is already, a key parameter when assessing technologies in the built environment.

All three above mentioned key elements are to some extent bound to standards and legislation. Hence, standards and legislation are essential to push new requirements, while setting the bar for future building design.

09:00-10:30 **Introduction**
Christoffer Plesner, *VELUX A/S, Denmark* & **Jannick Roth,** *WindowMaster International A/S, Denmark*

Update on Resilient cooling and indicators from the IEA EBC Annex 80
Peter Holzer, *Institute of Building Research & Innovation, Austria*

Resilient Ventilative cooling in Design Practice: Where next?
Paul O'Sullivan, *Munster University, Ireland*

Life cycle assessment: A design element for ventilation system selection
Jannick Roth, *WindowMaster International A/S, Denmark*

Lessons Learned from Irish Schools: Early-stage Insights on Overheating
Paul O'Sullivan, *Munster University, Ireland*

Resilient cooling in office buildings: case study in Belgium
Hilde Breesch, *KU Leuven, Belgium*

Design procedures for ventilative cooling integrated in new standards
Christoffer Plesner, *VELUX A/S, Denmark & Jannick Roth, WindowMaster International A/S, Denmark*

Questions and open Discussion

10:30-11:00 Coffee Break

ROOM A (1.008)

11:00-12:30	Session 6A - Topical Session (The role of carbon dioxide and particulate matter for assessing ventilation and respiratory disease transmission in buildings) *Chairs:* **Justin Berquist, Svein Ruud** *The objective of this topical session is to discuss some of the potential applications and limitations of CO2 and PM concentration measurements for assessing ventilation and filtration performance, IAQ, and respiratory disease transmission in buildings. Researchers with a breadth of expertise and publications in this area will present their research. The session programme outlined below includes the individuals selected to present, the expected presentation titles, and the corresponding presentation objective.*
11:00-12:30	**Sensitivity Analysis of CO2 Concentrations as Ventilation Metrics** **Oluwatobi Oke,** *National Institute of Standards and Technology, (NIST), United States of America* **Evaluation of Uncertainties of Using CO2 for Studying Ventilation Performance and Indoor Airborne Contaminant Transmissions** **Liangzhu (Leon) Wang,** *Concordia University, Canada* **Effects of ventilation on airborne transmission: particle measurements and performance evaluation** **Huijuan Chen,** *Research Institute of Sweden (RISE), Sweden* **Impact and benefits of the air cleaning measures implemented in two schools** **Liang (Grace) Zhou,** *National Research Council Canada (NRC), Canada*

ROOM B (1.001)

11:00-12:30	Session 6B - Long Oral Presentation Session (Indoor Environmental Quality) *Chairs:* **Alireza Afshari, Sonia Garcia** **Critical reflections on indoor-environmental quality constructs** **Ardeshir Mahdavi,** *TU Graz, Austria* **Ventilation and sleep quality** **Pawel Wargocki,** *Technical University of Denmark, Denmark* **Applicability and sensitivity of the TAIL rating scheme using data from the French national school survey** **Pawel Wargocki,** *Technical University of Denmark, Denmark* **An investigation of MVHR system performance based on health and comfort criteria in bedrooms of low-carbon social housing in South-Wales, UK** **Faisal Farooq,** *Cardiff University, United Kingdom* **Impact of optimized residential ventilation with energy recovery on health and well-being** **Martin Kremer,** *RWTH Aachen University, Germany* **A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices** **Magdalena Hajdukiewicz,** *Eindhoven University of Technology (TU/e), The Netherlands*

Thursday October 5th, 2023

ROOM C (2.1.042)

11:00-12:30	**Session 6C - Long Oral Presentation Session (Ventilative cooling & Natural Ventilation)** *Chairs:* **Dong Hwa Kang, Jensen Zhang** **A methodology for evaluating the ventilative cooling potential in early-stage building design** **Valentina Radice Fossati,** *Eurac Research, Italy* **Ventilation reliability: A pilot study on window opening behaviour in a primary school** (Student Competition) **Lara Tookey,** *Massey University, New Zealand* **A survey of building design practitioner perceptions of ventilative cooling in their building design processes** **Maha Sohail,** *Munster Technological University, Ireland* **Can naturally ventilated office buildings cope with dusty outdoor air?** **Evangelos Belias,** *EPFL, Switzerland* **Distribution of Particulate Matter Concentration and Temperature Stratification Examined by Zonal Model and Experimental Measurements in Room with A Novel Portable Displacement Ventilation Cooling Unit** **Toshio Yamanaka,** *Osaka University, Japan* **Thermal comfort and risk of draught with natural ventilation – assessment methods, experiences and solutions** **Jannick Roth,** *Windowmaster International A/S, Denmark*
12:30-13:30	Lunch Break

ROOM A (1.008)

13:30-14:30	**Session 7A - Long Oral Presentation Session (Air Cleaning)** *Chairs:* **Wouter Borsboom, Arnold Janssens** **Evaluation of sensor-based air cleaners to remove PM2.5 and TVOC from indoors with pollutant sources of smoking and burning candles** (Student Competition) **Li Rong,** *Aarhus University, Denmark* **Developing methodology for testing of gas-phase air cleaners based on perceived air quality** **Pawel Wargocki,** *Technical University of Denmark, Denmark* **Evaluating the impact of air cleaning on bioaerosols and other IAQ indicators in Belgian daycare facilities** **Sarah Paralovo,** *VITO, Belgium* **Removal of Odorants in Nursing Homes Using Air Cleaners** **Stig Koust,** *Danish Technological Institute, Denmark*

ROOM B (1.001)

13:30-14:30	Session 7B - Long Oral Presentation Session (Ventilation & infection risk) *Chairs:* **Gaëlle Guyot, Jelle Laverge** **What can CO2 measurements tell us about ventilation and infection risk in classrooms?** **Carolanne Vouriot,** *University of Cambridge, United Kingdom* **Indoor air modelling and infection risk assessment in a naturally ventilated patient room** **Natalia Lastovets,** *Tampere University, Finland* **Performance of Local Ventilation System Combined with Underfloor Air Distribution as Preventative Measures for Infectious Diseases in Consulting Room** (Student Competition) **Jun Yoshihara,** *Osaka University, Japan* **The numerical investigation of human micro-climate with different human simulators** **Haruna Yamasawa,** *Osaka University, Japan*

ROOM C (2.1.042)

13:30-14:30	Session 7C - Topical Session (Personalized Environmental Control Systems (PECS) operation and evaluation) *Chairs:* **Dragos-Ioan Bogatu, Bjarne W. Olesen** *The session will introduce IEA-EBC Annex 87 and discuss aspects related to PECS operation and evaluation. Current indoor environmental quality (IEQ) and energy performance evaluation methods alongside used key performance indicators (KPIs) will be described. Examples of both traditional and advanced control strategies will be presented. A secondary objective of the session is to gather input from the conference audience on the aforementioned topics.*
13:30-14:30	**Introduction to IEA EBC Annex 87** **Bjarne W. Olesen,** *Technical University of Denmark, Denmark* **Indoor environmental quality (IEQ) and energy performance evaluation of PECS** **Douaa Al-Assaad,** *KU Leuven, Belgium* **Physiological sensing for thermal comfort assessment** **Dragos-Ioan Bogatu,** *Technical University of Denmark, Denmark*
14:30-14:45	Room Change

ROOM A (1.008)

14:45-16:15	Session 8A - Topical Session (Post Pandemic Pontifications) Chairs: **Benjamin Jones, Max Sherman** *The COVID-19 pandemic highlighted the importance of indoor air quality and appropriate ventilation in buildings to prevent airborne disease transmission. As we move into the endemic phase, it remains crucial that we continue to prioritize effective ventilation and air cleaning to keep occupants as healthy as possible. This topical session will cover the latest research on airborne transmission mechanisms, including implications for ventilation system design, sizing, and operation. Presenters will share case studies of transmission mitigation and lessons learned from the pandemic response. There will be an emphasis on strategies for improving air quality in public buildings within the constraints of operating budgets. Attendees will gain practical knowledge to assess systems to make impactful upgrades, and communicate the ongoing importance of ventilation and air quality to stakeholders in a post-pandemic context. The goal is to ensure the health, safety, productivity, and wellbeing of building occupants now and in the future.*
14:45-16:15	**ASHRAE 241-2023 Control of Infectious Aerosols** (Long Oral Presentation) **Max Sherman,** *University of Nottingham, United Kingdom* **Can the Wells-Riley model universally assess airborne pathogen infection risk?** (Long Oral Presentation) **Benjamin Jones,** *University of Nottingham, United Kingdom* **Flow dynamic of human cough and measuring techniques: A review** (Long Oral Presentation) **Chen Zhang,** *Aalborg University, Denmark* **Evaluating the impact of air cleaning and ventilation of airborne pathogens and human bio-effluents at two primary schools in Belgium** (Long Oral Presentation) **Klaas De Jonge,** *Ghent University, Belgium* **Review of international standards describing air cleaner test methods** (Long Oral Presentation) **Hannelore Scheipers,** *Ghent University, Belgium* **Rethinking different ventilation strategies in a post-pandemic era: a CFD assessment** (Short Oral Presentation) **Alicia Murga Aquino,** *Kobe University, Japan* **How the COVID Pandemic and the Energy Crisis Have Influenced Indoor Environmental Conditions in non-residential Buildings** (Short Oral Presentation) **Aurora Monge,** *University of Navarra, Spain*

ROOM B (1.001)

14:45-16:15	Session 8B - Long Oral Presentation Session (Impact factors on IAQ) *Chairs:* **Marie Coggins, Andy Persily** **The impact of increased occupancy on particulate matter concentrations in mechanically-ventilated residential buildings in a subtropical climate** **German Hernandez Herrera,** *Universidad Politécnica de Madrid (UPM), Spain* **On-Site Capture Efficiency of Kitchen Range Hood Based on Particle Diameters and Exhaust Flow Rates** **Shinhye Lee,** *Seoul National University, Republic of Korea* **An investigation of cooking-related pollutants in the residential sector** **Daniela Mortari,** *University Savoie Mont Blanc, France* **Fine dust measurement in ducts of balanced ventilation systems** **Bart Cremers,** *Zehnder Group Zwolle, The Netherlands* **The Impact of Deep Energy Renovations on Indoor Air Quality and Ventilation in Irish Dwellings** **Hala Hassan,** *University of Galway, Ireland* **Financial impact of leaky ductwork in buildings – a calculation tool to raise awareness** **Nolwenn Hurel,** *PLEIAQ, France*
16:15-16:45	Coffee Break

ROOM D (1.042)

16:45-18:15	Closing session *Chairs:* **Arnold Janssens, Alireza Afshari** **Decoding 30 Years of Insights: Conclusions from ISIAQ's Landmark Webinar Series on Indoor Air Quality and Climate** **Ying Xu,** *Tsinghua University, China* **Summing up of the "Smart ventilation, IAQ & Health" track** **Benjamin Jones,** *University of Nottingham, United Kingdom* **Summing up of the "Building and ductwork airtightness" track** **Valerie Leprince,** *Cerema, France* **Summing up of the "Ventilative and resilient cooling" track** **Hilde Breesch,** *KU Leuven, Belgium* **Best paper/poster award & Student Competition awards** **Announcement of 2024 conference** **Closing**
20:00	Gala Dinner *(ticket required)*

43rd AIVC 11th TightVent & 9th venticool Conference

Welcome on behalf of AIVC, TightVent and venticool

Arnold Janssens

Peter Wouters

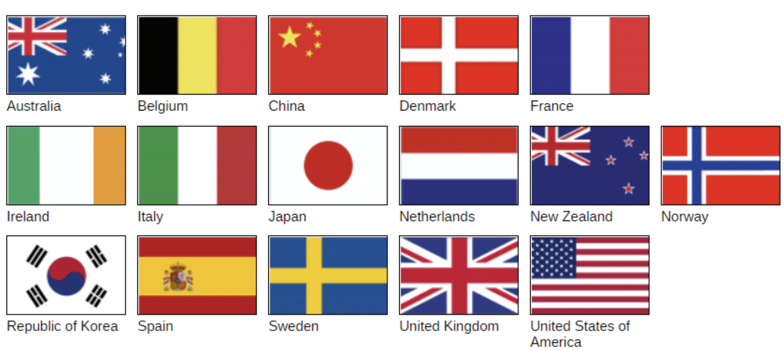
Operating Agents AIVC - INIVE

AIVC TightVent Europe venticool

Welcome on behalf of AIVC (1979 - …)

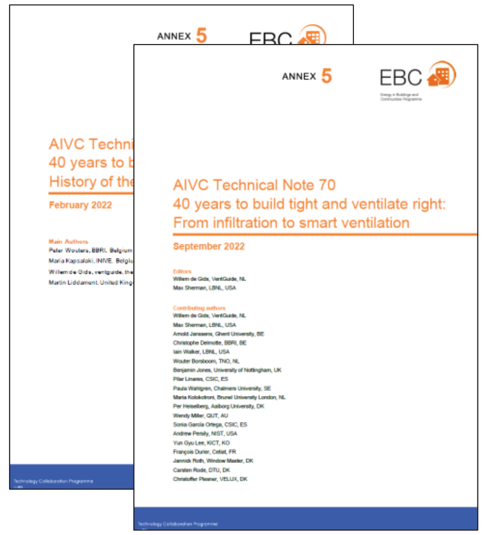
EBC Energy in Buildings and Communities Programme

AIVC



AIVC and Denmark

- 1 of 8 founding countries of AIVC
- (Almost) uninterrupted membership since creation of AIVC
- AIVC-conferences in Denmark:
  - 1993, Copenhagen, ‘Energy Impact of Ventilation and Air Infiltration’
  - 2012, Copenhagen, ‘Optimising Ventilative Cooling and Airtightness for [Nearly] Zero-Energy Buildings, IAQ and Comfort’
  - 2023, Copenhagen, ‘Ventilation, IEQ and health in sustainable buildings’



About · Events · Resources · Focus Fields & Projects · Contact & Join

EBC

Search...

Login / Register

HOME › EVENTS

Events

The AIVC holds a conference each year in September/October, a workshop in March/April and several webinars, covering a wide range of topics in the field of infiltration and ventilation in buildings. The conferences and workshops take place in one of the AIVC participating countries. Since 1980, the AIVC annual conferences have been an international meeting point for presenting and discussing major developments and results regarding infiltration and ventilation in buildings.

Click on the links below to know more.

Conferences

Workshops

Webinars

- **Annual conferences** in collaboration with TightVent and venticool platforms
- **Annual workshops** in collaboration with local hosts on themes of local interest
- **Webinars** presenting results of projects or publications.

43rd AIVC 11th TightVent & 9th venticool Conference

Welcome on behalf of TightVent (2011 - …) and Venticool (2013-…)

TightVent Europe
BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

venticool
the platform for resilient ventilative cooling

More focusing on knowledge generation aspects

AIVC

More focusing on awareness raising and market implementation

TightVent Europe
BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM

…Building and ductwork airtightness…

…Ventilative cooling…

venticool
the platform for resilient ventilative cooling

FAQs

Select a Category | nothing selected | Search

What is building airtightness?

What are the methods to detect leaks of the building envelope?

What are existing methods to estimate building airtightness? Are there other test methods apart from fan pressurization?

What is ductwork airtightness?

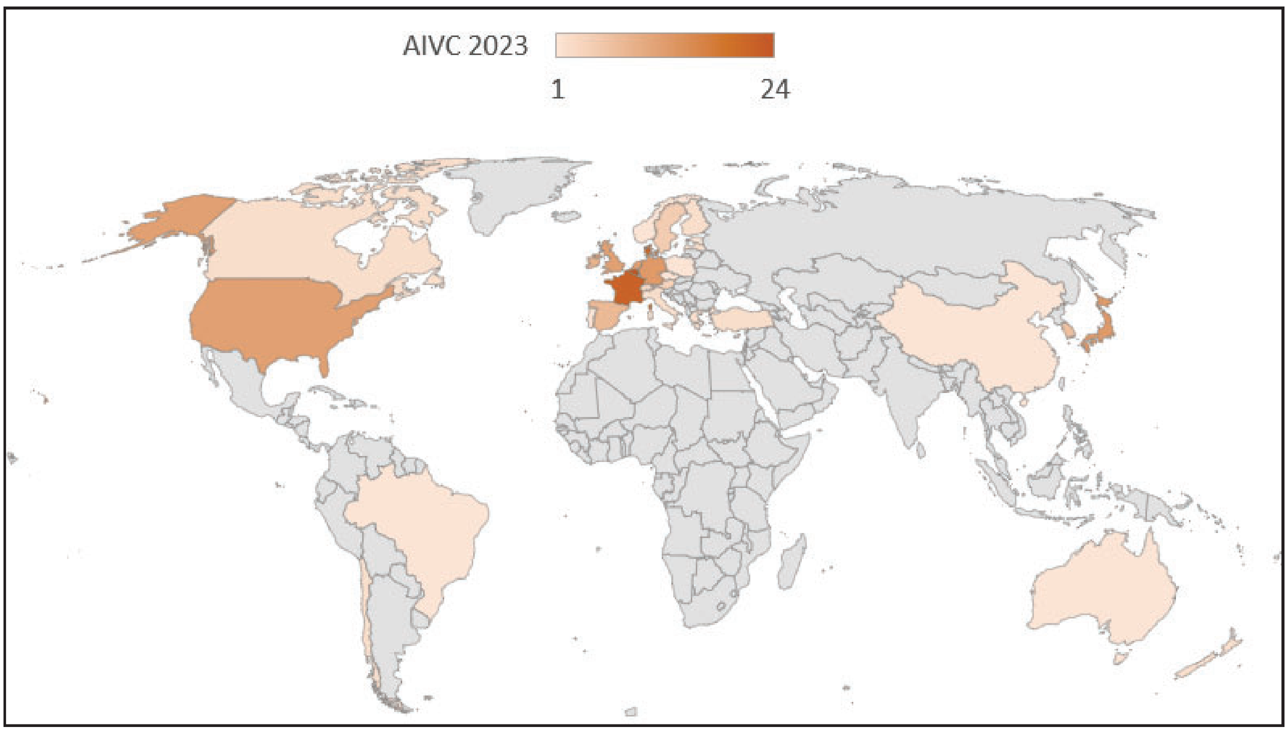
What is infiltration/exfiltration?

How is the building airtightness quantified?

How is the ductwork airtightness quantified?

What are the most common air leakage/infiltration paths?

7



8

Programme October 4

	Room A	Room B	Room C
09:00-10:30	Opening - Plenary session		
10:30-11:00	Coffee break		
11:00-12:30	Topical Session (Airborne cross infection and engineering solutions)	Long Oral Presentation Session (Building airtightness testing & prediction)	Topical Session (Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback)
12:30-13:30	Lunch break		
13:30-14:45	Topical Session (Energy Performance of Gas Phase Air Cleaning)	Topical Session (Revision of ISO 9972: Improvements in the reliability of airtightness measurements)	Long & Short Oral Presentation Session (Climate change & Resilient cooling)
14:45-15:00	Room change		
15:00-16:30	Topical Session (Real performance of (smart) residential ventilation - performance assurance, fault detection, continuous commissioning)	Topical Session (Building and ductwork airtightness regulations in various countries)	Topical Session (Resilient Cooling of Buildings meets Resilient Cooling in Cities)
16:30-17:00	Coffee break		
17:00-18:15	Short Oral Presentation Session (Indoor Air quality & Health)	Short Oral Presentation Session (Ventilation strategies & thermal comfort)	
18:15-19:00	Industry presentations (Acin Instrumenten, BCCA, Blowerdoor, DooApp, Lindab, Mez-Technik, Renson, Retrotec, Soudal, Velux, WindowMaster)		
19:00-21:00	Poster presentations & Student Competition – Industry stands – Cocktail reception with snacks		

Programme October 5

	Room A	Room B	Room C
09:00-10:30	Topical Session (The Role of Building Ventilation on Building Decarbonization)	Long Oral Presentation Session (Indoor Air Quality & ventilation)	Topical Session (Importance of good resilient building design and standards to ensure good ventilative cooling performance to reduce overheating and environmental impact)
10:30-11:00	Coffee break		
11:00-12:30	Topical Session (The role of carbon dioxide and particulate matter for assessing ventilation and respiratory disease transmission in buildings)	Long Oral Presentation Session (Indoor Environmental Quality)	Long Oral Presentation Session (Ventilative cooling & Natural Ventilation)
12:30-13:30	Lunch break		
13:30-14:30	Long Oral Presentation Session (Air Cleaning)	Long Oral Presentation Session (Ventilation & infection risk)	Topical Session (Personalized Environmental Control Systems (PECS) operation and evaluation)
14:30-14:45	Room change		
14:45-16:15	Topical Session (Post Pandemic Pontifications)	Long Oral Presentation Session (Impact factors on IAQ)	
16:15-16:45	Coffee break		
16:45-18:15	Closing Session		
20:00	Gala Dinner**		

Awards in closing session

- Best paper award
- Best poster award
- Student's competition award
  - Paper and poster based upon a bachelor or master's thesis
  - Presentations indicated in programme

Thank you!

- Organizing committee
- Scientific committee
- Session chairs
- Sponsors and exhibitors

- You: the authors and presenters!

Sponsors / Exhibitors

TightVent Partners

Lindab, retrotec, ACIN, BCCA, BlowerDoor GmbH, dooApp, SOUDAL, eurima, gonal, SIGA, BPIE

Venticool Partners

DUCO, RENSON, NAVENTA, Reynaers Aluminium, VELUX, WindowMaster, EuroWindoor, CIBSE Natural Ventilation, REHVA

Other Sponsors

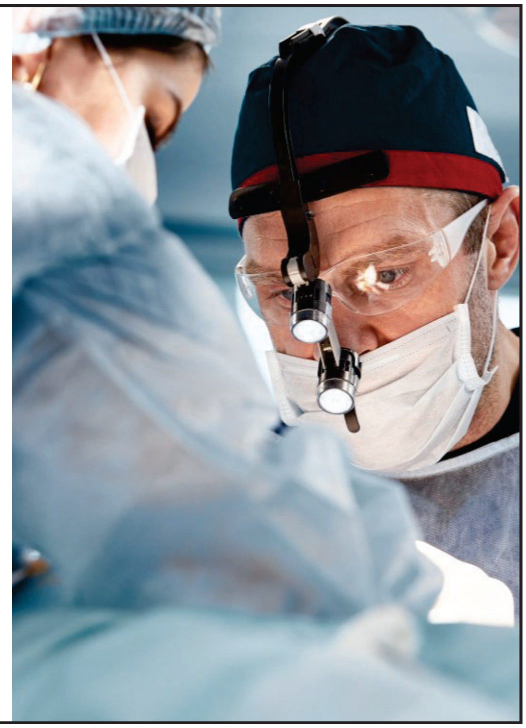
TSI, aranet, BUILD TEST SOLUTIONS

Tomorrow's Ventilation Solutions for Future Hospital Demands

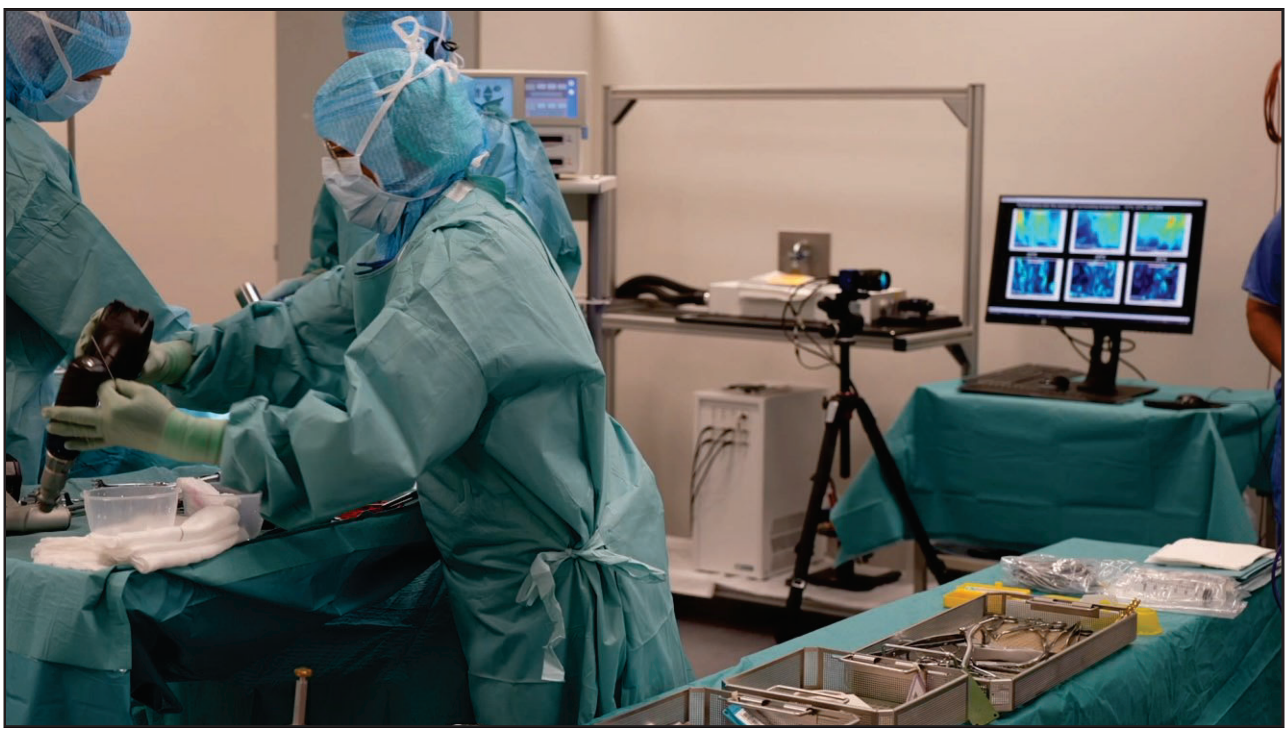
Reduction of Postoperative Surgical Infection through Fusion of CFD and XR

Presenter / Project manager:
Trond Thorgeir Harsem
Trond.thorgeir.harsem@norconsult.com

Norconsult



1



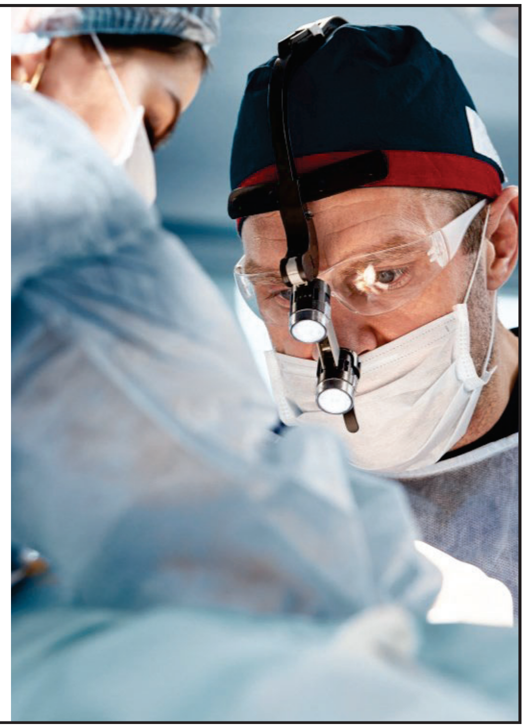
2

Tomorrow's Ventilation Solutions for Future Hospital Demands

Reduction of Postoperative Surgical Infection through Fusion of CFD and XR

Presenter / Project manager:
Trond Thorgeir Harsem
Trond.thorgeir.harsem@norconsult.com

Norconsult



3

Reduction of Postoperative Surgical Infection through Fusion of CFD and XR

Project partners:

NTNU - Norwegian University of Science and Technology

KTH - Royal Institute of Technology, Stockholm

CTH – Chalmers University of Technology

DTU – Technical University of Denmark

AAU – Aalborg University

Norconsult Digital, Sandvika, Norway

St. Olavs University hospital, Trondheim, Norway

The Project is financed by the Research Council of Norway

Norconsult

4

Motivation

- Postoperative Surgical site Infections (POSI) are a major problem in Norway and the rest of the world
- The human body emits 10,000 particles per minute, 10% of which contain bacteria
- World Health Organization (WHO): 50% of Bacteria that contribute to POSI will be antibiotic resistant in the near future
- In Europe 800 000 is affected every year for POSI (Health First Europe Launched in 2020)
- Approximately 1 500 patients die every year due to postoperative infections in Sweden (Sosialstyrelsen i Sverige)
- Compared to 324 death in car accident in 2018 in Sweden (Parastoo Sadeghian – PhD Defence 2022)

Norconsult

5

Research Project Goal

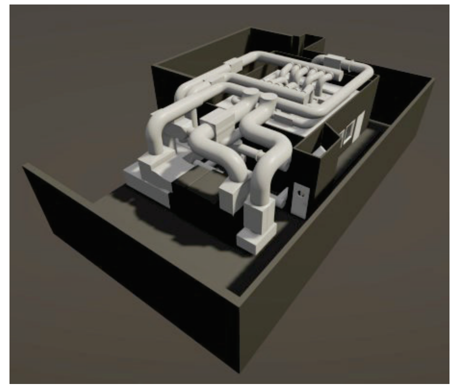
Increase the understanding of the airborne particle movement by developing an Extended Reality solution to reduce Postoperative Surgical site Infections (POSI).

Norconsult

6

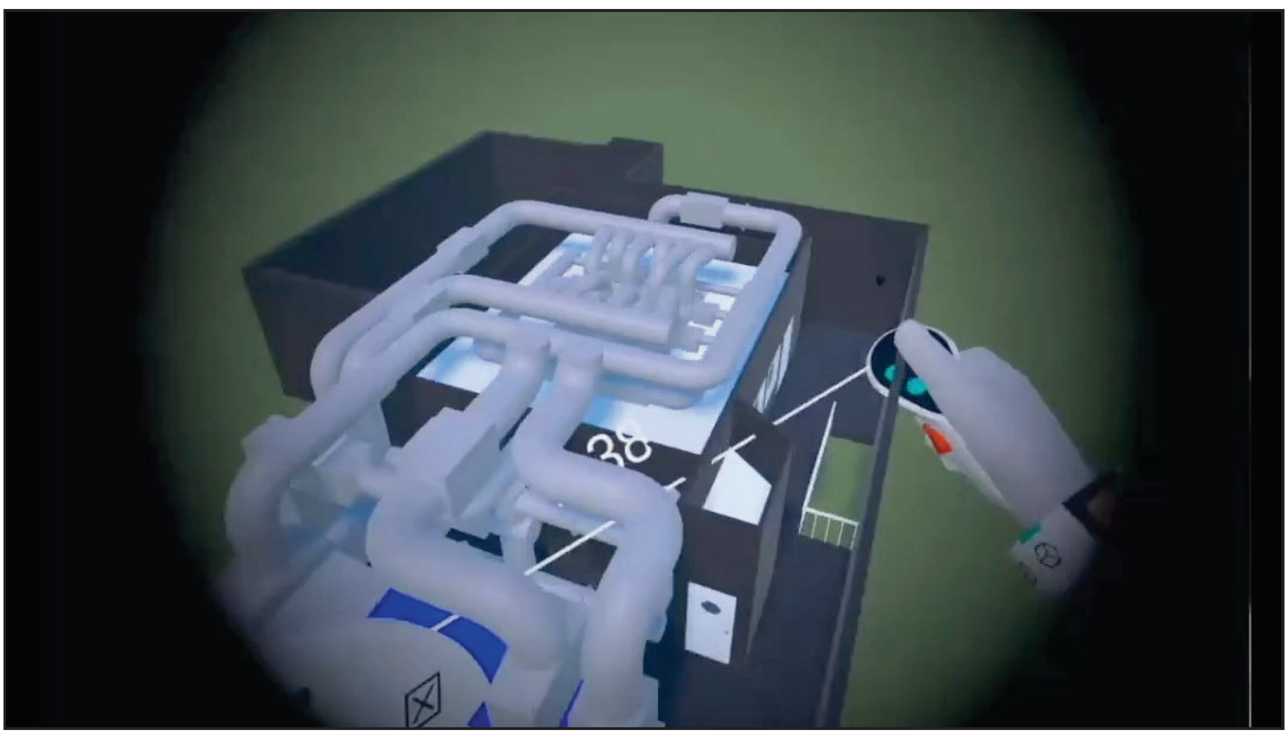
Methodology

- Build up an Operating Room Laboratory with different ventilation solution
- Computational Fluid Dynamics simulations will be validated against laboratory measurements
- Result visualization using custom developed Extended Reality Technology
- Visualization of sensor data and movement



Norconsult

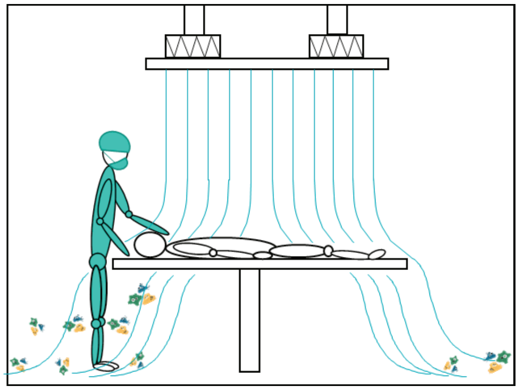
7



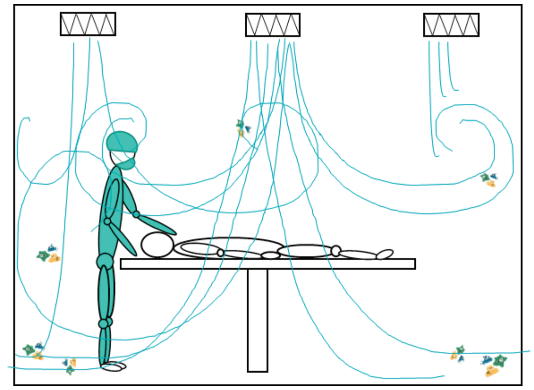
8

Normal Different Ventilation Solution in Operating Room

Laminar air flow (LAF)



Mixing ventilation (MV)



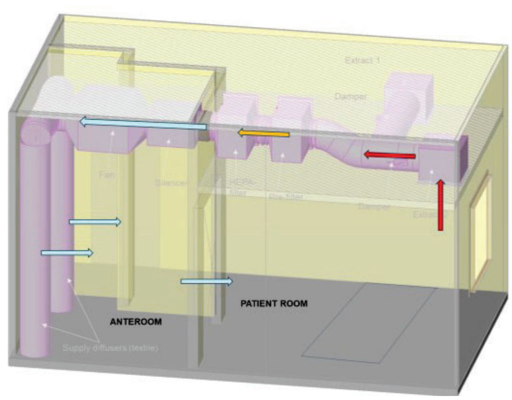
Norconsult

How to Make a Ultra Clean Operating Room

Where do the bacteria come from?

- Patient
- Health care workers
- Instruments
- Particles from the outside of the operating room

- To eliminate one of this factors we include results from an earlier research project – 2017-2019
  - "Upgraded patient room"
    - Results:
    - 99% reduced particle from patient room out to Corridor



Norconsult

IFHE 2018 BRISBANE, AUSTRALIA — IHEA — 6-11 OCTOBER 2018 BRISBANE CONVENTION & EXHIBITION CENTRE

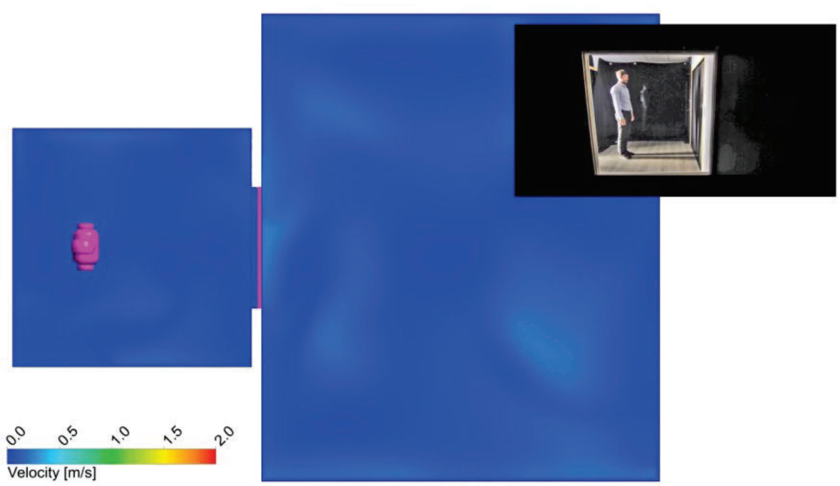
What The World Health Organiztion (WHO) says about Pandemic Influenza:

- We do not know what it will look like
- We do not know where it will come from
- We do not know who or how hard it will hit
- But it will come
- It is a question of “when” - not about “if”
- Sooner or later, the world will again be affected by a pandemic influenza

Norconsult

11

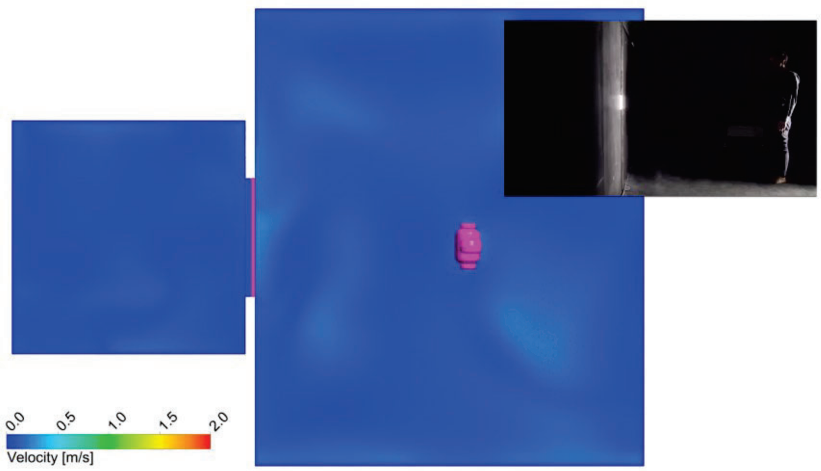
CFD and smoke visualization – entering patient room



Norconsult

12

CFD and smoke visualisation – exit patient room



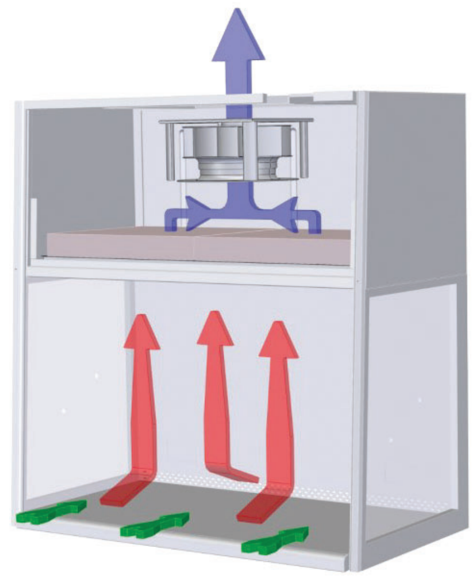
Summary of the results from the baseline cases CFD simulations and laboratory experiments

Description	Baseline cases			
	Door only (1)	Exit (2)	Entry (3. fast)	Entry (3.slow)
CFD model	755 litres	780 litres	1100 litres	680 litres
Laboratory experiments	765 litres	730 litres	800 litres	

Norconsult

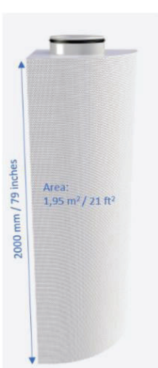
Inspiration: Fume Hoods

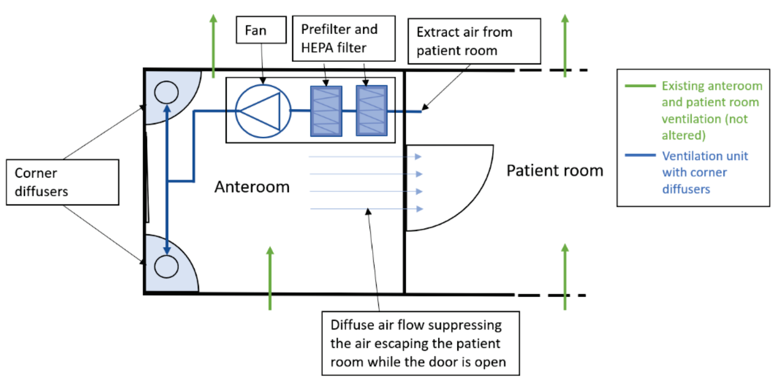
- Ventilation device that limits the exposure to hazardous or toxic fumes that are exhausted by material inside the device
- 0,4-0,6 m/s over the opening area



Norconsult

Installing a ventilation unit into the anteroom

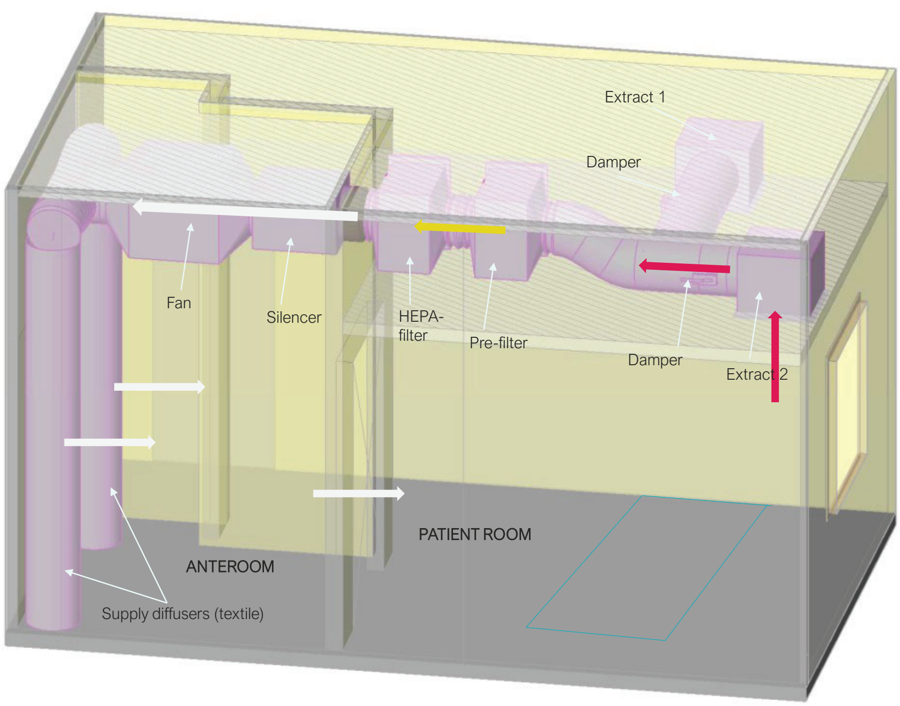




Ventilation solution through a hinged door

17

Upgraded patient room



18

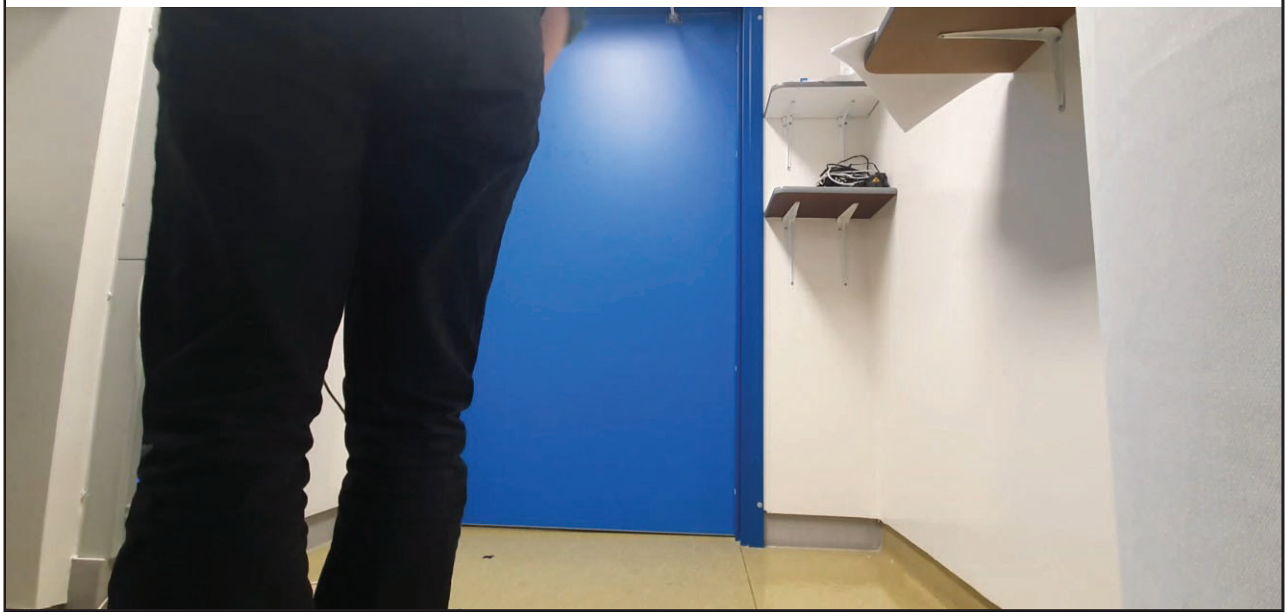
Smoke visualization without recirculated air

19

Patient room WITH air Barrier

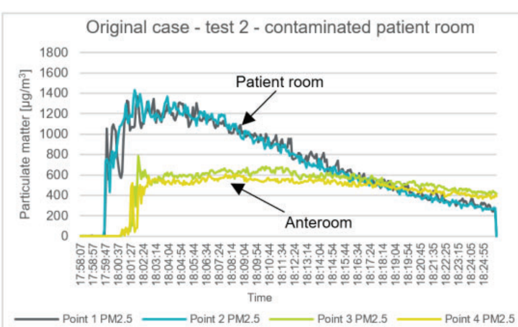
20

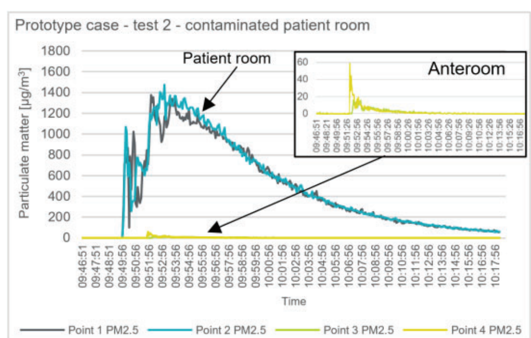
Smoke visualization with recirculated air



Results

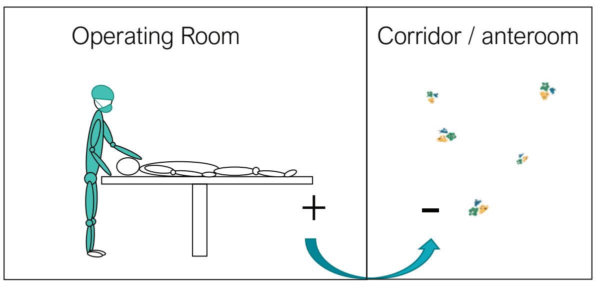
- Approximately 99% reduction of particle transfer to the anteroom with the presented ventilation solution compared to the base case





Pressure differensial Operating Room – Corridor /Anteroom

- The Operating Room is kept at positive pressure related to their adjacent spaces to ensure that no contaminated air can enter the room by ensuring the correct air flow direction
- When opening the door between to room => No pressure difference



Reasons for Traffic Flow in an Operating Room

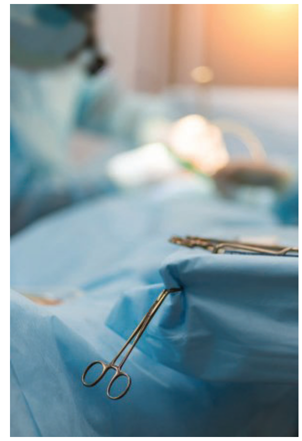
Typical reasons for traffic flow in an Operating Room

- Expert consultation
- Need for more instruments
- Lunch or coffee breaks
- Team member leaving or entering after incision or before closure
- Student visits

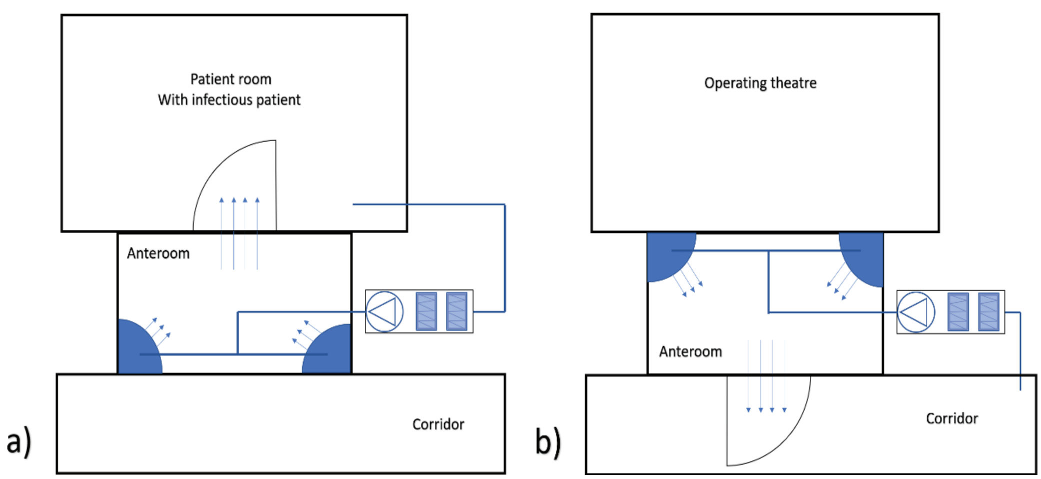
The number of door openings can rise up to *37 openings per hour* [7]

Research Question

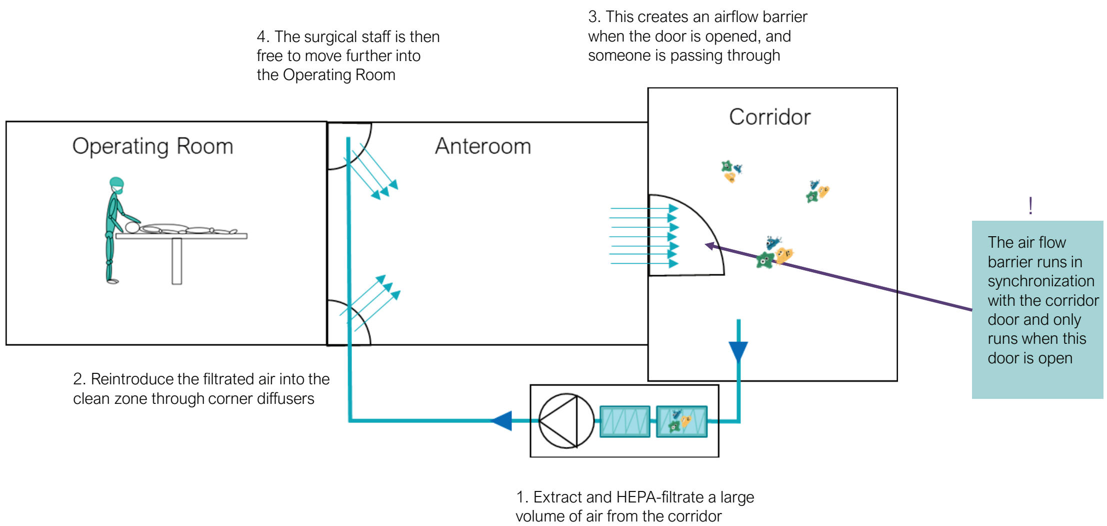
- Is it possible to *reduce the particle migration to the Operating Room* caused by door opening and passage?



Ida: Installation of recirculation unit in the ante room into the operation room



Solution Transferred from Earlier Research Project

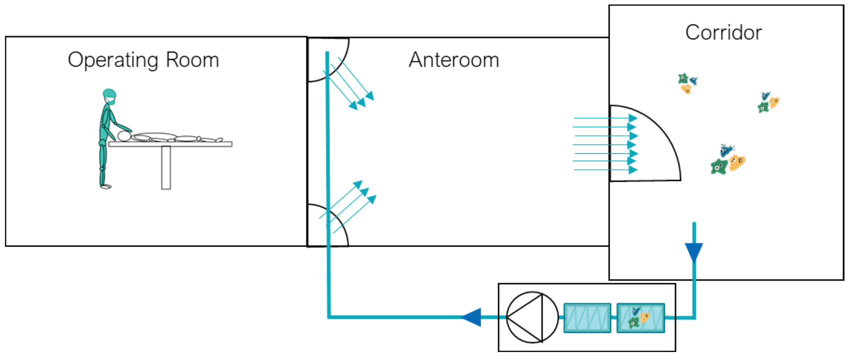


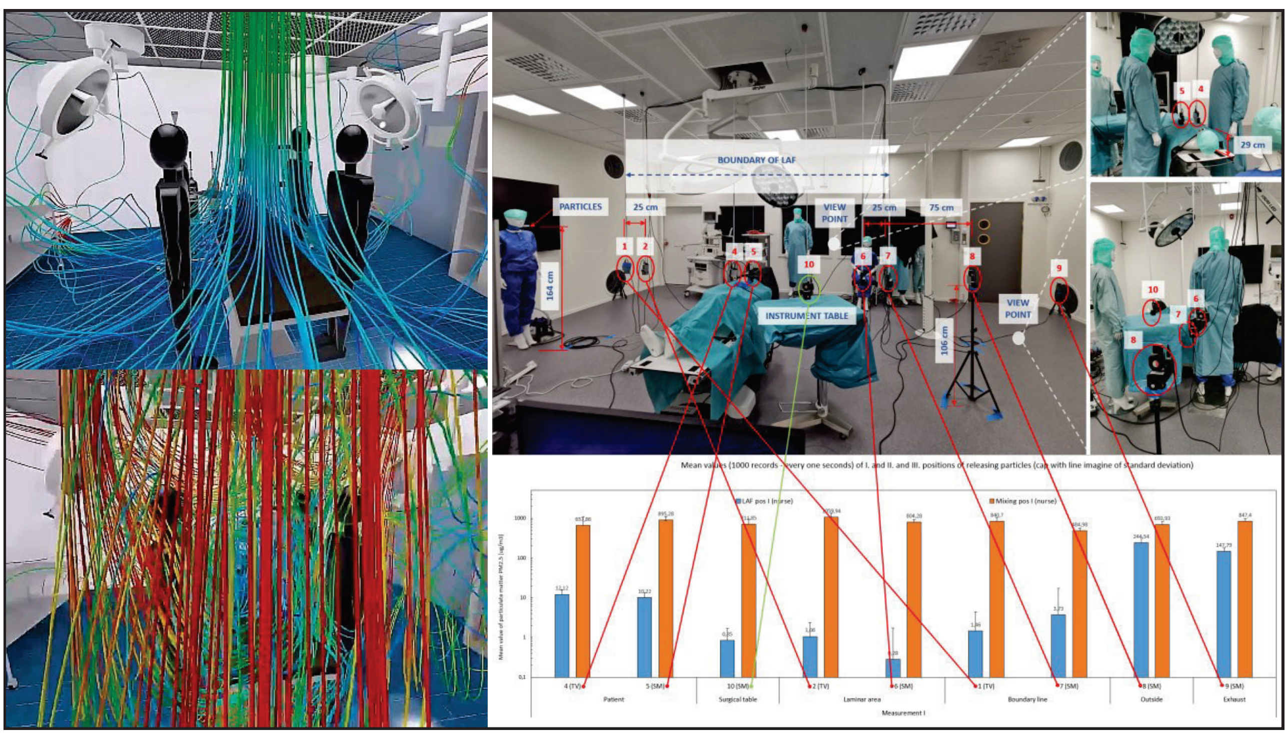
27

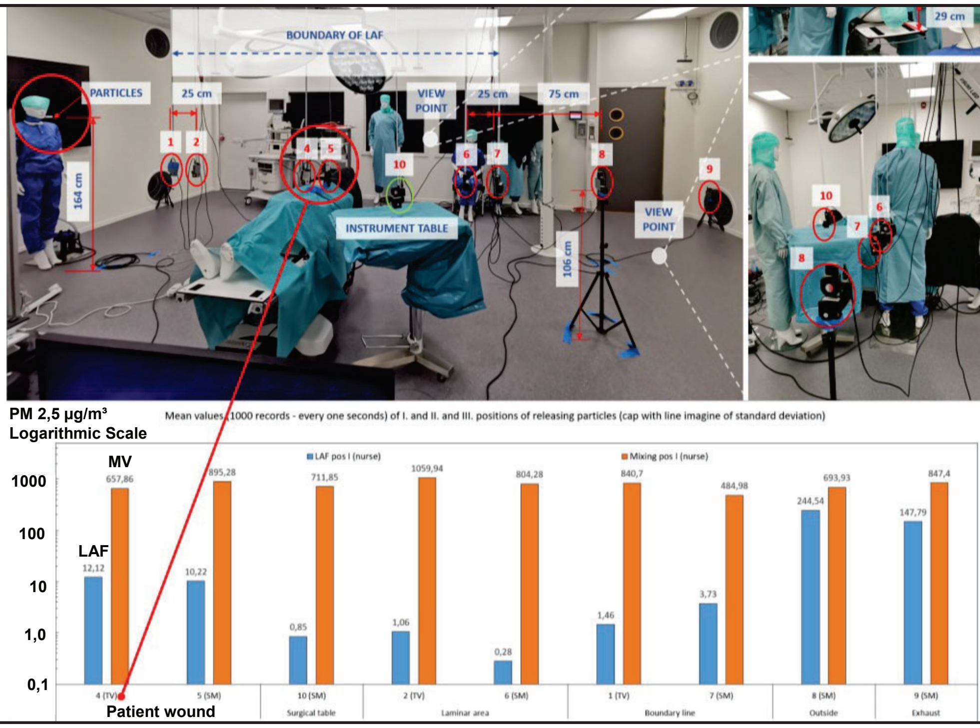
28

Where do the bacteria come from?
One of four sources are eliminated!

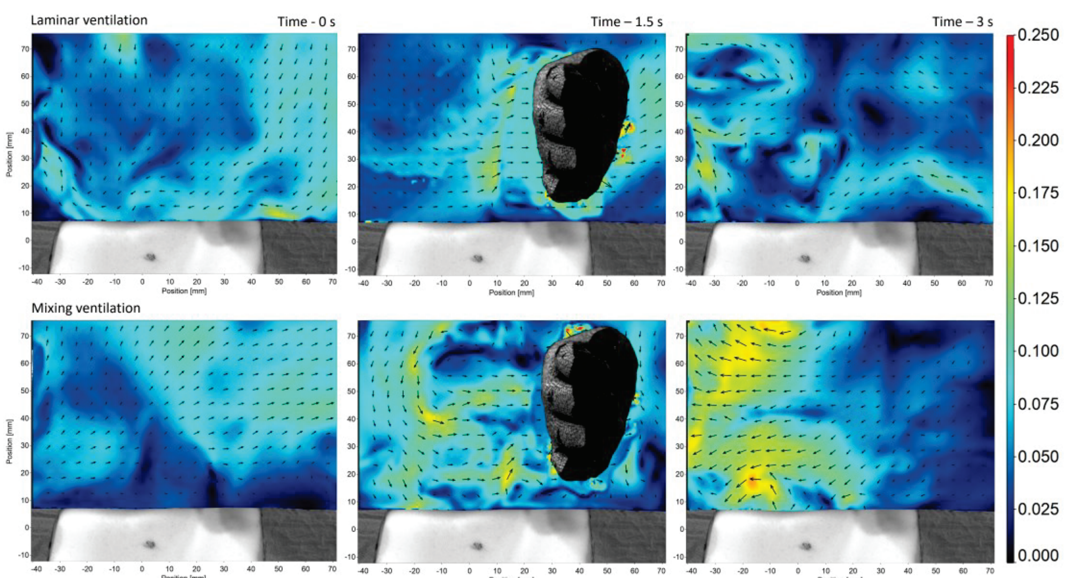
- Patient
- Health care workers
- Instruments
- Outside of the operating room







PIV – Particle movment close to the wound



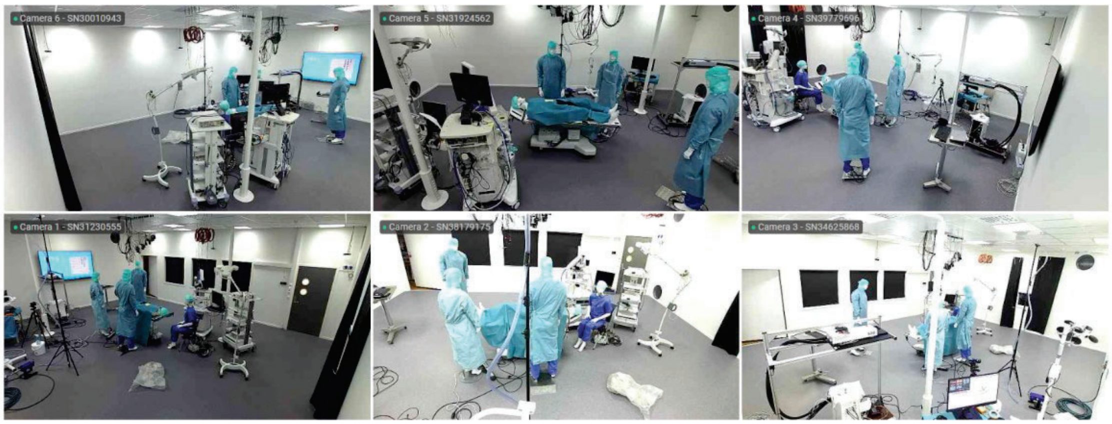
Norconsult

Motion Capture 6 Stereo CAM

SKS Video Wall

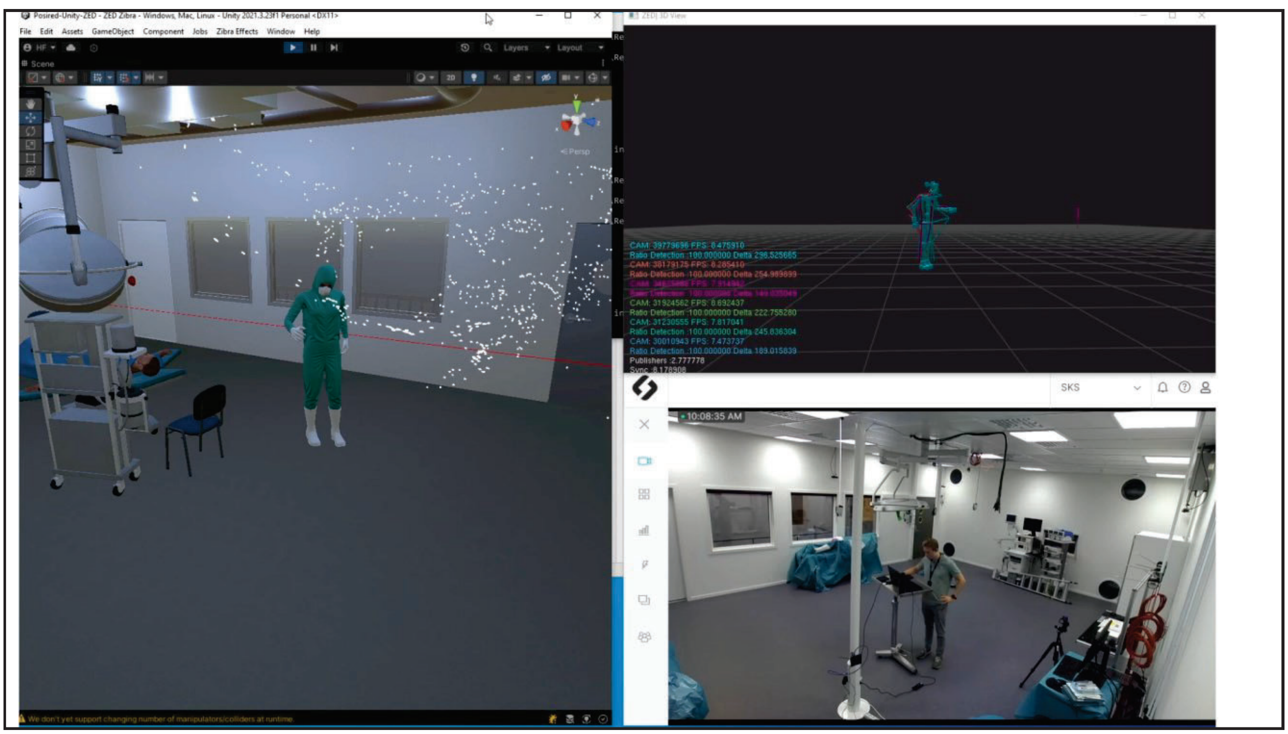
Full Screen

All devices

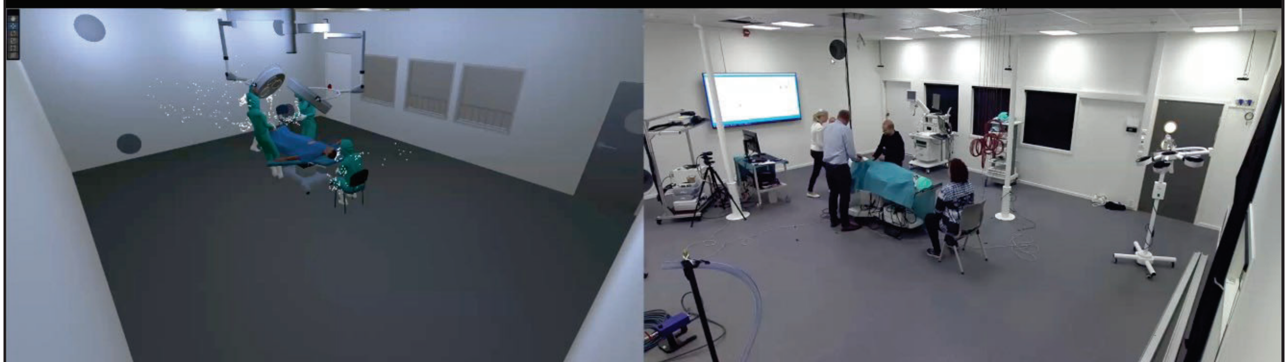


Norconsult

33



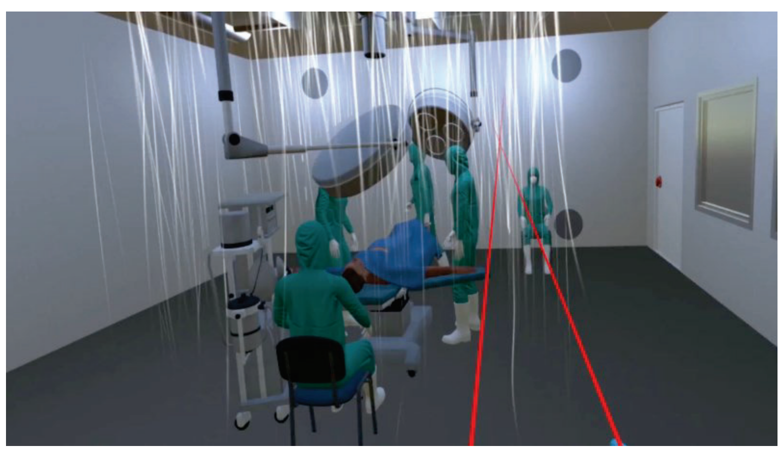
34



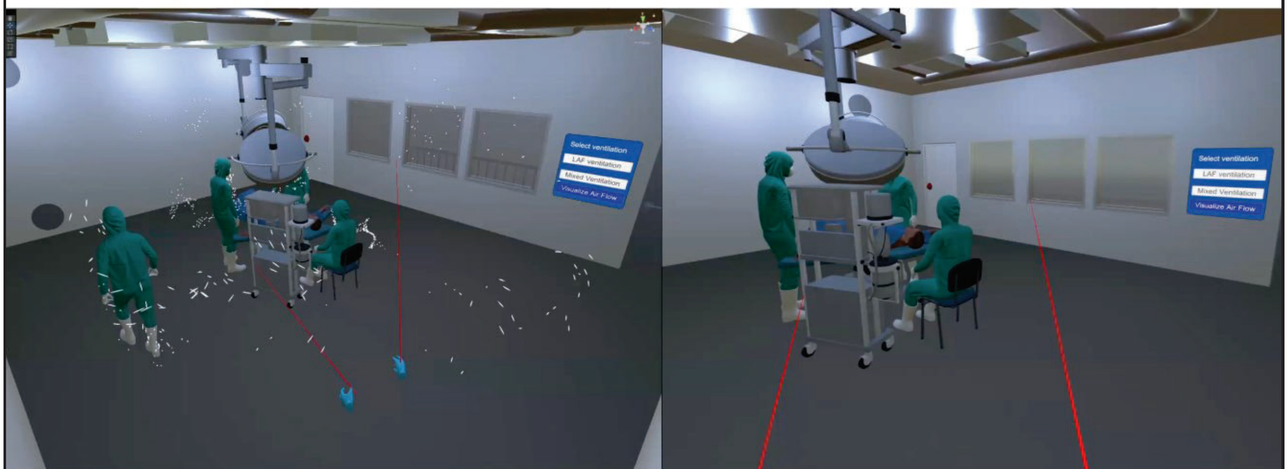
Norconsult

XR Solution

- Clean Air is an essential factor
- Understanding how operating personel's movement and ventilation solution affect particle dispersion
- Visible virtual air and particle flow



Norconsult

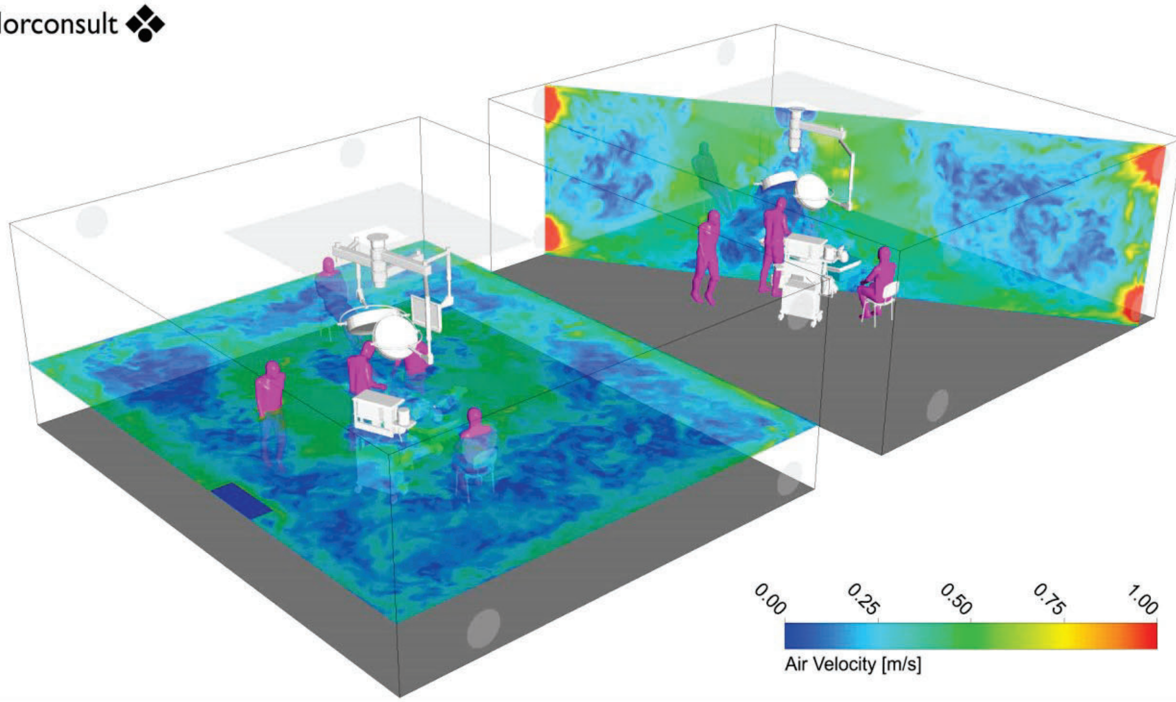


IAQVEC 2023 Sample Presentation

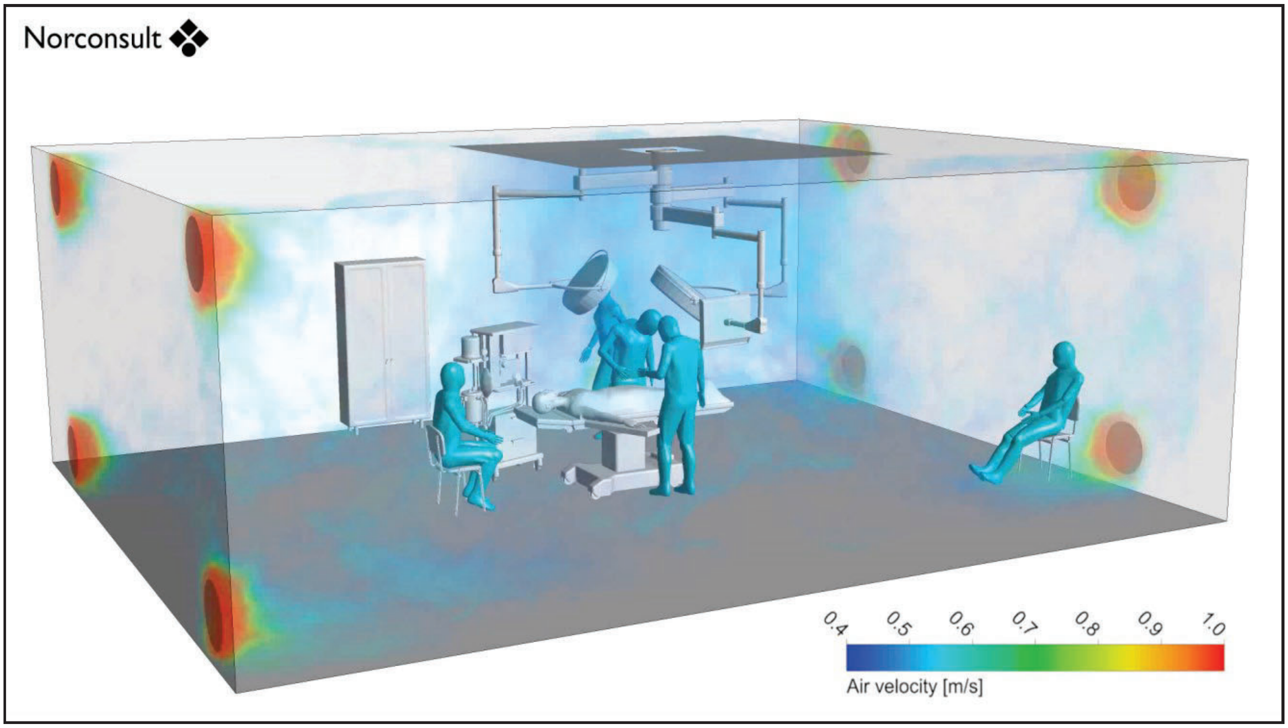
Norconsult

37

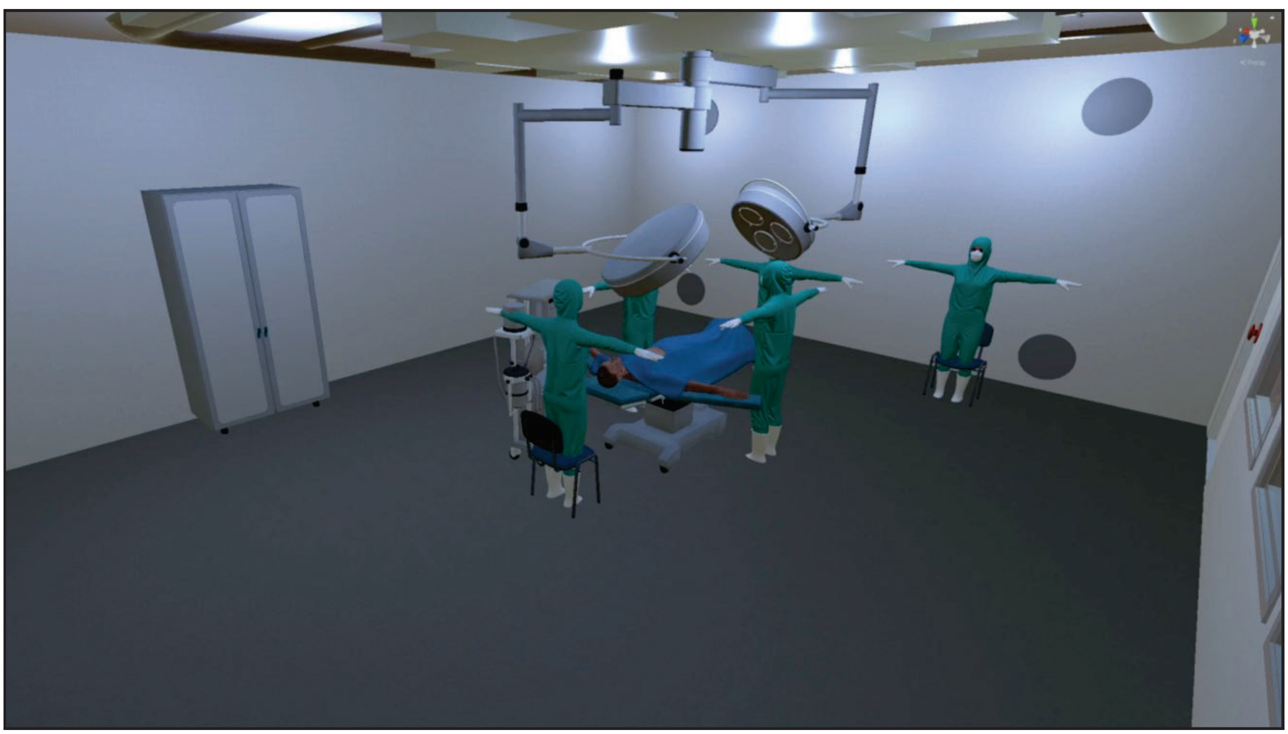
Norconsult



38

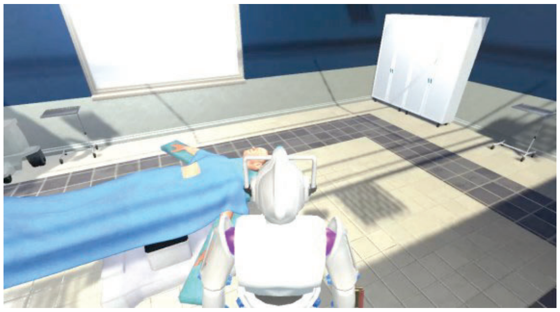


39


40

Machine Learning

- Machine learning to make agents perform simple tasks



Norconsult

41

Results and Conclusions

- Training of medical personel with use of XR
- Increase the knowledge of medical persons and designers
- This knowledge will reduce the amount of Post Operative Surgical Infections
- Further research will contribute to increasing understanding of which factors affect particle concentration (read bacteria) in the patient's wound area, ie:
  - Pre- and post-surgery
  - Ventilation solutions
  - Tempersasture conditions
  - Behavior and habit of operating personel

Norconsult

42

43

Thank you for your attention

Trond Thorgeir Harsem[1,2]
trond.thorgeir.harsem@norconsult.com

[1] Norconsult, Sandvika, Norway
[2] KTH - Royal Institute of Technology, Stockholm

Norconsult

44

Norconsult

Every day we improve everyday life

Users and practices in heating and ventilating homes – why do they behave different than we think?

Kirsten Gram-Hanssen

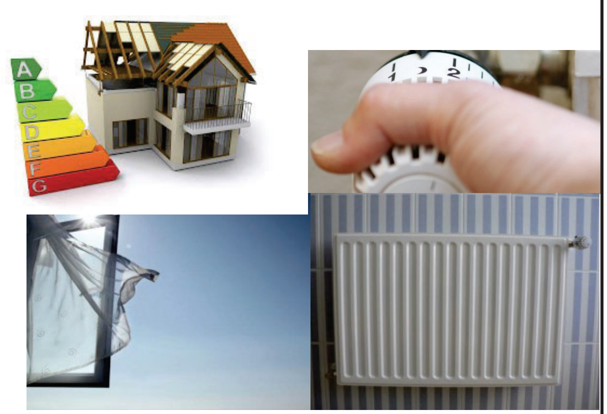
AIVC 2023-Copenhagen AAU 3-5 oktober 2023

AALBORG UNIVERSITY

1

What I will talk about....

- Healthy indoor air quality *and* reduced energy consumption are compulsory
- For both goals the interplay between users, buildings and technologies is the key
- Users are different – and different from what designers think – and we need to understand this



AALBORG UNIVERSITY
DENMARK

2

When designing technology or modeling buildings we anticipate behavior

But often user behavior is different from anticipations….

- Comparing calculated and actual heating in homes show systematic huge difference
- G-labeled homes use much less than expected - and A-labeled much more
- The building efficiency impact behavior
- This has policy relevance for reducing energy consumption

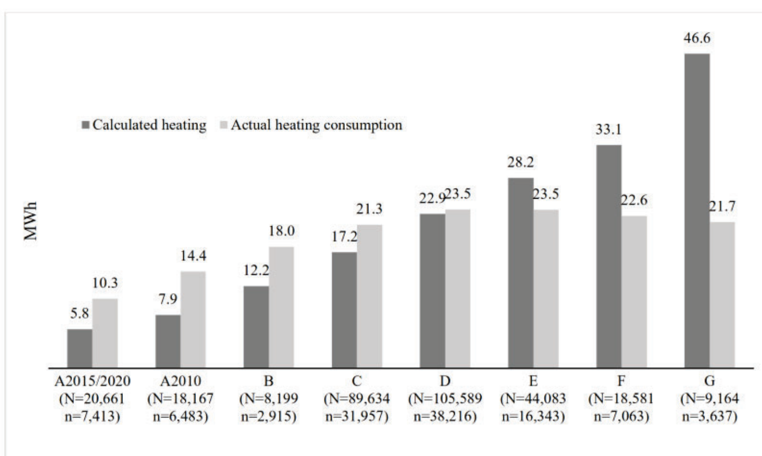


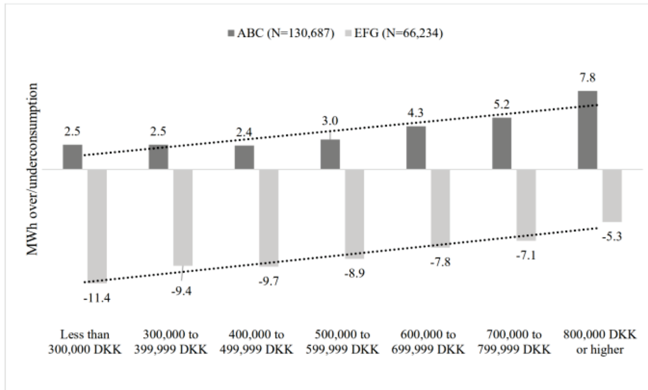
Figure 1. Comparison of means of calculated heating demand and actual heating consumption in houses in MWh for 2019 to 2021 across labels. N=314,078 observations. n=114,022 households.

(Hansen & Gram-Hanssen, 2023).

Do income explain all of this discrepancy?

- There are over-consumption in all ABC-labeled houses
- There are under-consumption in all EFG-labeled houses
- Households' economy influence how much over- and under-consumption.
- But economy do not explain all: the efficiency of the house impact behavior

Figure 4. Comparison of over- and underconsumption in MWh from lower to higher income households.



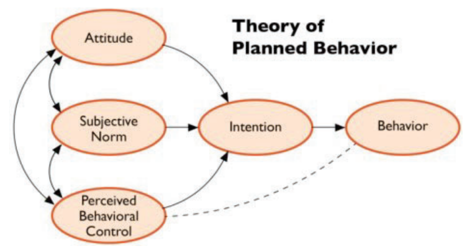
(Hansen & Gram-Hanssen, 2023).

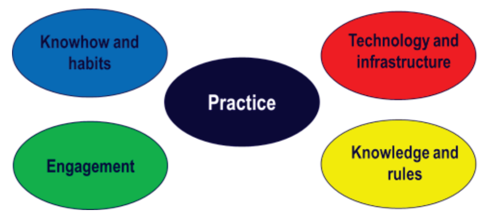
AALBORG UNIVERSITY DENMARK

Users are important – how to conceptualise them?

Practice theoretical approaches *versus* Behavioural

- Routinised *versus* intentional
- Focus on the practices we all carry *versus* on the individual person
- Technology and infrastructure included *versus* not included as forming practices
- Understand how something become normal and change over time





(Gram-Hanssen, 2014)

AALBORG UNIVERSITY
DENMARK

Practices are collective – but with socio-economic variations

We all do the same - though with variations related to:

- Our material possessions and housing type (depend on economy)
- Routines and cultures from upbringing we (unconsciously) bring with us
- Knowledge and skills often related to specific materiality
- Much of this relates to gender, education and age

(Gram-Hanssen, 2021)

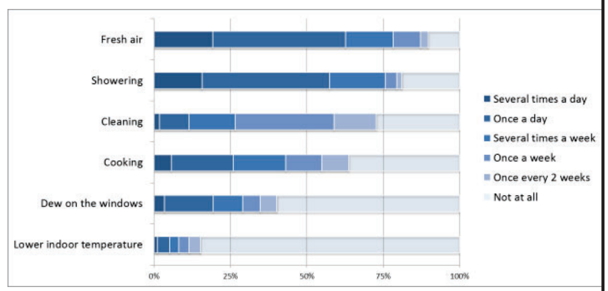
AALBORG UNIVERSITY
DENMARK

How often have you aired and why? .....as part of routines and daily practices

Little socio-demographic variation:

- ➢ Age, income and education show no significant correlations
- ➢ Families with children air more often
- ➢ Households with immigrant or descendant air more often
- ➢ The age of the house (and thus air-tightness) *do not* influence airing practices

	Which of the following statements fits your way of airing best?
I am airing after a routine	38% (464)
I do not have a fixed routine, but airing out when I think there is need for it	55% (671)
3. Don't know or missing	7%



(Hansen, et al 2018)

AALBORG UNIVERSITY DENMARK

Changing routines of airing and heating by means of payment

- An experiments where residents pay for poor indoor climate rather than for heating
- Cloud based solution with indoor climate measurements of CO_2, temperature, and humidity
- To prevent people from having an unhealthy indoor air quality, e.g. turning down too much the heat and airing too little to save money

(Gram-Hansen, et al 2023)

AALBORG UNIVERSITY DENMARK

Indoor climate measurements: Feedback and payments to influence users

- High CO_2, temperature, and humidity mean more payment; but also low temperature and low humidity (to prevent overventilation/waste of heat) means more payment

Table 1. Examples of specifications of limits for indoor climate measures used for calculating heating cost distribution.

	Good – basic payment	Less good – additional payment	Poor – higher additional payment
Temperature, °C	18–21	16–18 and 21–23	<16 and >23
Humidity, %RH	30–50	20–30 and 50–60	<20 and >60
CO_2 concentration, ppm	<800	800–1000	>1000

- Mixed experiences:
  - Better communication is needed about the system
  - Measurements can be good for the dialog between resident and building managers
  - Some understood the system some did not
  - Some got angry with the ideas

(Gram-Hanssen, et al 2023)

AALBORG UNIVERSITY
DENMARK

Are smart technology a solution to "user-problems" ?

Discrepancies between professional's view and real-life users

13

Professionals tend to think that:

Users tend to:

"The less occupant interfere with regulating the better. We should automate and control it for them"

"The more automation the better comfort and convenience for the user"

"Ordinary people are not interested and do not understand HVAC technologies"

Experience systems they don't understand, and which works contra intuitive

Experience systems failure and problems of interoperability

Find workarounds if the automation do not work as they prefer or they do not understand it

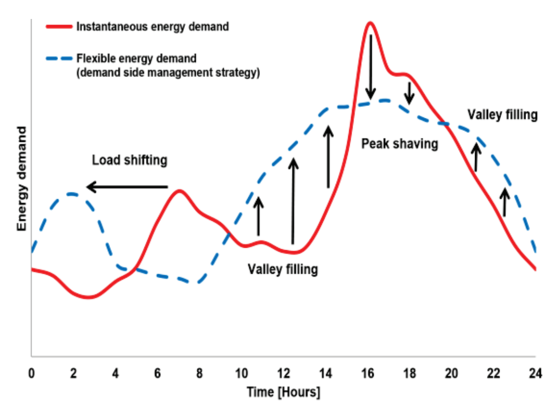
(Andersen et all, 2022; Aagaard, 2021)

AALBORG UNIVERSITY
DENMARK

It can get even more complicated in the future energy system…

14

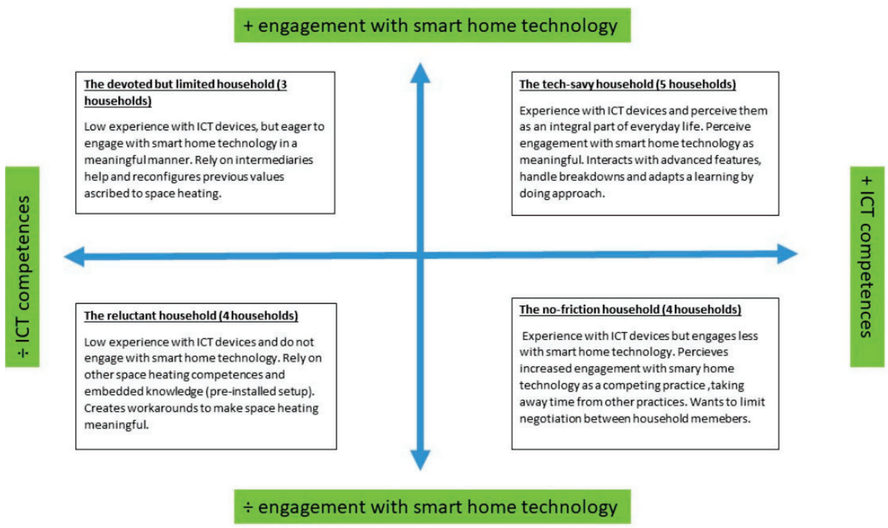
- The future energy system will rely on renewable energy – flexible demand and load shifting will be increasingly relevant
- Buildings can serve as short time flexibility generator – including preheating and short time turning down heating
- Will involve even more complexity to HVAC management and the interaction between technologies, buildings and users.



(Larsen & Gram-Hanssen, 2020)

AALBORG UNIVERSITY
DENMARK

Different types of users of smart control

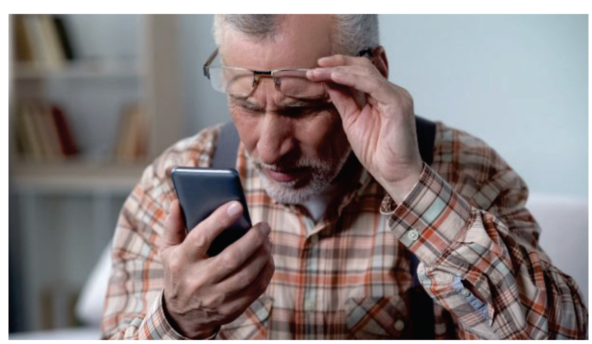


(Larsen & Gram-Hanssen, 2020)

AALBORG UNIVERSITY
DENMARK

Socio-economics of smart tech competences and interest

- The older generation will (long time ahead) not be as good as the young ones to understand and use smart tec
- The most tech interested are male. Not that females don't have competences - or that all male are tech nerds
- If AI should be part of the solutions, we need systems that work for *all* users



(Strengers et al, 2022)

AALBORG UNIVERSITY
DENMARK

What I tried to say ….

- Users are important – we will not achieve healthy indoor air quality or reduced energy consumption without involving the users
- Technology and behavior cannot be separated
- User are different when it comes to competences and engagements
- Real knowledge, not assumptions, of users should be included already in the design of new technologies and building system

AALBORG UNIVERSITY
DENMARK

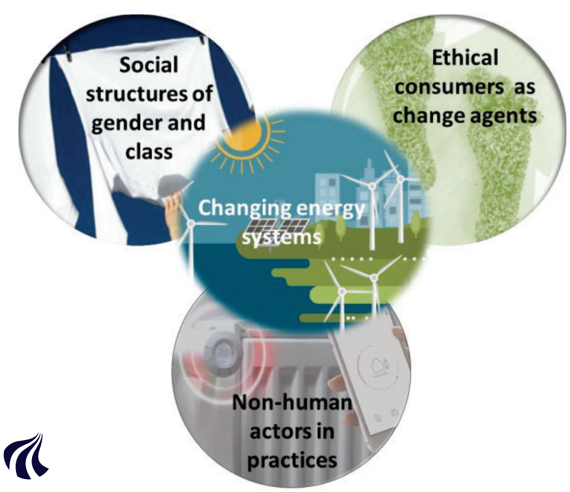
17

18

The project behind

ERC advanced grant eCAPE:
New Energy Consumer roles and smart technologies – Actors, Practices and Equality. Grant agreement number 786643

www.ecape.aau.dk



European Research Council
AALBORG UNIVERSITY
DENMARK

18

References

- Andersen, P. V. K., Christensen, L. L., Gram-Hanssen, K., Georg, S., Horsbøl, A., & Marszal-Pomianowska, A. (2022). Sociotechnical imaginaries of resident roles: Insights from future workshops with Danish district heating professionals. Energy Research & Social Science, 87.
- Gram-Hanssen, K. (2014). New needs for better understanding of household's energy consumption – behaviour, lifestyle or practices? Architectural Engineering & Design Management, 10(1/2), 91–107.
- Gram-Hanssen, K. (2021). Conceptualising ethical consumption within theories of practice. Journal of Consumer Culture, 21(3), 432-449.
- Gram-Hanssen, K., Bonderup, S., Aagaard, L. K., & Askholm, A. S. M. (2023). Energy justice in heat metering: Findings from a Danish experiment of metering and distribution in residential apartment buildings. Energy Research and Social Science, 104,
- Hansen, A. R., & Gram-Hanssen, K. (2023). Over- and underconsumption of residential heating: Analyzing occupant impacts on performance gaps between calculated and actual heating demand: NSB 2023: 13th Nordic Symposium on Building Physics. NSB 2023: 13th Nordic Symposium on Building Physics - Aalborg University - CREATE, Aalborg, Denmark.
- Hansen, A. R., Gram-Hanssen, K., & Knudsen, H. N. (2018). How building design and technologies influence heat-related habits. Building Research & Information, 46(1), 83–98.
- Larsen, S. P. A. K., & Gram-Hanssen, K. (2020). When Space Heating Becomes Digitalized: Investigating Competencies for Controlling Smart Home Technology in the Energy-Efficient Home. Sustainability, 12(15), Article 15. Aagaard, L. K. (2021). The meaning of convenience in smart home imaginaries: Tech industry insights. Buildings and Cities, 2(1), 568–582.
- Strengers, Y., Gram-Hanssen, K., Dahlgren, K., & Aagaard, L. K. (2022). Energy, emerging technologies and gender in homes. Buildings and Cities, 3(1), 842–853.

AALBORG UNIVERSITY
DENMARK

WHAT WE KNOW ABOUT SMART VENTILATION

Dr Gaëlle Guyot, France

AIVC Conference 2023, 4-5th October, Copenhague, Keynote

1

AGENDA

- Context
- What we know
- What we need

About the definition
About the history of the terminology
About the strategies
About the performances

2

AGENDA

- Context
- What we know
- What we need
  - From researchers
  - From industrials
  - From policy makers

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

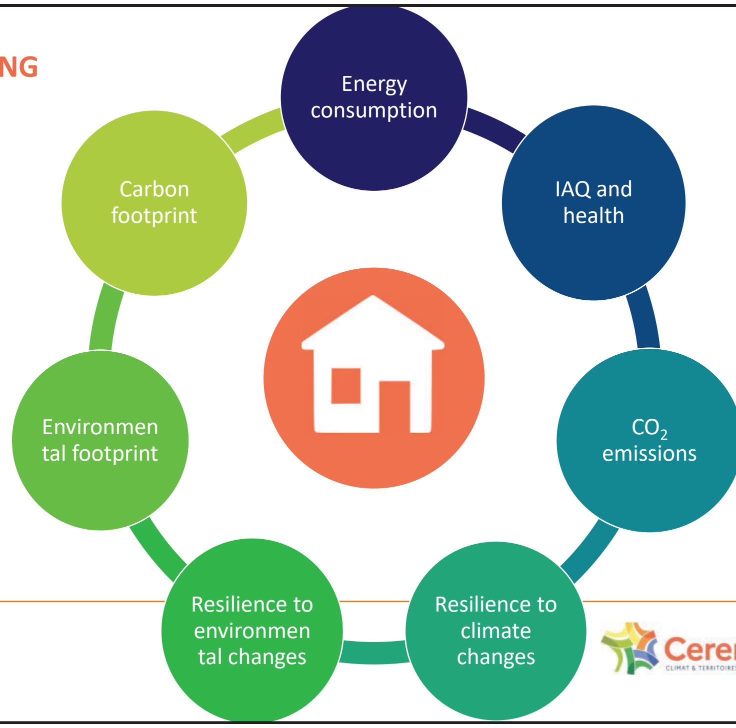
Cerema
CLIMAT & TERRITOIRES DE DEMAIN

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

CONTEXT

THE BUILDINGS‘ SECTOR IS FACING MULTIPLE CHALLENGES



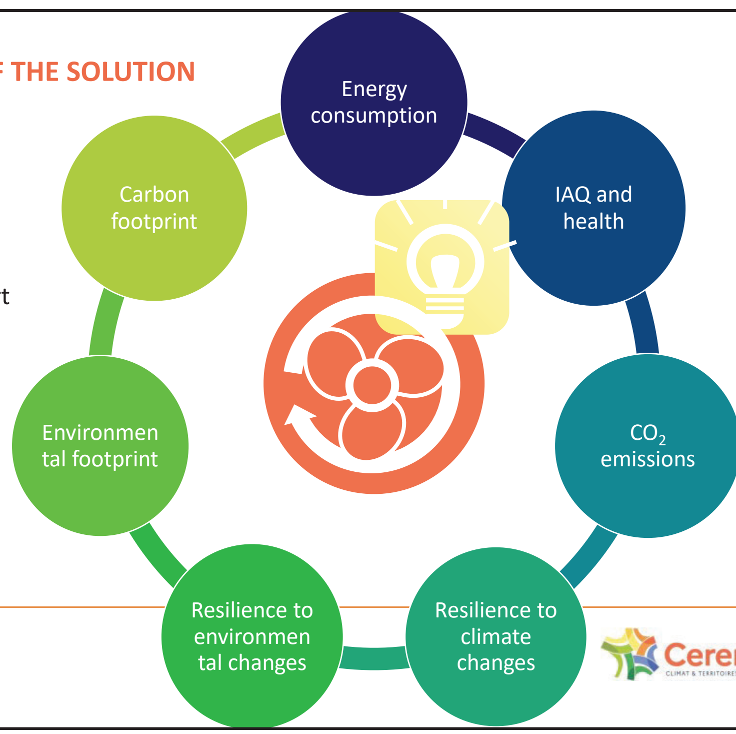
RÉPUBLIQUE FRANÇAISE

Cerema

5

SMART VENTILATION IS PART OF THE SOLUTION

Ventilation in buildings is at the heart of all these challenges



RÉPUBLIQUE FRANÇAISE

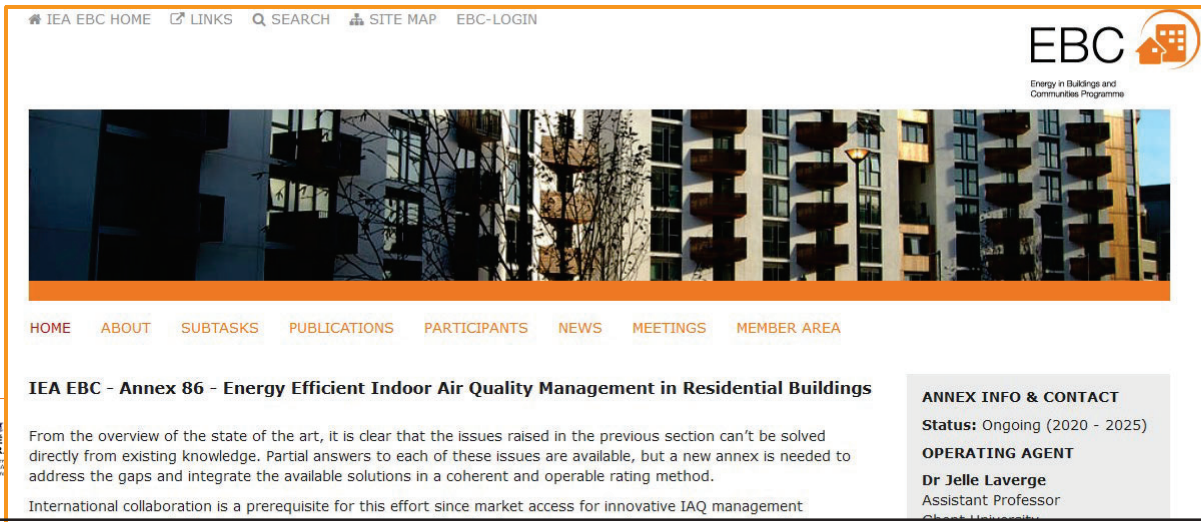
Cerema

6

IEA-EBC ANNEX 86

The IEA-EBC Annex 86 : Energy Efficient Indoor Air Quality Management in Residential Buildings

ST4-smart ventilation : pushing an international effort about the promotion of smart ventilation strategies



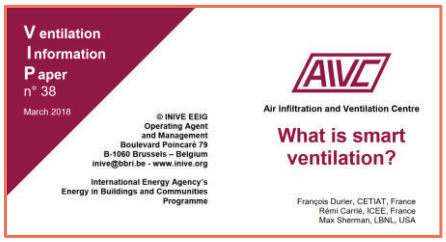
RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

WHAT WE KNOW ?

DEFINITION OF SMART VENTILATION

“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). (…)”.


Ventilation
Information
Paper
n° 38
March 2018

© INIVE EEIG
Operating Agent
and Management
Boulevard Poincaré 79
B-1060 Brussels – Belgium
inive@bbri.be - www.inive.org

International Energy Agency's
Energy in Buildings and Communities
Programme

AIVC
Air Infiltration and Ventilation Centre

What is smart ventilation?

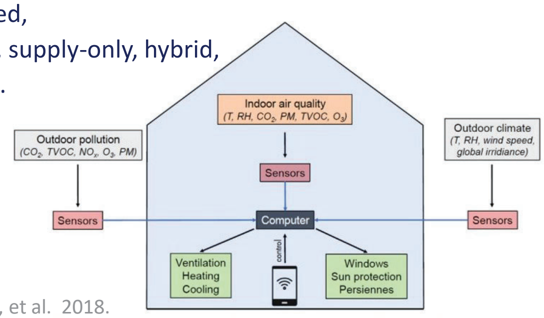
François Durier, CETIAT, France
Rémi Carrié, ICEE, France
Max Sherman, LBNL, USA

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

DEFINITION OF SMART VENTILATION

- Demand-controlled ventilation (DCV) = a specific subset of smart ventilation
- A wide range of systems currently available in the literature and on the market depending on
  - the type of sensing parameters : **indoor**, humidity, occupancy, VOC, **outdoor** climate, pollution, temperature, etc.,
  - the type of sensing combinations,
  - The type of air terminal devices (ATD),
  - the type of installations: centralized/decentralized,
  - the types of techniques: balanced, exhaust-only, supply-only, hybrid,
  - and the types of controls and control algorithms.



RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Schieweck, et al. 2018.

Possible manipulated variables (indoors and outdoors) for the control of ventilation, indoor climate and indoor pollutants

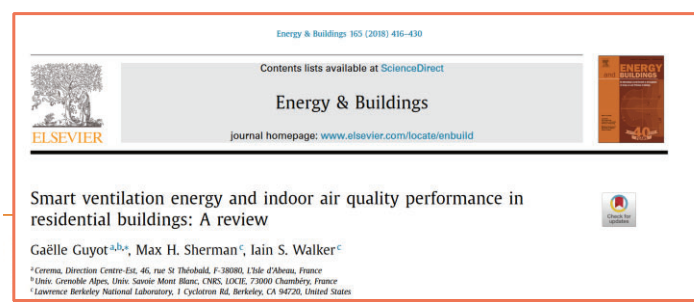
HISTORY

- "smart ventilation" first used fairly recently by LBNL researchers (Walker et al., 2014; Less and Walker, 2016; Lubliner et al., 2016)
- These terms have been increasingly used since
- DCV emerged after the oil crisis of the early 1980 (Anon, 1983; Barthez and Soupault, 1984; Nicolas, 1985).
- More recently, a favorable context – pushed by the 2003 EPBD in Europe
  - with more than 20-30 DCV systems approved and available in countries such as Belgium, France and the Netherlands (Guyot et al., 2018b).

PERFORMANCES OF RESIDENTIAL SMART VENTILATION – FIRST STATE OF THE ART IN 2018

- With various smart ventilation systems based on CO_2-, humidity-, combined CO_2- and TVOC-, occupancy-, outdoor temperature-controlled ventilation, energy savings up to 60% could be obtained without compromising, and sometimes improving, IAQ
  - 38 studies from 1979 to 2016

⇒ a clear potential for improve IAQ and save energy


Energy & Buildings 165 (2018) 416–430

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enbuild

Smart ventilation energy and indoor air quality performance in residential buildings: A review

Gaëlle Guyot[a,b,*], Max H. Sherman[c], Iain S. Walker[c]

[a] Cerema, Direction Centre-Est, 46, rue St Théobald, F-38080, L'Isle d'Abeau, France
[b] Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, LOCIE, 73000 Chambéry, France
[c] Lawrence Berkeley National Laboratory, 1 Cyclotron Rd, Berkeley, CA 94720, United States


LBNL 2001056

Ernest Orlando Lawrence Berkeley National Laboratory

Residential smart ventilation: a review

Gaëlle Guyot[1], Max H. Sherman[2], Iain S. Walker[2] & Jordan D. Clark[2]

[1] Cerema & Savoie Mont Blanc University
[2] Building Technologies and Urban Systems Division

September 2017

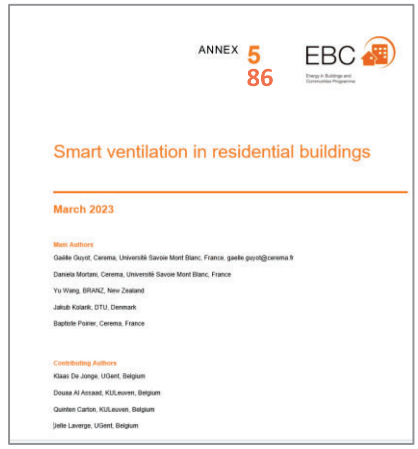
Cerema
CLIMAT & TERRITOIRES DE DEMAIN

PERFORMANCES OF RESIDENTIAL SMART VENTILATION – STATE OF THE ART IN 2023

- On-going
- In the Framework of the IEA-EBC Annex 86
- And of a new AIVC Technical note

Dr Daniela MORTARI, PUCPR, Cerema, Univ. Savoie Mont Blanc Brasil-France

Dr Yu WANG, BRANZ, New Zealand



ANNEX 86 EBC

Smart ventilation in residential buildings

March 2023

Main Authors

Gaëlle Guyot, Cerema, Université Savoie Mont Blanc, France, gaelle.guyot@cerema.fr

Daniela Mortari, Cerema, Université Savoie Mont Blanc, France

Yu Wang, BRANZ, New Zealand

Jakub Kolarik, DTU, Denmark

Baptiste Poirier, Cerema, France

Contributing Authors

Klaas De Jonge, UGent, Belgium

Douaa Al Assaad, KULeuven, Belgium

Quinten Carton, KULeuven, Belgium

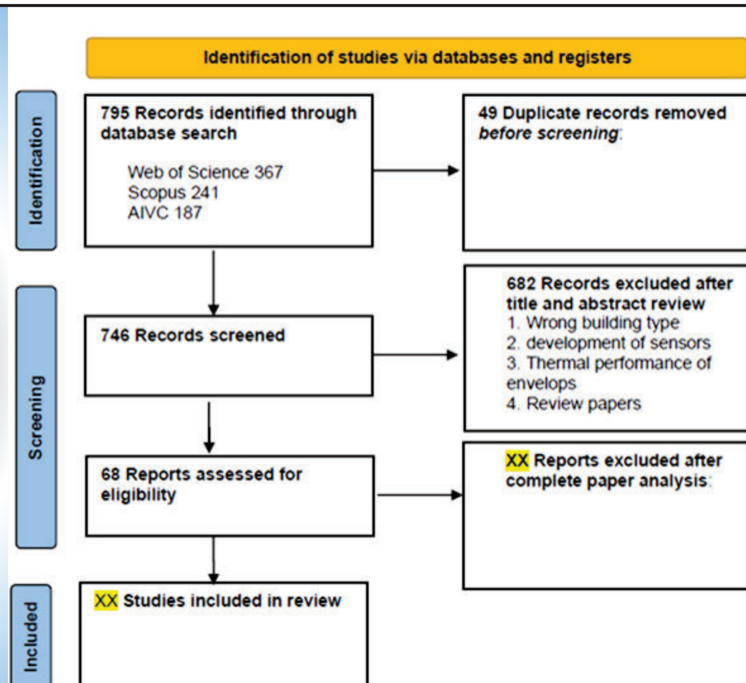
Jelle Laverge, UGent, Belgium

Bibliometric analysis has been performed

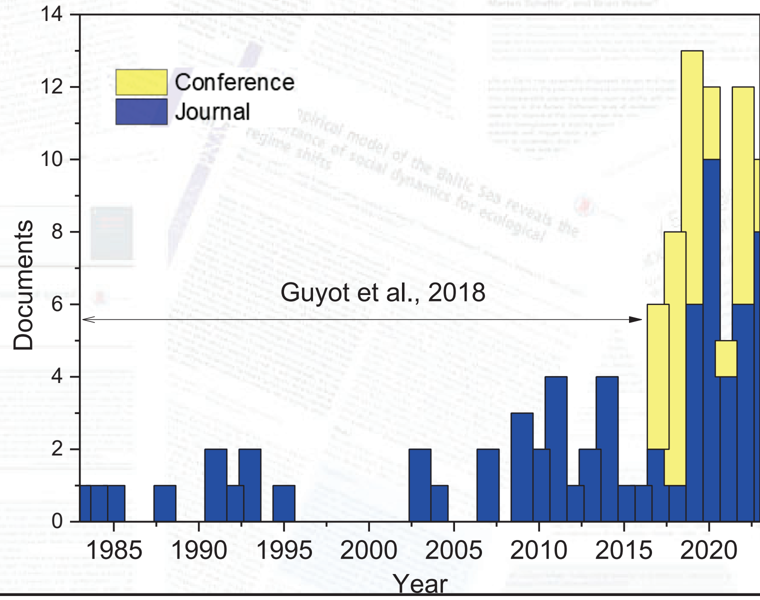
(manually and VOSviewer)

Collaboration

counts one paper for each Institution and country



PUBLICATION BY YEAR



15

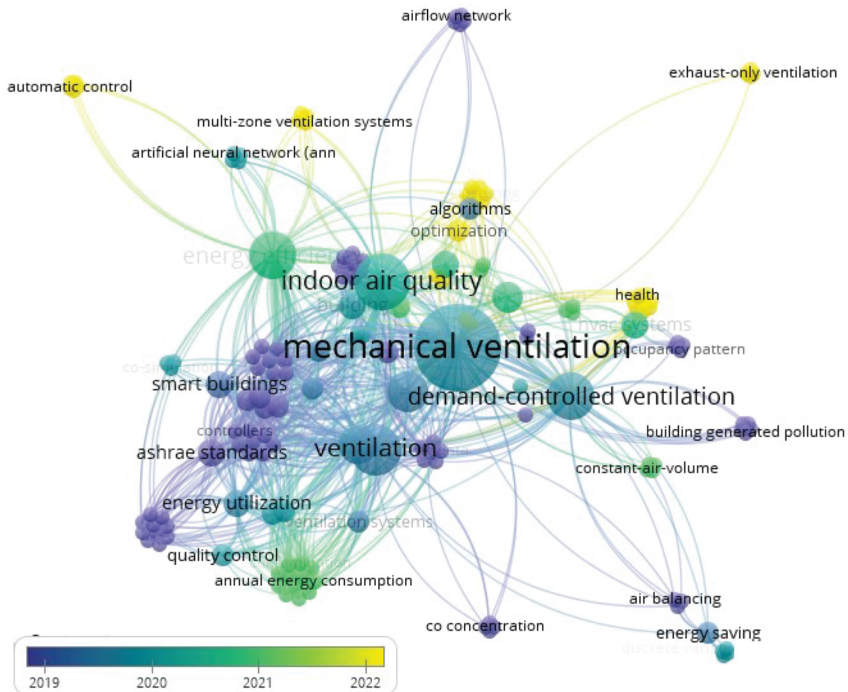
RANK OF INSTITUTIONS ACCORDING TO THE NUMBER OF ARTICLES

RANK	INSTITUTION	DOCUMENTS	PROPORTION
1	Ghent University	15	22.1%
2	Lawrence Berkeley National Laboratory	8	11.7%
3	Renson Ventilation, Belgium	6	8.8%
4	Technical University of Denmark	6	8.8%
5	CEREMA, Lyon, France	4	5.8%
6	The Ohio State University	4	5.8%
7	Belgian Building Research Institute (BBRI)	3	4.4%
8	Université Savoie Mont Blanc	3	4.4%
9	Nanyang Technological University	3	4.4%
10	Fraunhofer Institute for Solar Energy systems (ISE)	2	2.9%
11	AERECO SA France	2	2.9%
12	CETHIL-EDF Joint Laboratory, BHEE, France	2	2.9%
13	City University of Hong Kong	2	2.9%
14	Dankook University	2	2.9%
15	Flemish Institute for Technical Research, Belgium	2	2.9%
16	National Institute of Standards and Technology, USA	2	2.9%
17	Norwegian University of Science and Technology	2	2.9%
18	Seoul National University	2	2.9%
19	Southeast University, China	2	2.9%
20	Université Grenoble Alpes	2	2.9%
21	Université de Lyon	2	2.9%
22	Vrije Universiteit Brussel	2	2.9%

16

VOSViewer Results

Keywords occurence by year



RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

WHAT WE NEED ?

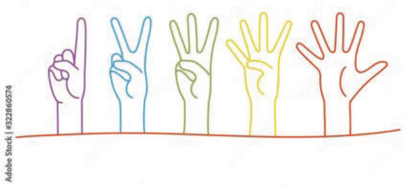
AGENDA

- Context
- What we know
- **What we need**

From researchers

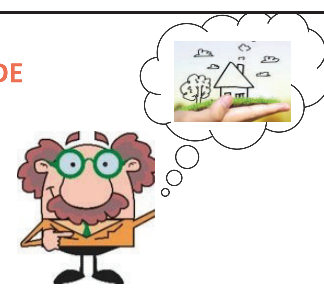
From industrials

From policy makers

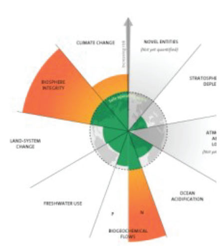


RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

1- SOBER SYSTEMS ADAPTED TO THE CHALLENGES OF OUR DECADE

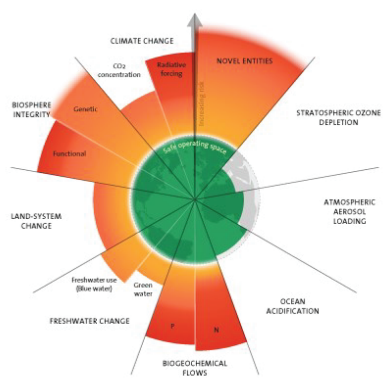


2009



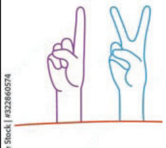
3 boundaries crossed

2023



6 boundaries crossed

- At this time on the history, we need ventilation systems :
  - Sober (energy and resources),
  - Reliable,
  - With long-term performances over the ventilation system's lifetime – 20 years (Durmisevic, 2006; Feist et al., 2020),
- Many of them already exist !



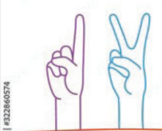
2-ROBUST AND IMPROVED PERFORMANCE-BASED ASSESSMENT SCHEMES

- Remains a barrier in many countries !
- Final report of the IEA EBC Annex 9 (1982-1986) described the 2 approaches for ventilation standards:
  - The prescriptive approach, in which an outdoor air flow rate is stated
  - The air quality approach, in which a limiting maximum pollutant concentration is defined and the building designer or user, is required to supply sufficient air to ensure that this is not exceeded = Performance-based approach but not only IAQ

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

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



2-ROBUST AND IMPROVED PERFORMANCE-BASED ASSESSMENT SCHEMES

- Remains a barrier in many countries !
- Final report of the IEA EBC Annex 9 (1982-1986) described the 2 approaches for ventilation standards:
  - The prescriptive approach, in which an outdoor air flow rate is stated
  - The air quality approach, in which a limiting maximum pollutant concentration is defined and the building designer or user, is required to supply sufficient air to ensure that this is not exceeded = Performance-based approach but not only IAQ

"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!"

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

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

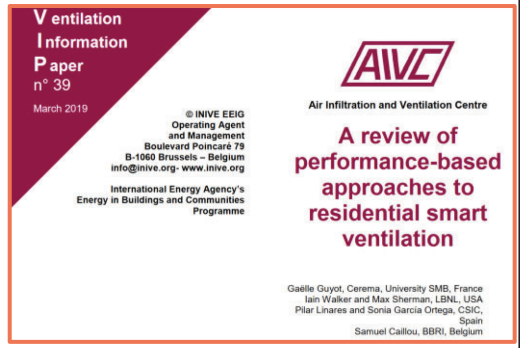
Cerema
CLIMAT & TERRITOIRES DE DEMAIN

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

2-ROBUST AND IMPROVED PERFORMANCE-BASED ASSESSMENT SCHEMES

- To date, however, most national regulations and standards => the prescriptive approach

- In the field of smart ventilation
  - SV must undergo procedures/calculations in order to demonstrate their performances
  - before being authorised or used in buildings,


Ventilation Information Paper n° 39

March 2019

© INVE EEIG
Operating Agent and Management
Boulevard Poincaré 79
B-1060 Brussels – Belgium
info@inive.org - www.inive.org

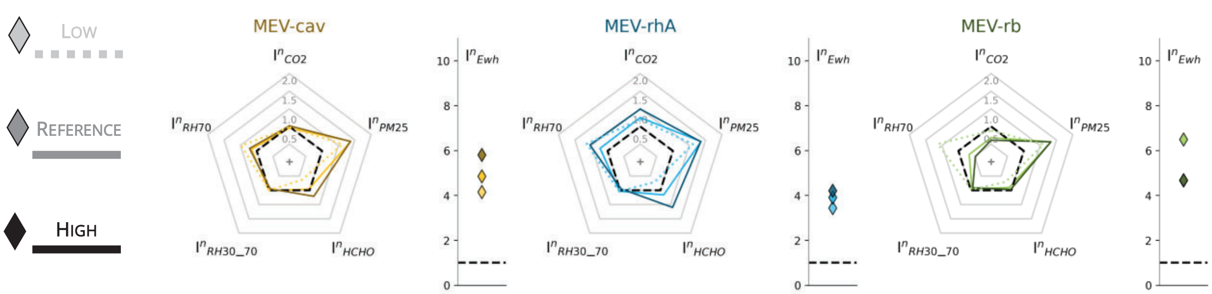
International Energy Agency's Energy in Buildings and Communities Programme

AIVC
Air Infiltration and Ventilation Centre

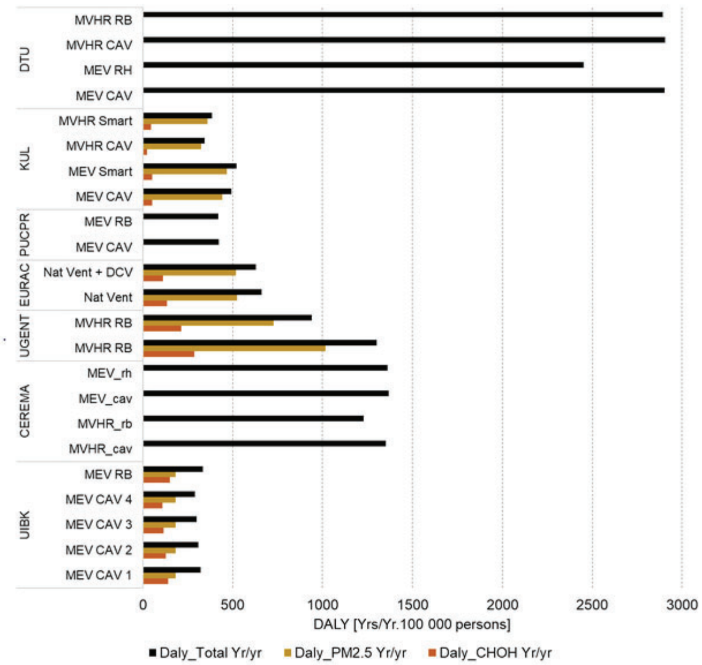
A review of performance-based approaches to residential smart ventilation

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

EXAMPLE OF ENERGY AND IAQ PERFORMANCE RESULTS



Reference : Baptiste Poirier, et al., 2023, to be published

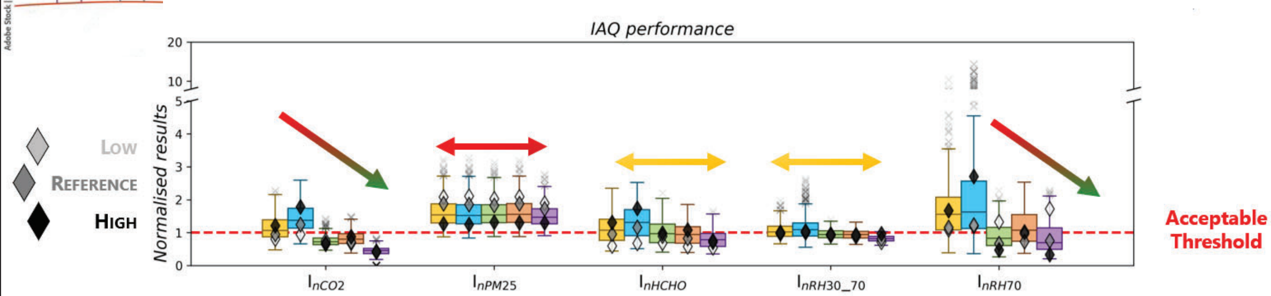


Reference : Klaas DeJonge, Quinten Canton, On-going work on the common exercise in the Annex 86-ST4

RÉPUBLIQUE FRANÇAISE

Cerema

UNCERTAINTY AND SENSITIVITY MUST BE CONSIDERED



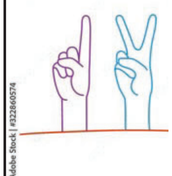
Baptiste Poirier et al., 2023, to be published

RÉPUBLIQUE FRANÇAISE

Keynote – smart ventilation, AIVC conference 2023

Cerema

UNCERTAINTY AND SENSITIVITY MUST BE CONSIDERED



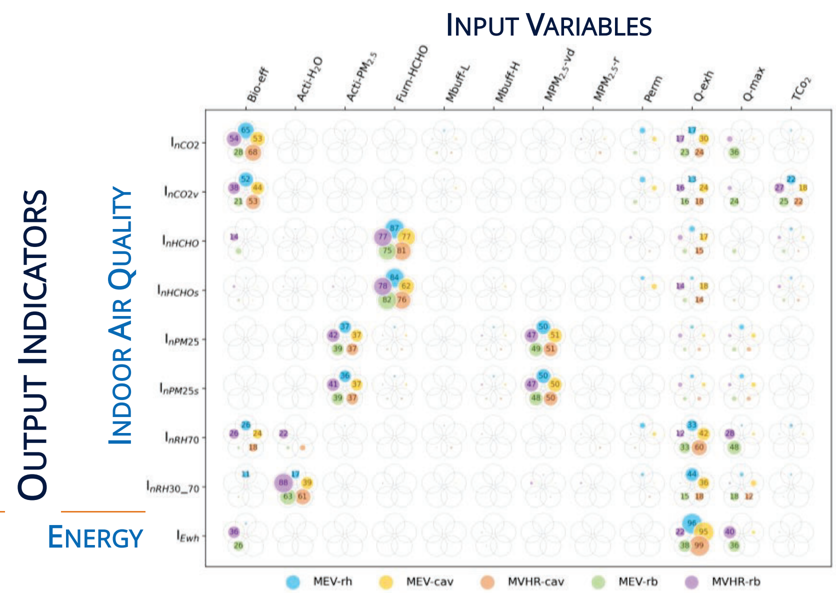
MEV-cav

MEV-rh

MEV-rb

MVHR-cav

MVHR-rb

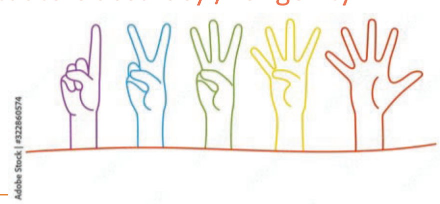


RÉPUBLIQUE FRANÇAISE

Baptiste Poirier et al., 2023, to be published

SMART VENTILATION NEEDS SPECIAL ATTENTION

- Ventilation in general suffers from a lack of quality (design, installation, maintenance)
- With smart ventilation, we generally allow lower airflows at some times when needs are low (no occupancy, low emissions, etc...)
  - ⇒ We have to secure even more the performances over the ventilation lifetime – 20 years
  - ⇒ 3 - Requirements for sensors and actuators accuracy / longevity
  - ⇒ 4 - Secure long-term performances
  - ⇒ 5 - Adapted inspection protocols



RÉPUBLIQUE FRANÇAISE

Cerema

3- REQUIREMENTS ON SENSORS OR ACTUATORS

The only example : Belgium

MONITEUR BELGE — 13.11.2015 — BELGISCH STAATSBLAD 68615

Art. 2. Le présent arrêté entre en vigueur le 1[er] décembre 2015.

Bruxelles, le 29 octobre 2015.

La Ministre de l'Enseignement de Promotion Sociale, de la Jeunesse, des Droits des femmes et de l'Egalité des chances,

Mme I. SIMONIS

VERTALING

MINISTERIE VAN DE FRANSE GEMEENSCHAP

[C − 2015/29552]

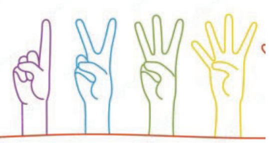
29 OKTOBER 2015. — Ministerieel besluit tot goedkeuring van het referentiedossier van de onderwijseenheid « Burgerzin » (code 050202U11D1), gerangschikt op het niveau van het lager secundair overgangsonderwijs voor sociale promotie

3.2.4 Incertitude des capteurs de détection

Les capteurs utilisés pour la détection des besoins, comme spécifié dans la suite du texte, doivent avoir une incertitude maximale sur la valeur du paramètre mesuré comme suit :

- Pour les capteurs de concentration en CO_2 : +/- 40 ppm + 5 % de la valeur, entre 300 et 1 200 ppm (exemple pour une exigence de 950 ppm, l'intervalle de tolérance est compris entre 862 ppm et 1 038 ppm);
- Pour les capteurs d'humidité relative (RH) : +/- 5 points de pourcentage d'humidité relative, entre 10 % et 90 % (exemple pour une exigence de 35 % d'humidité relative, l'intervalle de tolérance est compris entre 30 % et 40 % d'humidité relative).

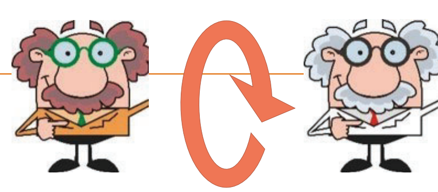
29



4- MORE STUDIES ABOUT LONG-TERM DURABILITY OF PERFORMANCES

- Ventilation lifetime – 20 years !

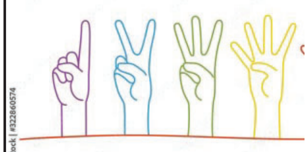
1. the intrinsic technological durability of all the components, sensors, controllers of these intelligent systems during their aging and their life in the building;
2. the robustness in use, i.e., the robustness of all these components to the use made of them by the occupants: maintenance (or absence), cleaning (or absence), unforeseen use (obstruction, clogging, ...) linked to different reasons specific to the occupants, to their understanding of the issues, of the systems, and to the way the systems take into account their needs and expectations.



RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

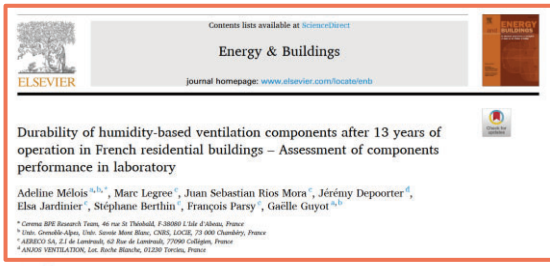
Cerema
CLIMAT & TERRITOIRES DE DEMAIN

30



4- MORE STUDIES ABOUT LONG-TERM DURABILITY OF PERFORMANCES

- Very few studies found in the literature
  - 3 in 2023
  - Zero in the Annex 86 group (so far)
  - « Long-term »: sometimes only one year …



Contents lists available at ScienceDirect

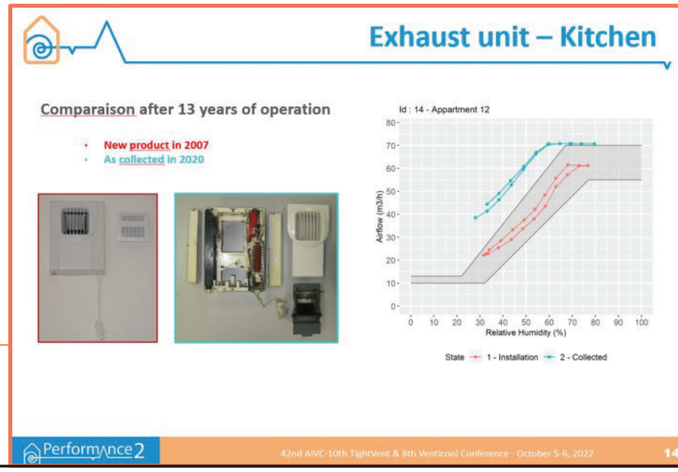
Energy & Buildings

journal homepage: www.elsevier.com/locate/enb

Durability of humidity-based ventilation components after 13 years of operation in French residential buildings – Assessment of components performance in laboratory

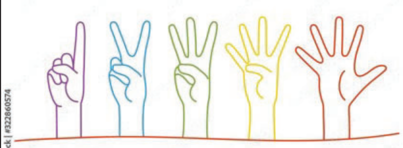
Adeline Mélois [a,b,*], Marc Legree [c], Juan Sebastian Rios Mora [c], Jérémy Depoorter [d], Elsa Jardinier [c], Stéphane Berthin [c], François Parsy [c], Gaëlle Guyot [a,b]

[a] Cerema BPE Research Team, 46 rue St Théobald, F-38080 L'Isle d'Abeau, France
[b] Univ. Grenoble-Alpes, Univ. Savoie Mont Blanc, CNRS, LOCIE, 73 000 Chambéry, France
[c] AERECO SA, Z.I de Lamirault, 62 Rue de Lamirault, 77090 Collégien, France
[d] ANJOS VENTILATION, Lot. Roche Blanche, 01230 Torcieu, France



RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

31



5- ADAPTED INSPECTION PROTOCOLS REGULARLY REQUIRED

- Emerging inspection protocols and quality management schemes should include specificities due to smart ventilation
- Including a frequency of inspections adapted to the long-term performances offered by the systems and/or the sensors ⚠
  - Not only at building's commissioning, Ventilation lifetime – 20 years !
- Smart ventilation can offer online and continuing commissioning = a huge opportunity !

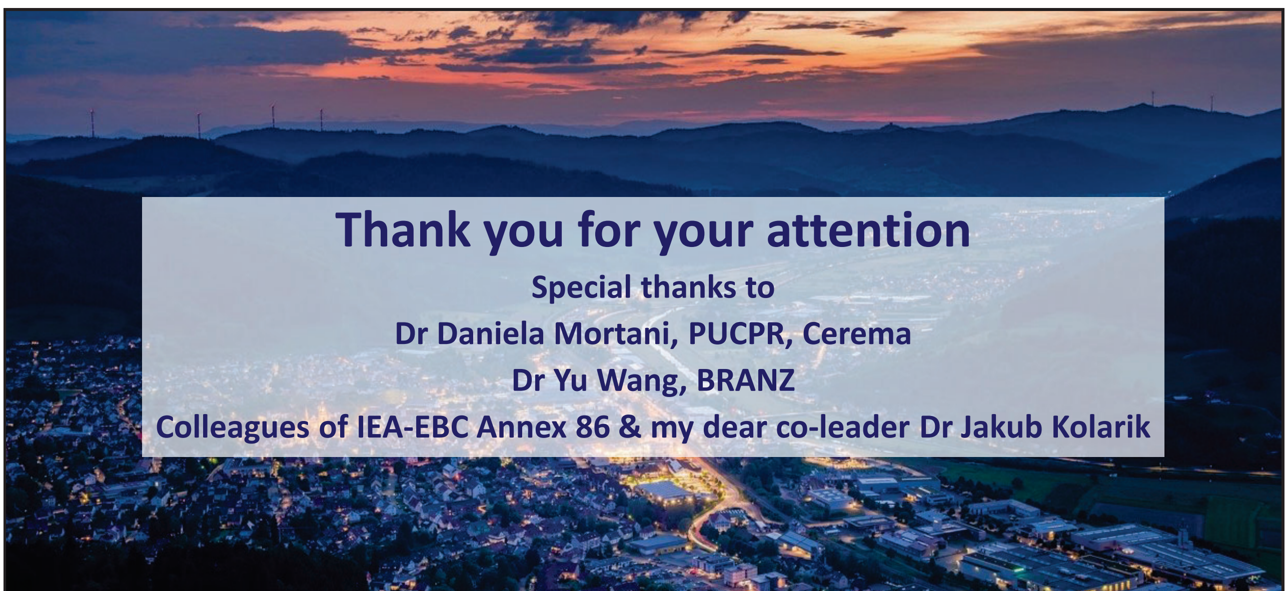
RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

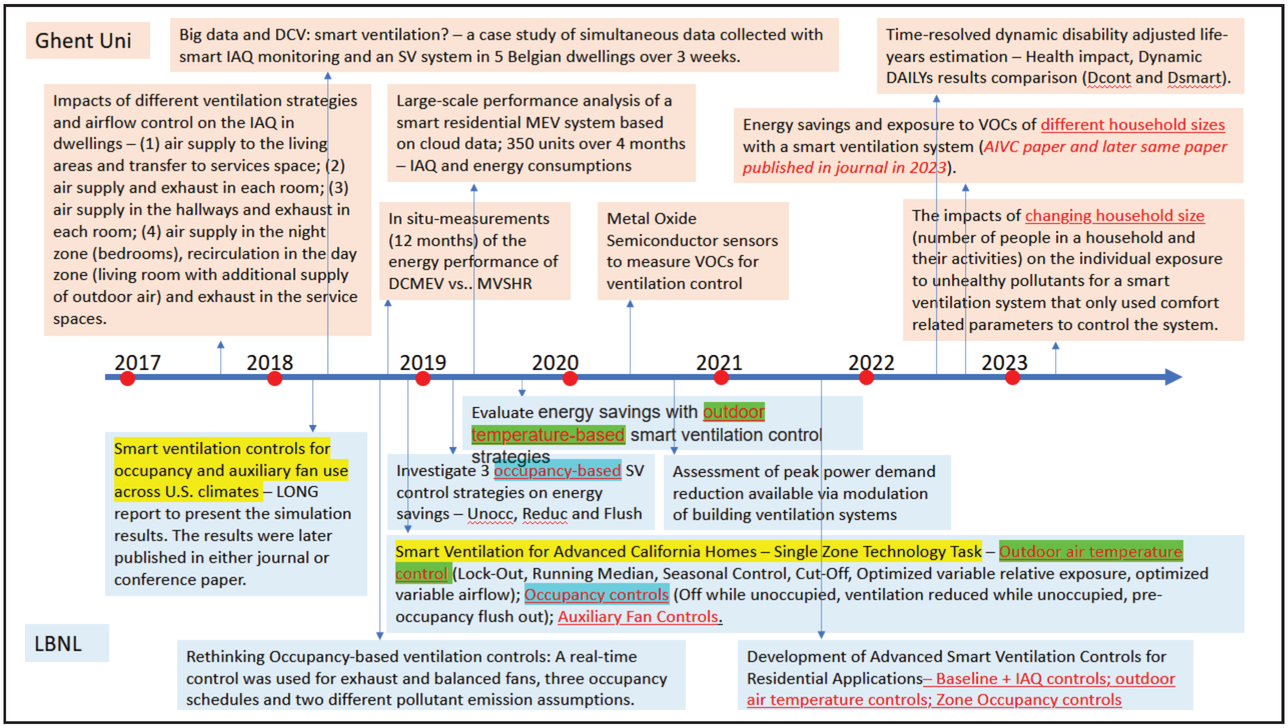
Cerema
CLIMAT & TERRITOIRES DE DEMAIN

32

WHAT WE NEED ? TO RESUME

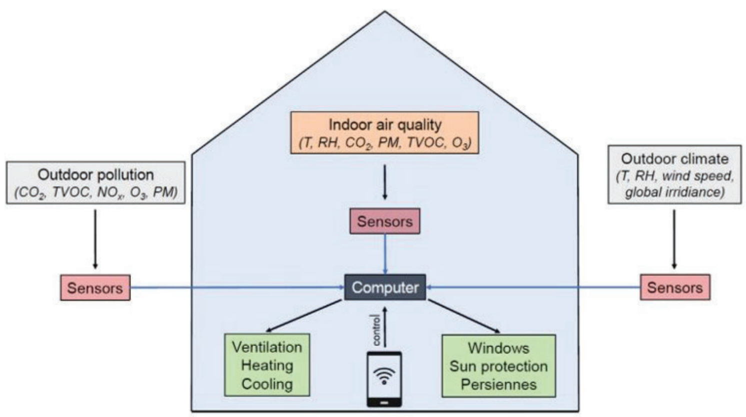
1. Sober systems adapted to the challenges of our decade — INDUSTRIALS / RESEARCHERS = PULL
2. Robust and improved performance-based assessment schemes E+IAQ — POLICY MAKERS / RESEARCHERS = PUSH
3. Requirements on sensors or actuators — INDUSTRIALS / POLICY MAKERS / RESEARCHERS = PULL & PUSH
4. More studies about long-term durability of performances — INDUSTRIALS / RESEARCHERS = PULL
5. Adapted inspection protocols regularly required — POLICY MAKERS / RESEARCHERS = PUSH





35

+ Occupant detection
+ Computer not necessary



Possible manipulated variables (indoors and outdoors) for the control of ventilation, indoor climate and indoor pollutants

Schieweck, A., Uhde, E., Salthammer, T., Salthammer, L.C., Morawska, L., Mazaheri, M., Kumar, P., 2018. Smart homes and the control of indoor air quality. Renewable and Sustainable Energy Reviews 94, 705–718. https://doi.org/10.1016/j.rser.2018.05.057

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

36

IMPACT OF THE SELECTED IAQ PERFORMANCE INDICATOR

- *"Zonal controls that saved energy by reducing outside airflow achieved typical reductions in ventilation-related energy of 10% to 30%, compared to the 7% savings from the unzoned control. However, this was at the expense of increased personal concentrations for some contaminants in most cases. In addition, care is required in the design and evaluation of zonal controls, because control strategies may reduce exposure to some contaminants, while increasing exposure to others"*

Walker, I., Less, B., Lorenzetti, D., Sohn, M.D., 2021. Development of Advanced Smart Ventilation Controls for Residential Applications. Energies 14, 5257. https://doi.org/10.3390/en14175257

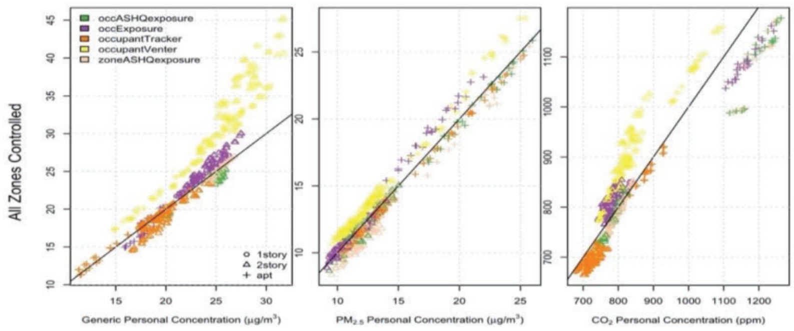


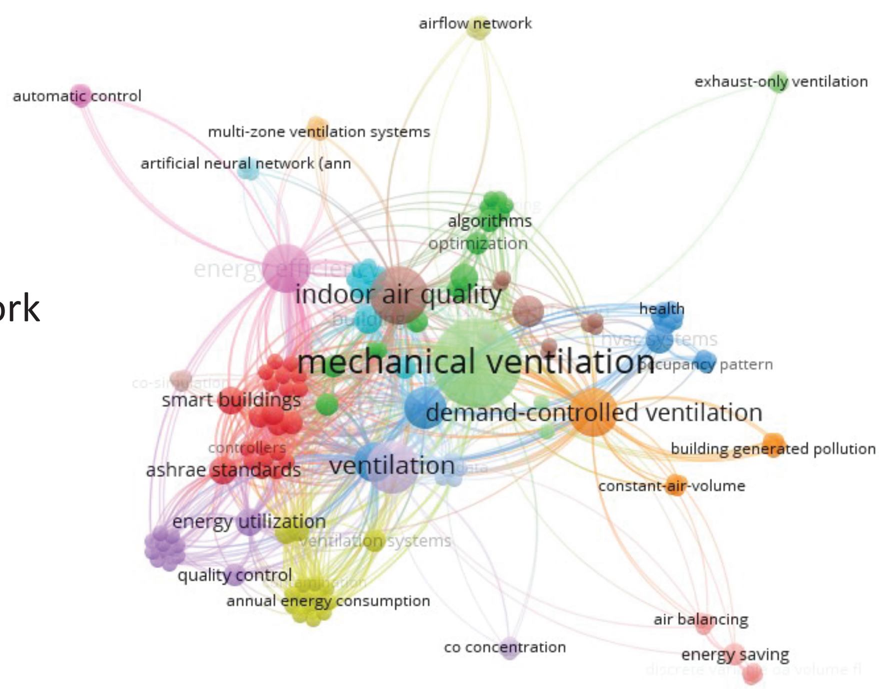
Figure 5. Comparison of annual median personal contaminant exposure by for systems controlling all zones or only two zones for different control strategies (colours) and dwelling types (symbols).

RÉPUBLIQUE FRANÇAISE

VOSViewer results

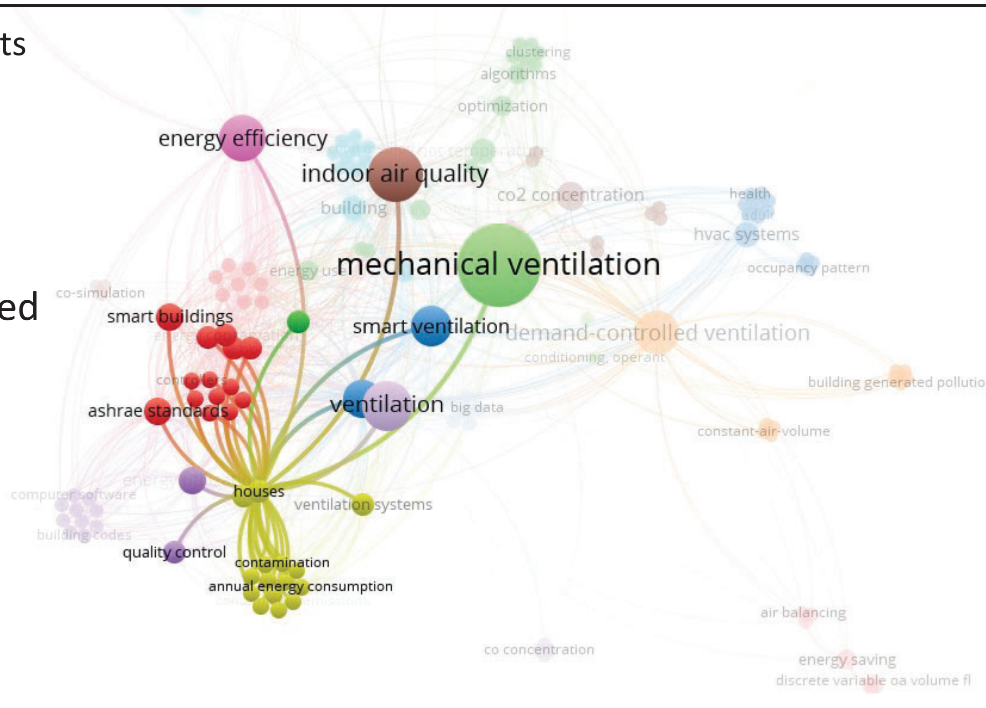
Keywords

co-occurrence network



VOSViewer Results

Keywords incidence related to “houses”



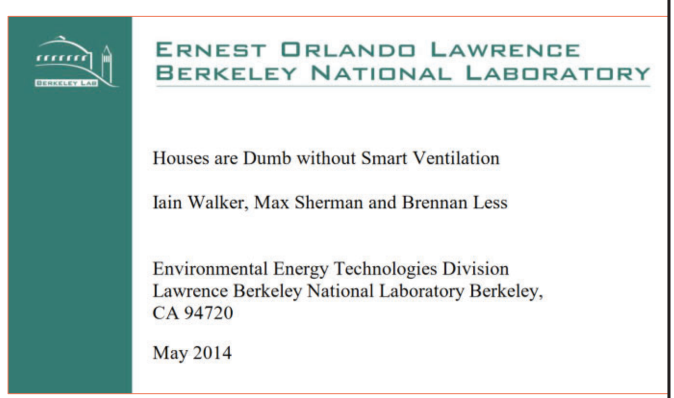
39

« HOUSES ARE DUMB WITHOUT SMART VENTILATION »

Isn’t it dumb to provide a constant ventilation airflow rate ?

- Everywhere throughout a building,
- whatever the boundary conditions: climate, outdoor pollution, seasons, …
- whatever the needs of the occupants;
- whatever the risks of damage to the buildings.

=> totally unsuited to our challenging changing world and our need to adapt


ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

Houses are Dumb without Smart Ventilation

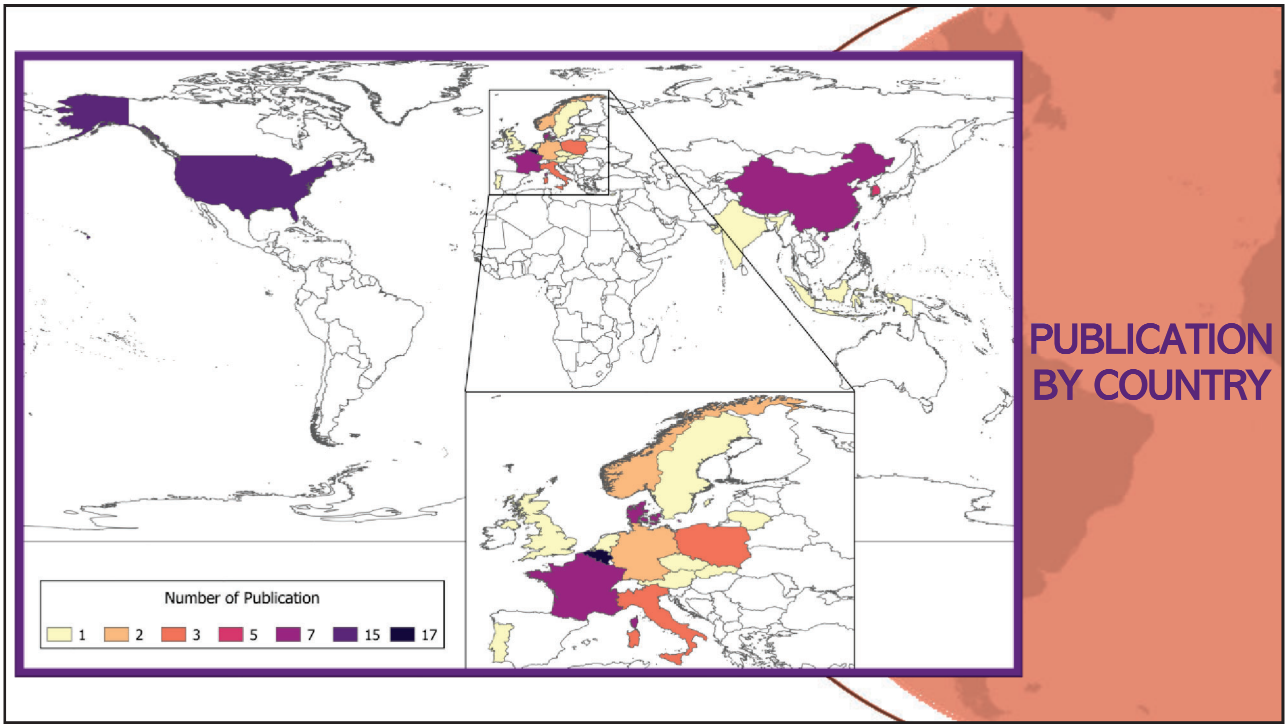
Iain Walker, Max Sherman and Brennan Less

Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory Berkeley, CA 94720

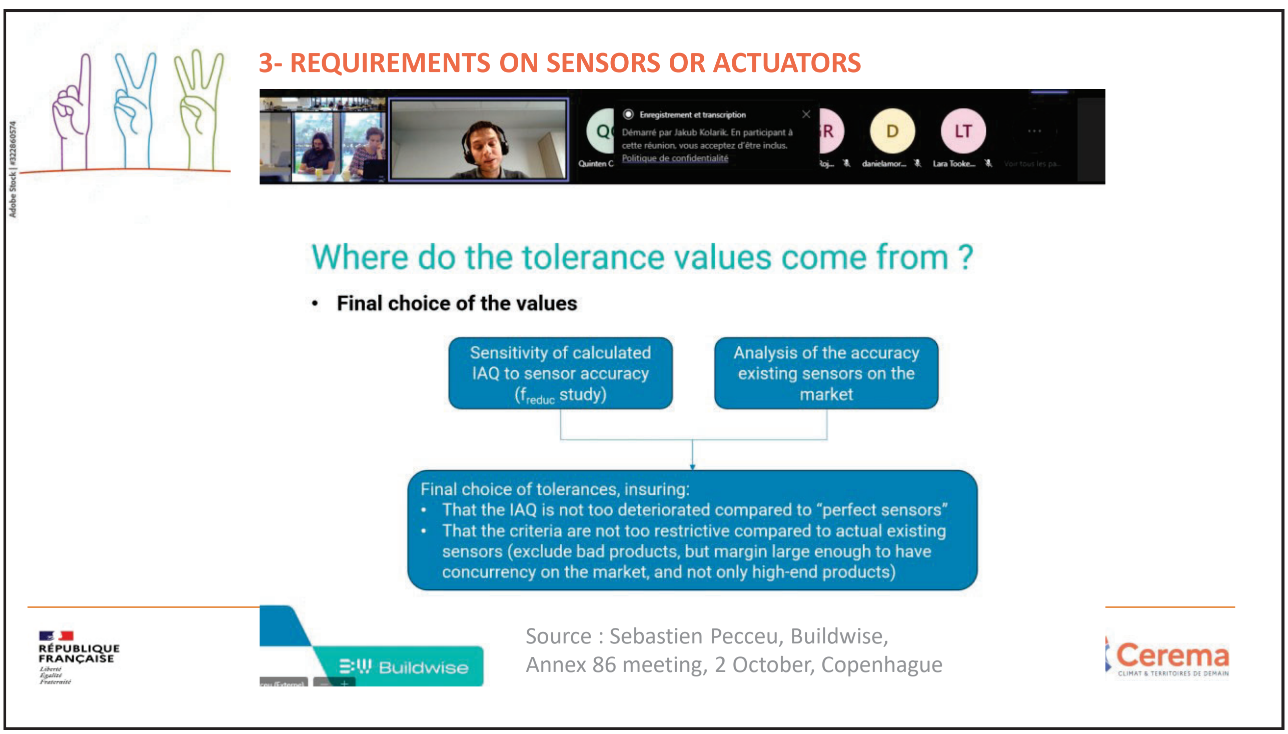
May 2014

RÉPUBLIQUE FRANÇAISE

Cerema


Number of Publication
1
2
3
5
7
15
17
PUBLICATION BY COUNTRY

41


3- REQUIREMENTS ON SENSORS OR ACTUATORS
Where do the tolerance values come from ?
• Final choice of the values
Sensitivity of calculated IAQ to sensor accuracy (f_{reduc} study)
Analysis of the accuracy existing sensors on the market
Final choice of tolerances, insuring:
• That the IAQ is not too deteriorated compared to "perfect sensors"
• That the criteria are not too restrictive compared to actual existing sensors (exclude bad products, but margin large enough to have concurrency on the market, and not only high-end products)
Source : Sebastien Pecceu, Buildwise,
Annex 86 meeting, 2 October, Copenhague

42

DALYing with DALYs

Why *acceptable* IAQ should consider harm

Dr Benjamin Jones
Associate Professor
University of Nottingham
benjamin.jones@nottingham.ac.uk

1

indoor air quality

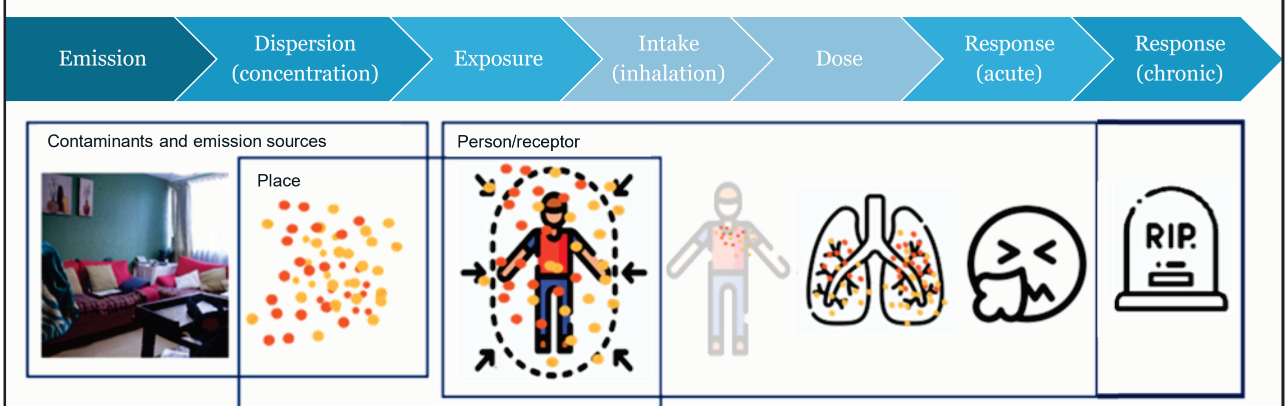
2

2

Acceptable indoor air quality: *air in which there are no known contaminants at harmful concentrations, as determined by cognizant authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.*

3

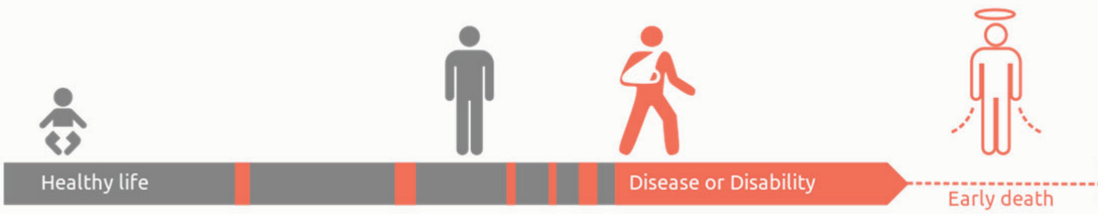
3



4

4

Chronic harm



Metrics Overview: AIVC VIP#36

Ventilation
Information
Paper
n° 36
September 201

© INIVE EEIG
Operating Agent
and Management
Boulevard Poincaré 79
B-1060 Brussels – Belgium
inive@bbri.be - www.inive.org

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] 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.

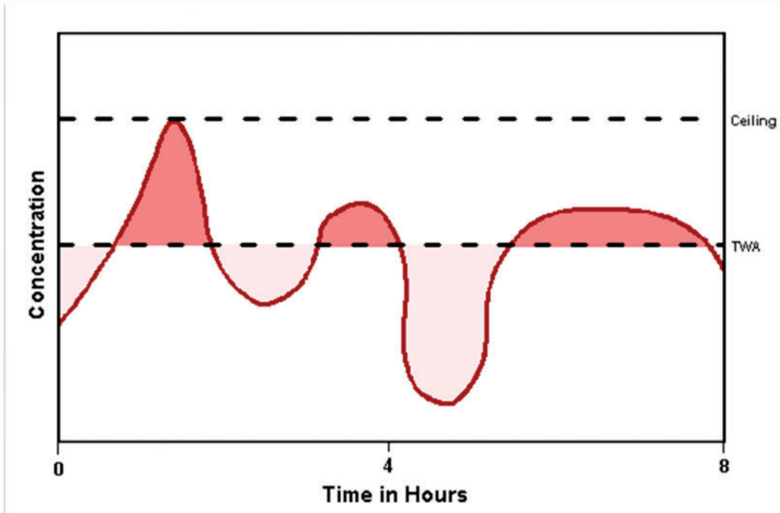
1 Problems

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. Unvented 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.

[3] CfDC. 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.

1

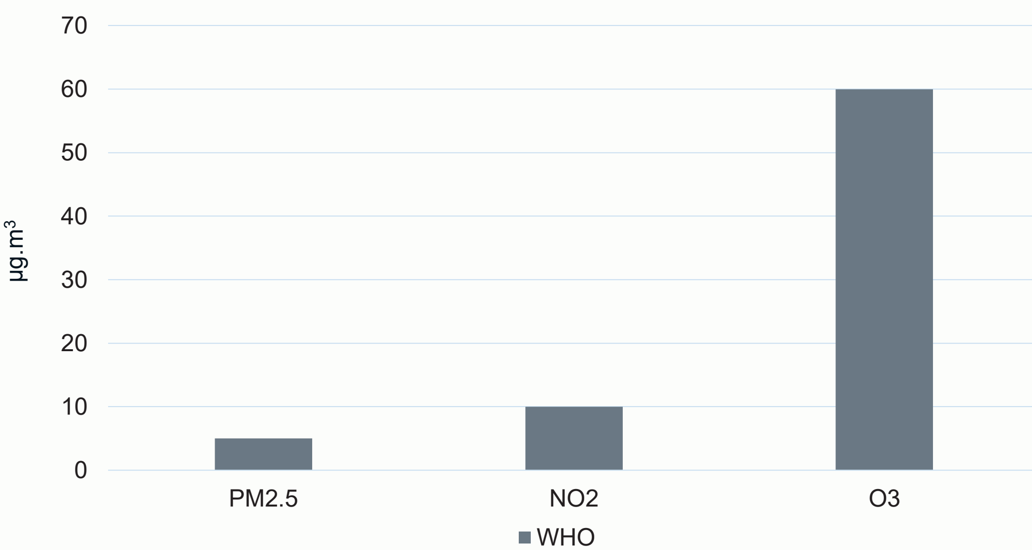
Current acceptability



7

7

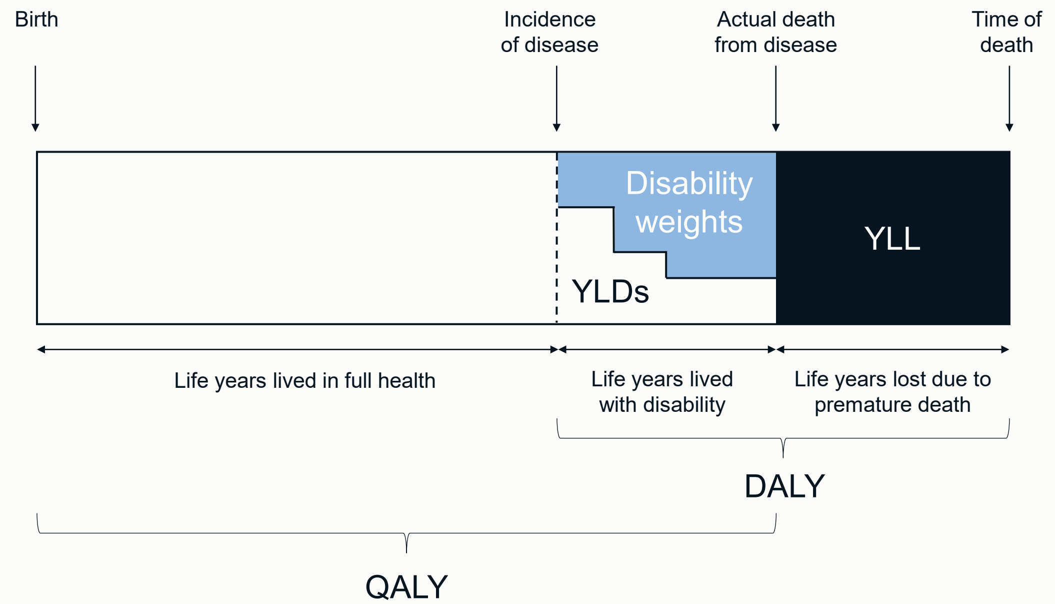
WHO threshold values



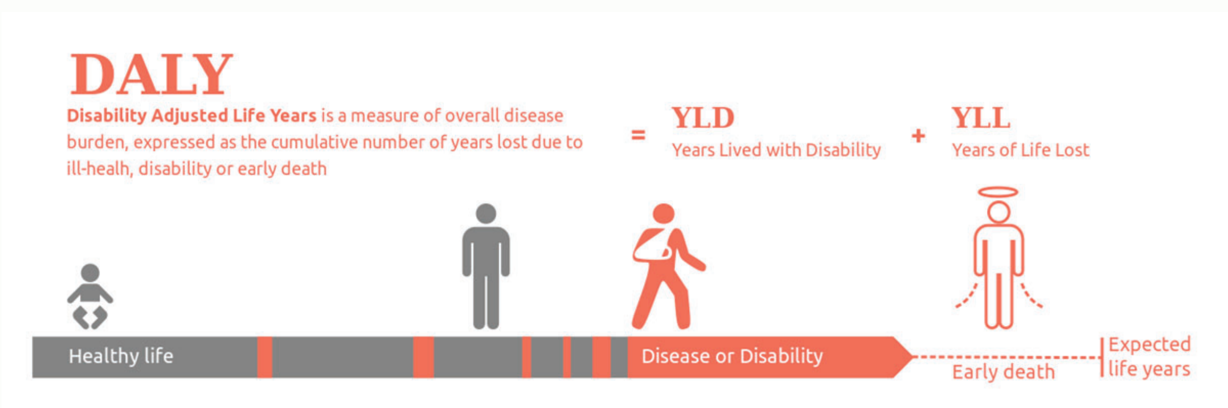
8

8

Health Adjusted Life Years



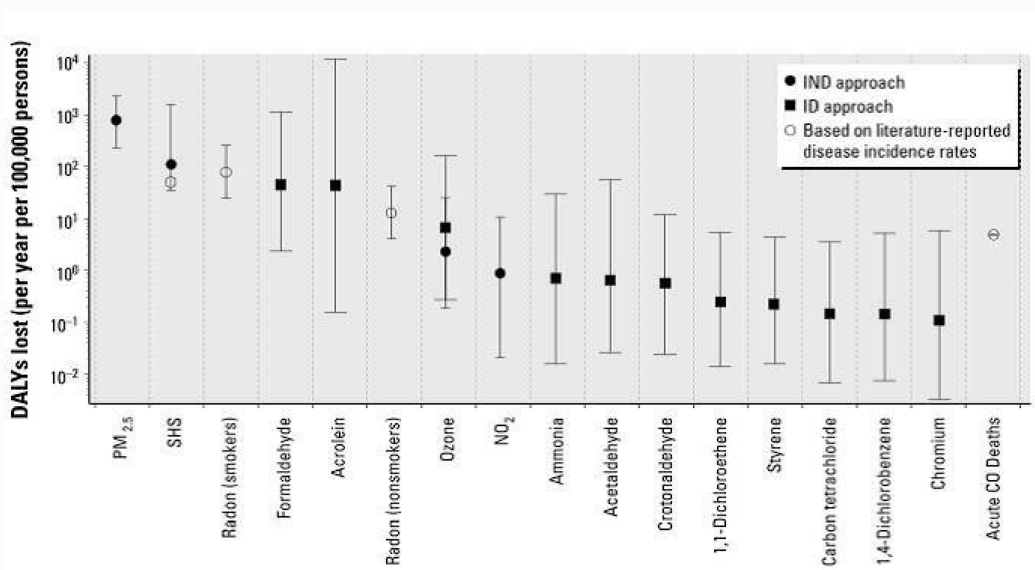
Disability Adjusted Life Years (DALYs)



Acceptable harm? (DALYs)

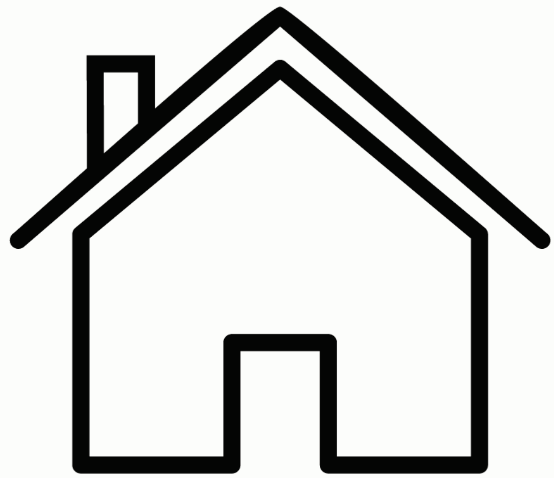
Alcoholism	Smoking	Transport injuries
1,200	2,600	1,000

Previous work

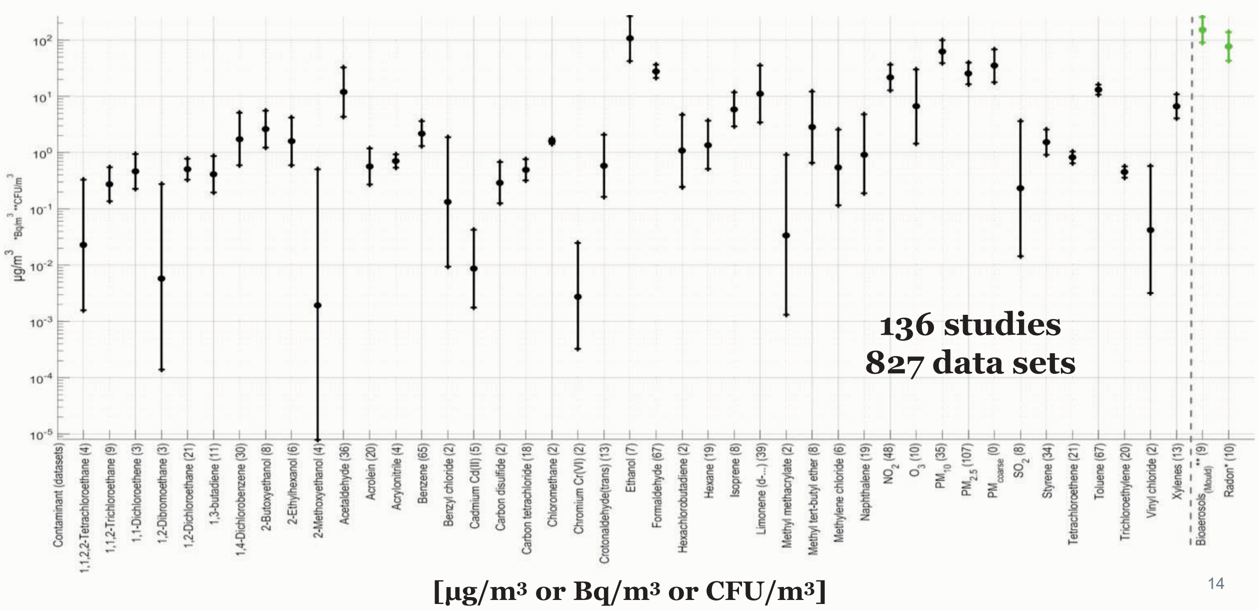


Logue JM, Price PN, Sherman MH, Singer BC. A Method to Estimate the Chronic Health Impact of Air Pollutants in U.S. Residences. Environmental Health Perspectives. 2011;120(2):216-22.

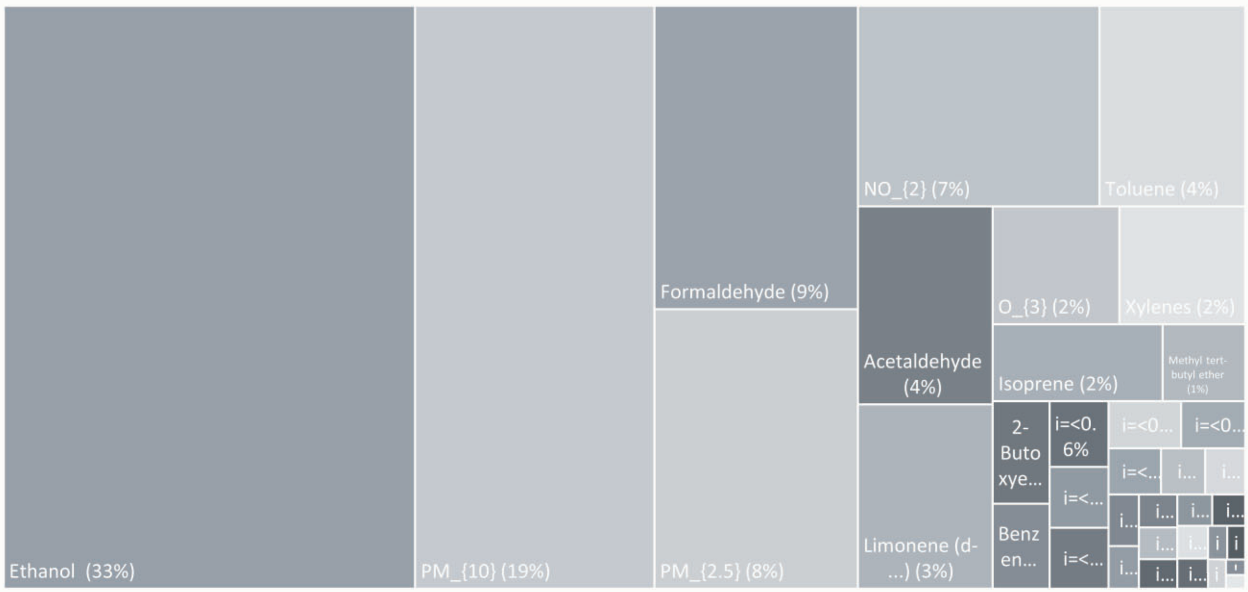
Chronic harm in houses



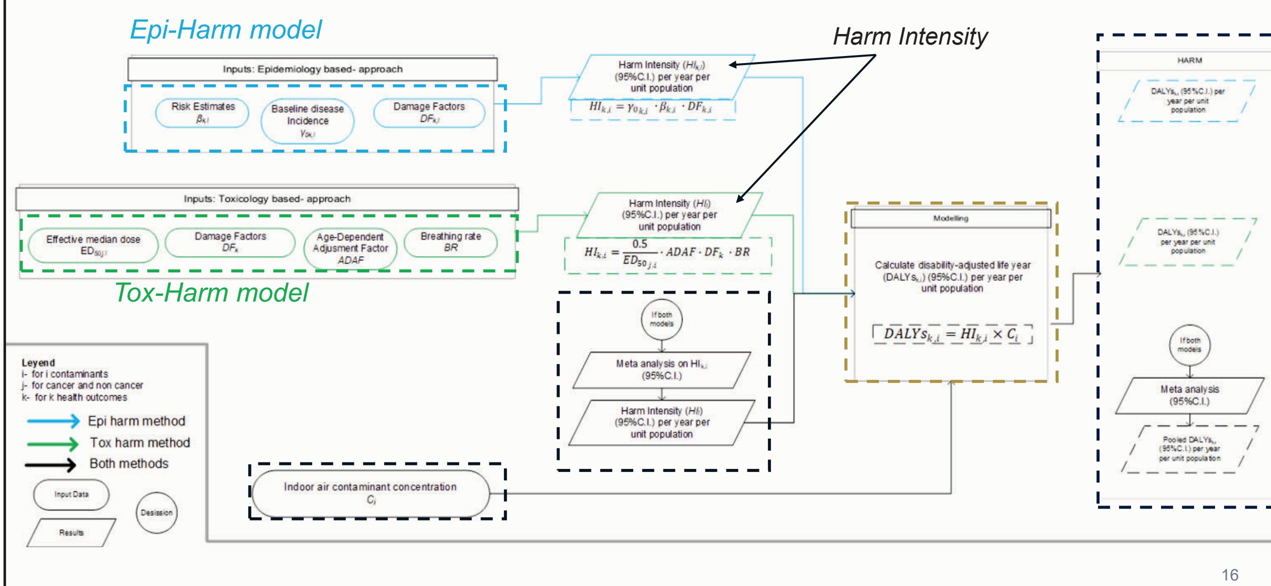
Concentrations



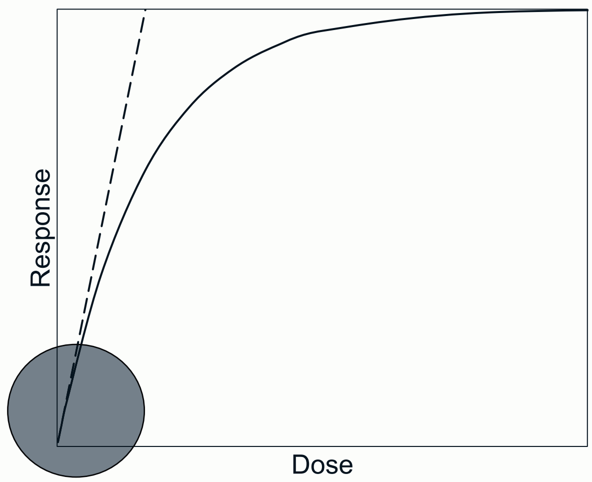
Concentrations



Harm model



Linearity



17

17

$$Harm = C \times HI$$

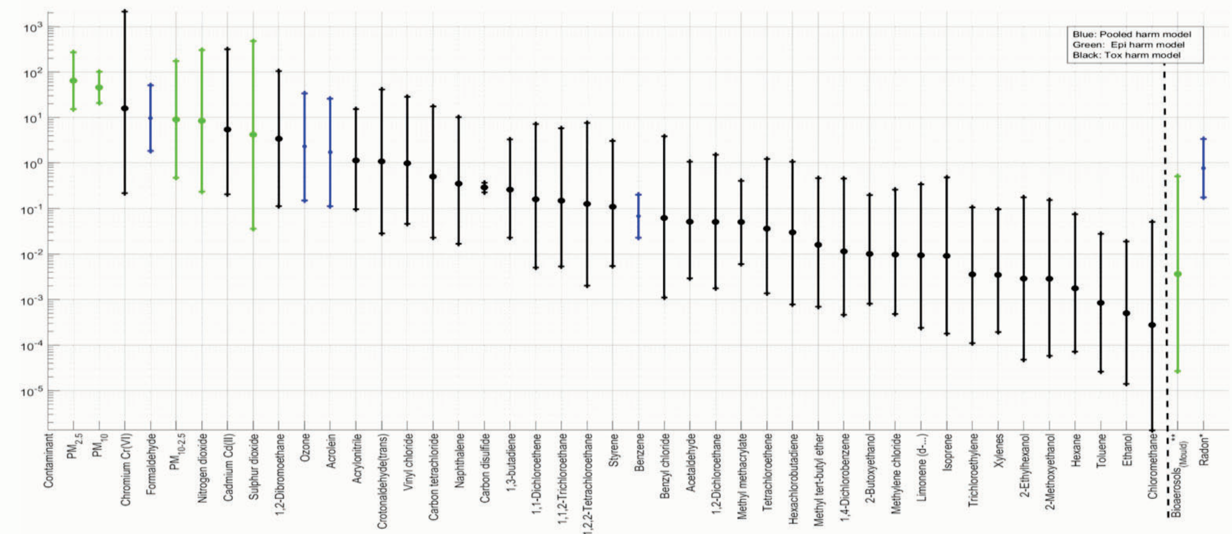
[DALYs/person/year] = [µg/m^3] × [DALYs/µg/m^3/person/year]

(or per Bq/m^3 or per CFU/m^3)

18

18

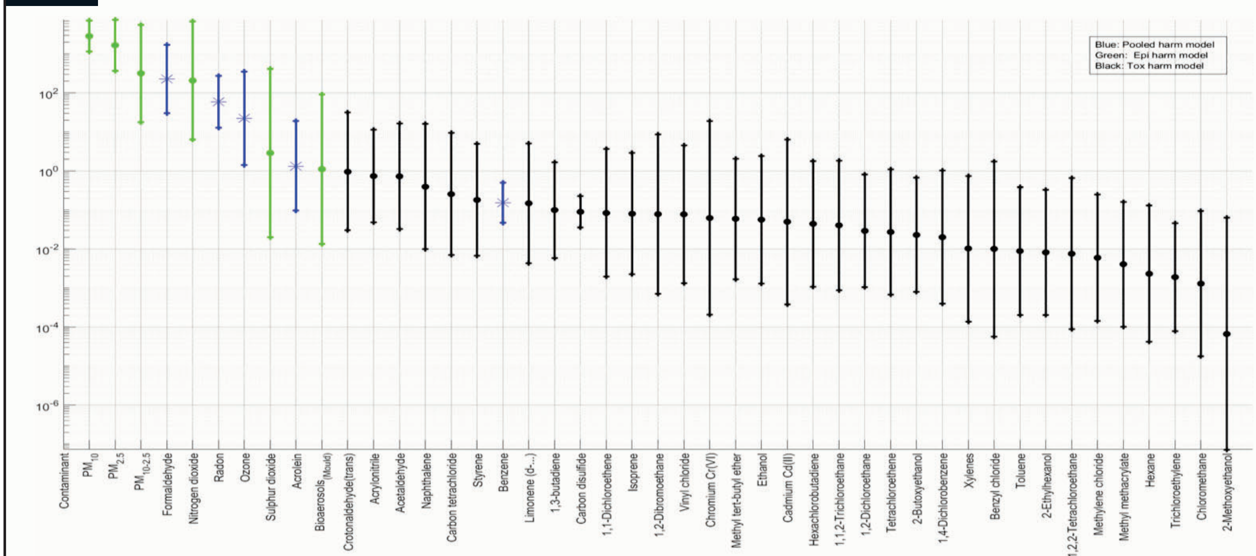
Harm intensity



DALY/(μg/m^3)/10^5 people/year [or per Bq/m^3 or per CFU/m^3]

19

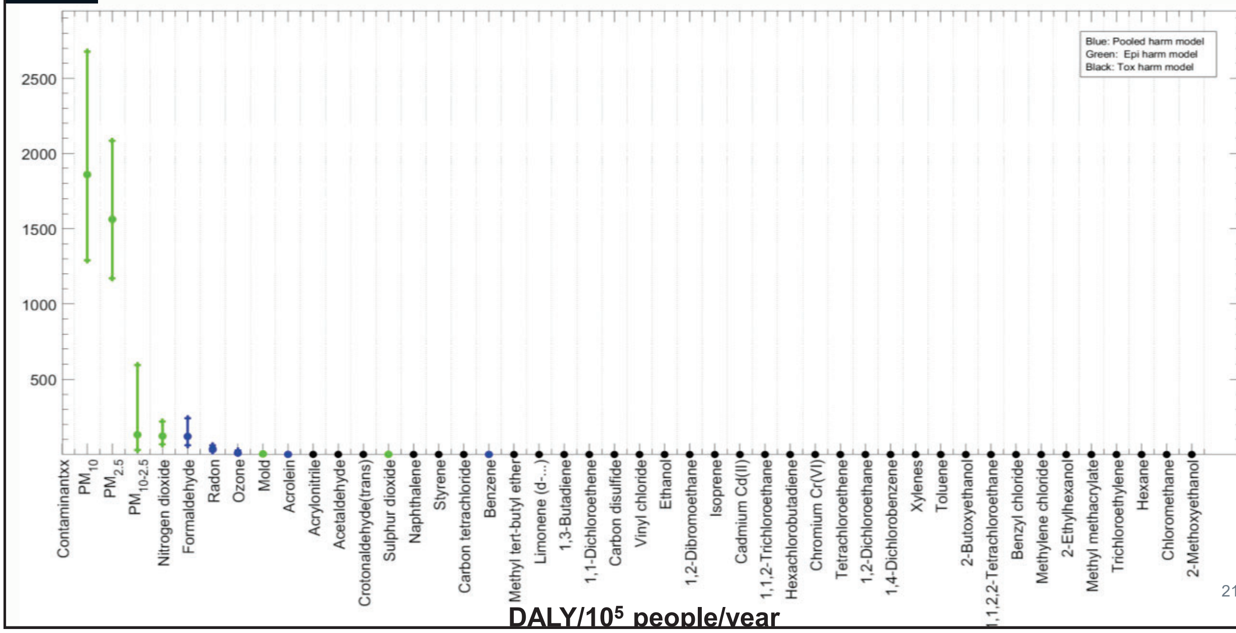
Total harm



DALY/10^5 people/year

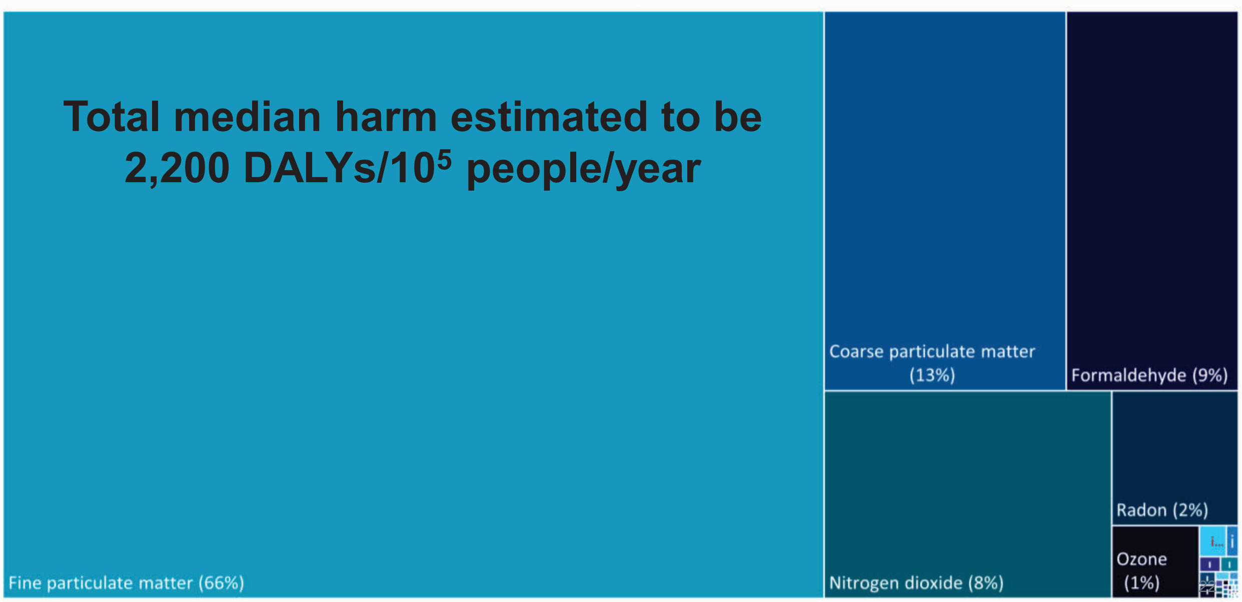
20

Total harm



21

Total harm



22

Total Harm (DALYs)

Dwelling IAQ	Alcoholism	Smoking	Transport injuries
2,200	1,200	2,600	1,000

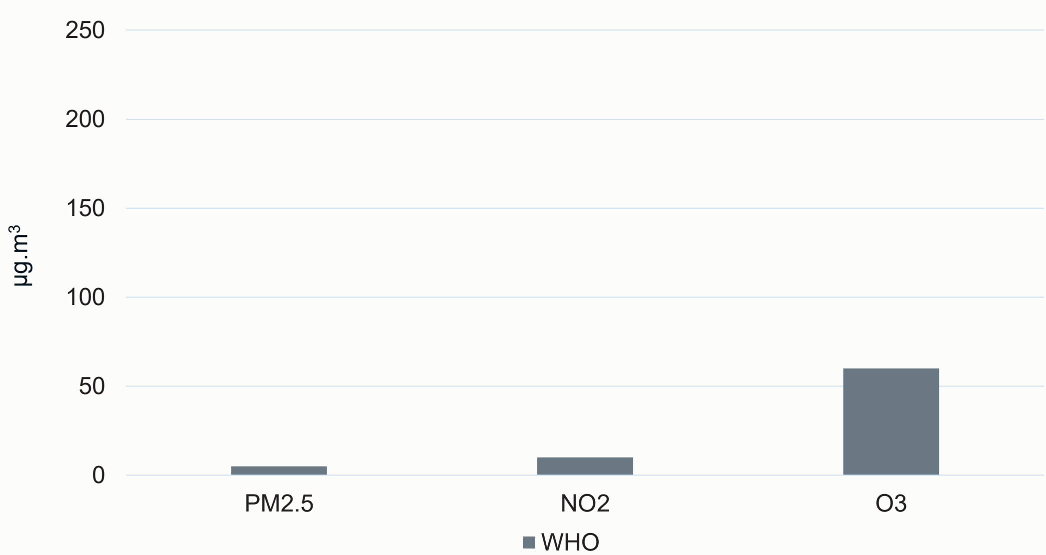
Contaminants of Concern

	Harm (DALYs/10^5 people/year)	Harm Intensity (DALYs/μg.m^{-3}/10^5 people/year)
$PM_{2.5}$	1600	60
$PM_{10-2.5}$	130	3.8
Nitrogen Dioxide (NO_2)	120	5.7
Formaldehyde (HCHO)	120	4.3
Radon (Rn)	34	0.44
Ozone (O_3)	10	1.3

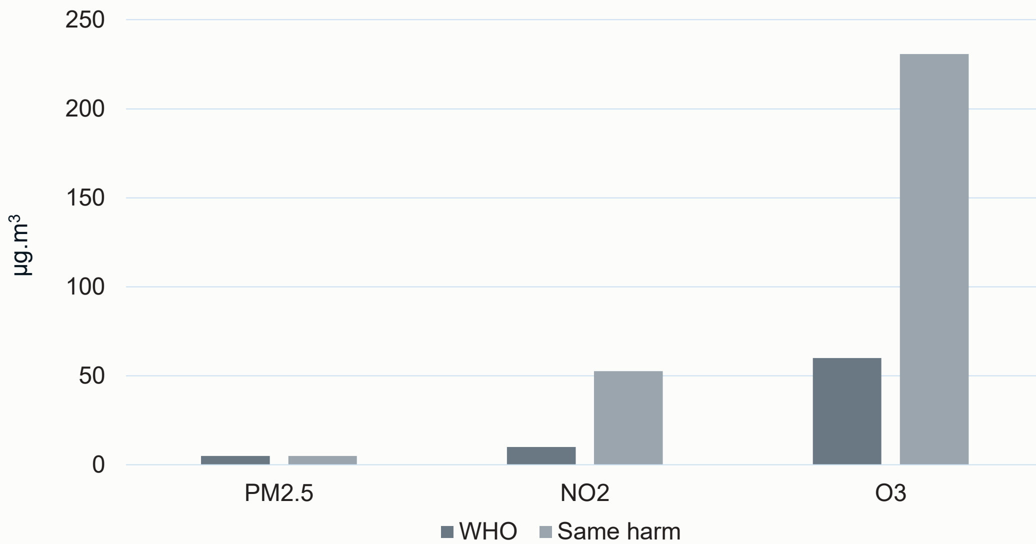
Harm Intensities for CoCs

	Harm Intensity (HI) (DALYs/µg.m^{-3}/10^{5} people/year)	HI Limiting Concentration (µg.m^{-3} or bq.m^{-3})
$PM_{2.5}$	60	50
$PM_{10-2.5}$	3.8	25
Formaldehyde (HCHO)	4.3	50
Nitrogen Dioxide (NO_2)	5.7	240
Ozone (O_3)	1.3	500
Radon (Rn)	0.44	450

Harm from WHO threshold values



Harm from WHO threshold values



27

Harm budget

28

Reference scenario

- Singer *et al.* 2020. Indoor air quality in California homes with code-required mechanical ventilation. Indoor air 30(5).
- N=70
- *All* comply with CalEnergyCode

$PM_{2.5}$	5μg.m^{-3}
HCHO	23μg.m^{-3}
NO_2	9μg.m^{-3}

Guideline values used for Rn (100Bq/m^3) and for O_3 (40μg.m^{-3}).

- Total harm of 610 DALYs/10^5 people/year

29

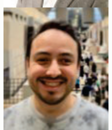
Harm (DALYs)

Reference	Dwelling IAQ	Alcoholism	Smoking	Transport injuries
610	2,200	1,200	2,600	1,000

30

Acknowledgements

Benjamin Jones
University of Nottingham



Giobertti Morantes Quintana
University of Nottingham

Constanza Molina
Pontifical University of Santiago, Chile

Max Sherman
University of Nottingham
& Lawrence Berkeley National Laboratory

University of Nottingham UK | CHINA | MALAYSIA

CIBSE

EBC Energy in Buildings and Communities Programme

IEA Annex 86

AIVC

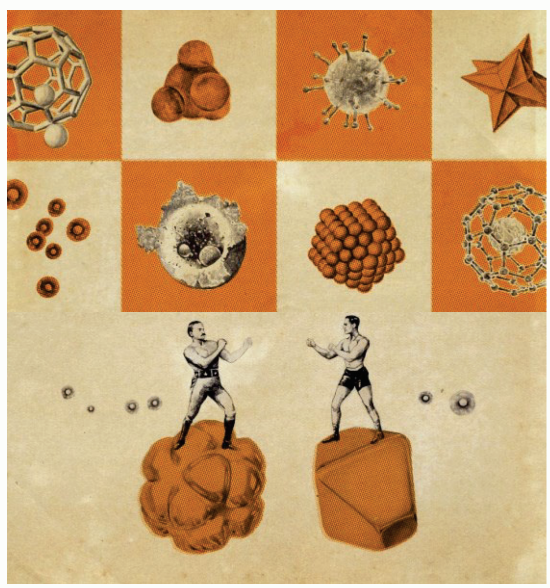
Summary

1. Developed a harm intensity metric that quantifies the chronic health impact (in DALYs) per unit concentration of an air contaminant. **They apply to any environment.**
2. Identified the most harmful indoor air contaminants in dwellings that should be prioritized declaring them *Contaminants of Concern*.
3. Estimated the total harm caused by typical exposures to indoor air contaminants in dwellings.
4. Propose the concept of a ***harm budget*** to define acceptable indoor air quality based on the harm caused by priority contaminants.

Thank you

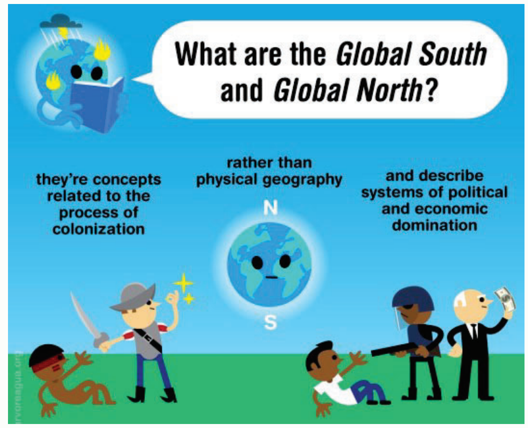
Equitoxicity

- We assume PM equitoxicity
- PM composition does vary
- Separate indoor/outdoor PM risk estimates are unavailable
- PM size predicts long-term harm
- Indoor PM found to be coated in PAHs and other VOCs
- Would have to be 12x less harmful to be equivalent to PM_{10}, HCHO and NO_2
- Precautionary principle



What do these concentrations represent?

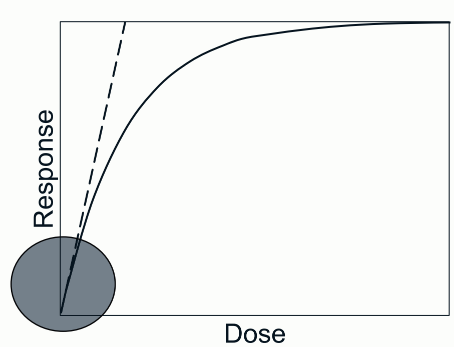
- Indoor concentrations represent the Global North
  (USA, China, Canada, UK most represented)
- Caution needed for regional comparisons due to lifestyle/location differences
- Include common household activities
- Avoid niche construction types
  (e.g. Passivhaus)
- Fieldwork essential to reduce uncertainty



35

Linearity

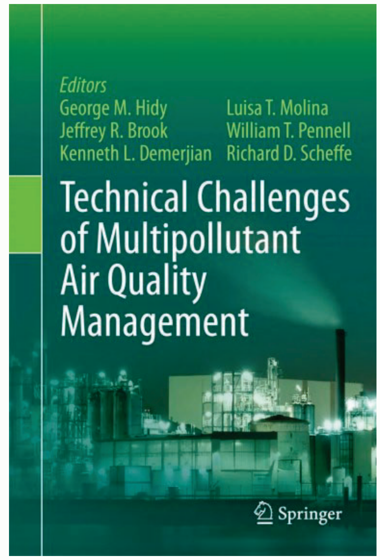
- We don't know if the Poissonian C-R relationship represents these contaminants
- It is good modelling practice to linearise a model, if possible
- It is possible ***here*** because the concentrations commonly found in dwellings are low enough
- Harm Intensities might be given with upper concentration limits
- We have done an error analysis and this will be in the Annex 86 report



36

Synergistic responses

- We do not do this
- It is not possible to do
- Assumes additivity for indoor pollutant effects.
- Additivity simplifies complex interactions, may underestimate/overestimate impacts.
- Future research should explore pollutant interactions for accuracy.



37

What about acute effects?

- This data is for chronic harm
- Some contaminants may have significant short-term acute impacts
- Estimate acute harm is a future project

38

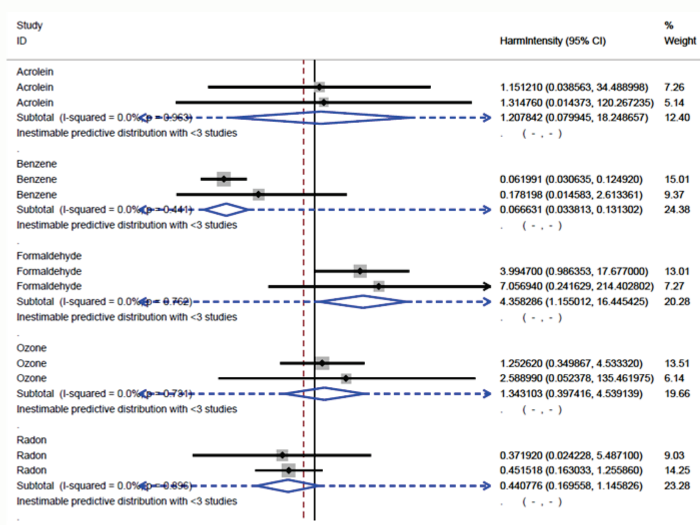
Where does the health data come from?

- Toxicological
  - USEtox 2.0
  - Global burden of disease collaborative network for damage factors
  - Standard breathing rate

- Epidemiological
  - Global burden of disease collaborative network (incidence rates, damage factors))
  - Academic literature (for risk estimates)

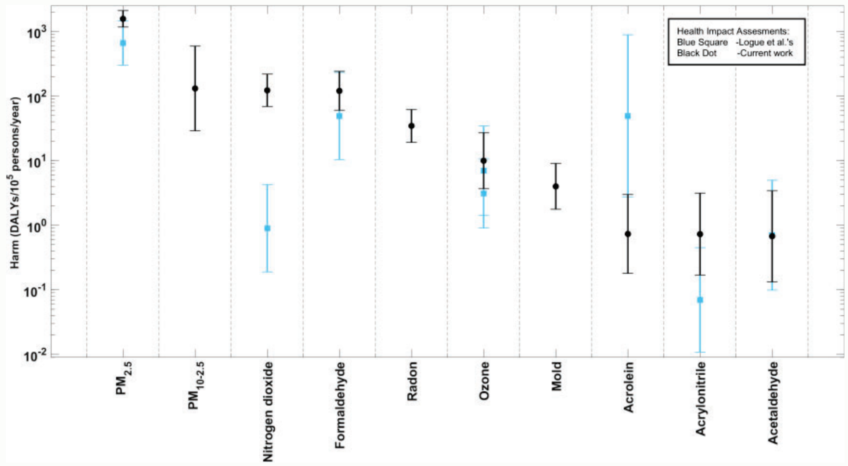
Merging of epi and tox data

- Central estimates may not align due to methodological differences
- Perfect parity is challenging
- Despite challenges, parameters align



Differences from Logue

- Damage factors from 2019 Global Burden of Disease study.
- Consulted toxicology studies with lower uncertainty
- Health data, like PM2.5, became more robust and precise



My favourite contaminant isn't on the list ☹

There is either

- insufficient data to determine a harm intensity

OR

- It isn't harmful in the concentrations found in dwellings

People aren't harmed by the contaminant they aren't exposed to….

Human exposure against airborne pathogens in an office environment

Risto Kosonen, Sami Lestinen and Simo Kilpeläinen

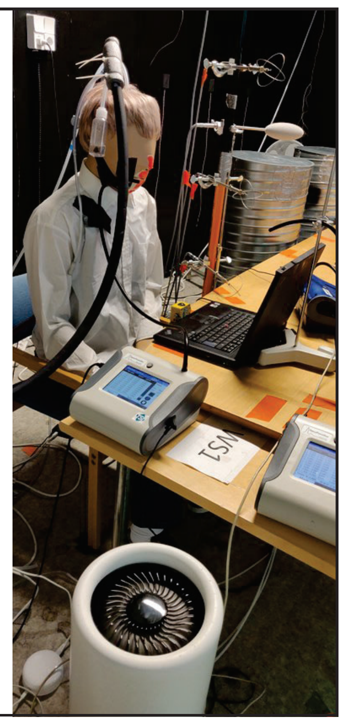
Aalto University, School of Engineering, Department of Mechanical Engineering, Espoo, Finland

Aalto University
School of Engineering

1

Motivation

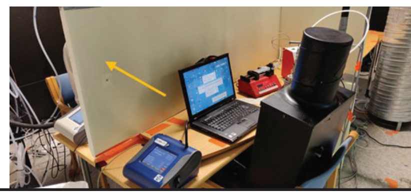
- **Exposure to airborne pathogens** is considerable risk in office environments.
- During **COVID-19 pandemic**, the office workers have been instructed to maintain safety distance, hand hygiene and face masks.
- **Face masks** might worsen working performance and thinking (breathing resistance, CO_2 rebreathing and decreasing O_2).
- **Alternative or additional protection methods** are necessary.
- **Remotely working** may not be possible all the time.

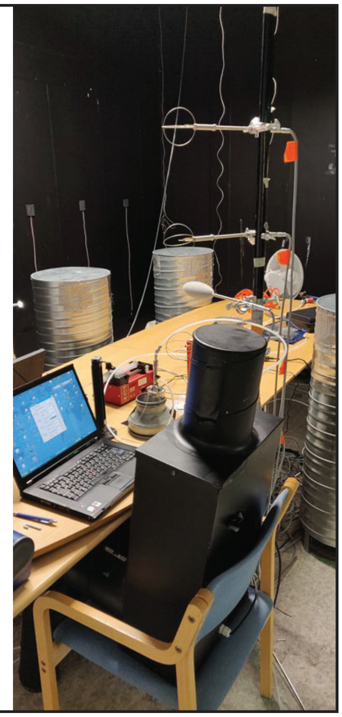


2

Objectives

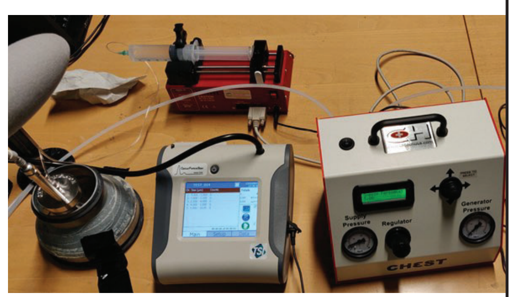
- **Investigating** aerosol transmission with different protection methods (sick-healthy, opposite places, distance 1.2 m).
- **Understanding** potential of each protection method.
- **Comparing** filtering and structural protection methods.
- **Providing** new knowledge for occupational health and safety purposes.

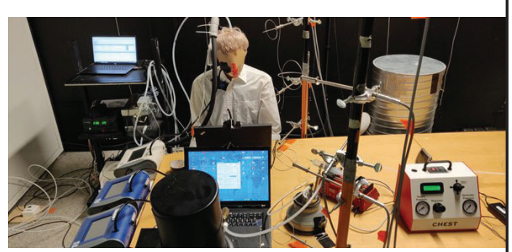




Methods – infected thermal dummy

- **Exhalation simulator** was used as an infection source.
- **Exhalator** was built by combining the exhalation simulator and a thermal dummy.
- **Exhaling** was set at 6 L/min (continuous)
- **Paraffin oil** was aerosolized in the Blaustein atomizer (0.6 mL/h, syringe pump).
- **Aerosol distribution** near source had similarities with earlier studies*

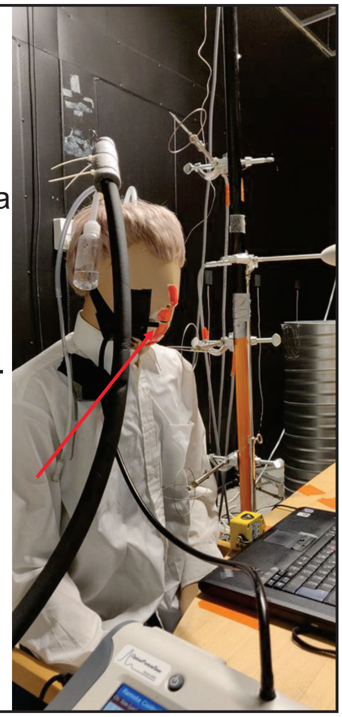




*Morawska et al. 2009. Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities. Journal of aerosol science, 40(3), 256-269.
*Johnson et al. 2011. Modality of human expired aerosol size distributions [Article]. Journal of aerosol science, 42(12), 839-851.

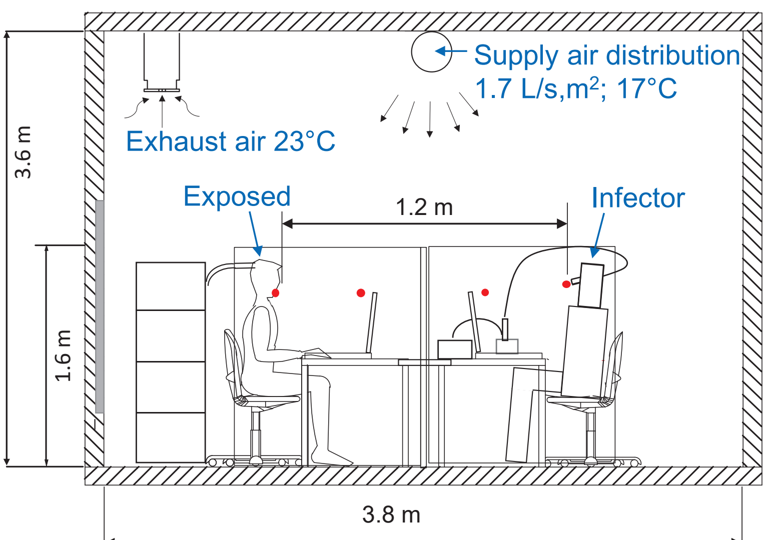
Methods – exposed thermal manikin

- Seated **breathing thermal manikin**.
- Body segments were heated under **'comfort mode'** where a target temperature in each segment was constant.
- Breathing was set at **6 L/min**.
- Breathing cycle: **2.5 s** (in) **1 s** (break) **2.5 s** (out) **1 s** (break).
- Exhalation air temperature was set at **35°C**.
- Relative humidity of exhaled airflow was **85%**.
- Exhalation nose jets were directed **45°** downwards.
- Concentration measurement was **2 cm** beside the mouth.

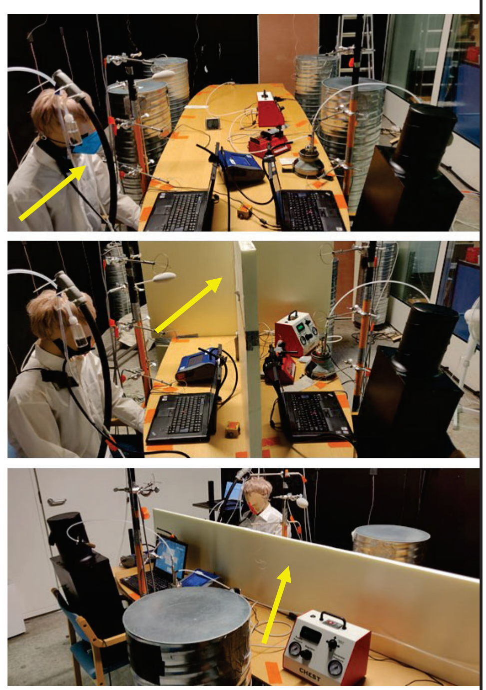


5

Side-view of test chamber

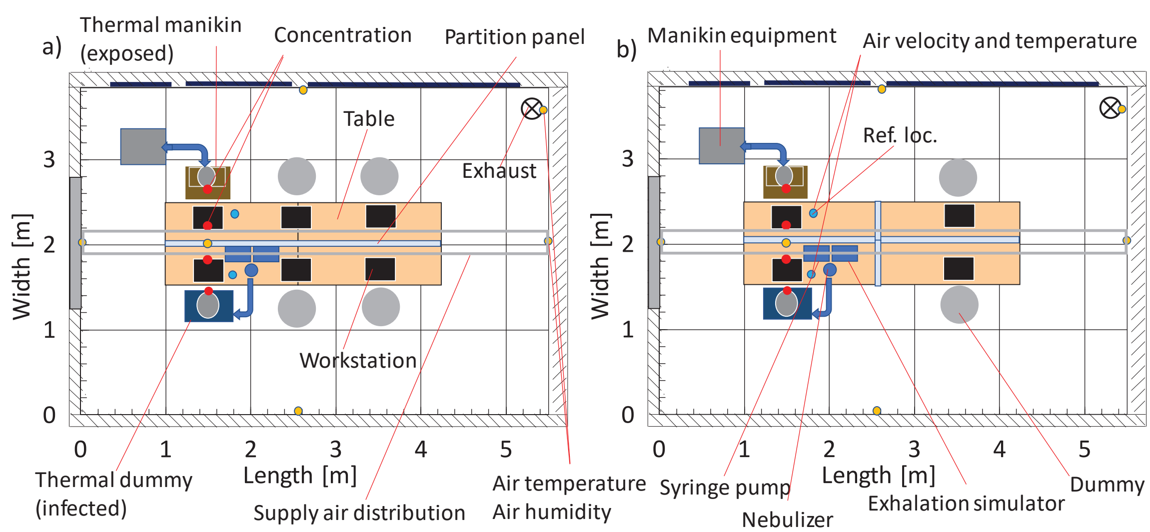


- Heat gain 12.5 W/m^2



6

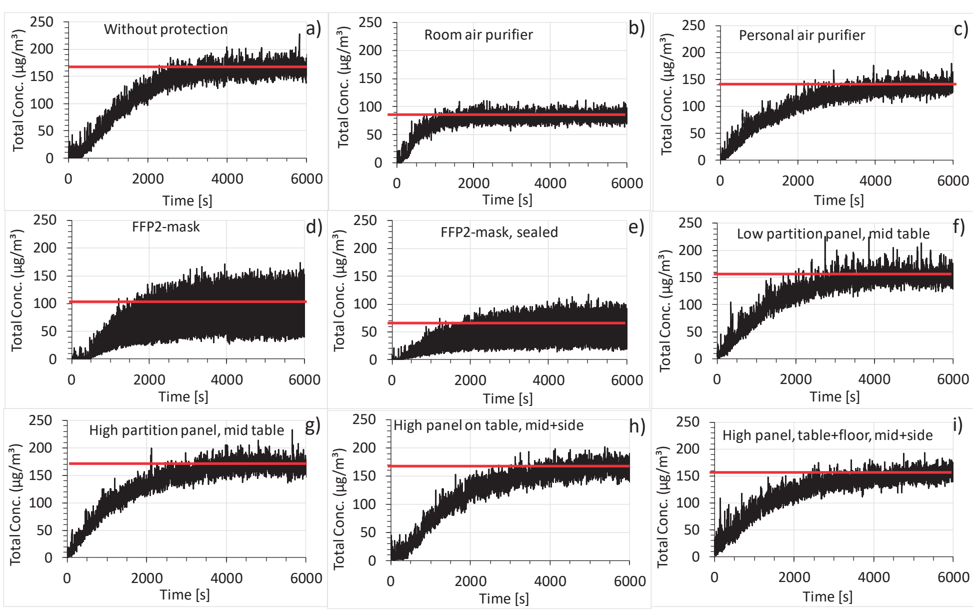
Top-view of test chamber



a) Meeting setup b) Workstation setup

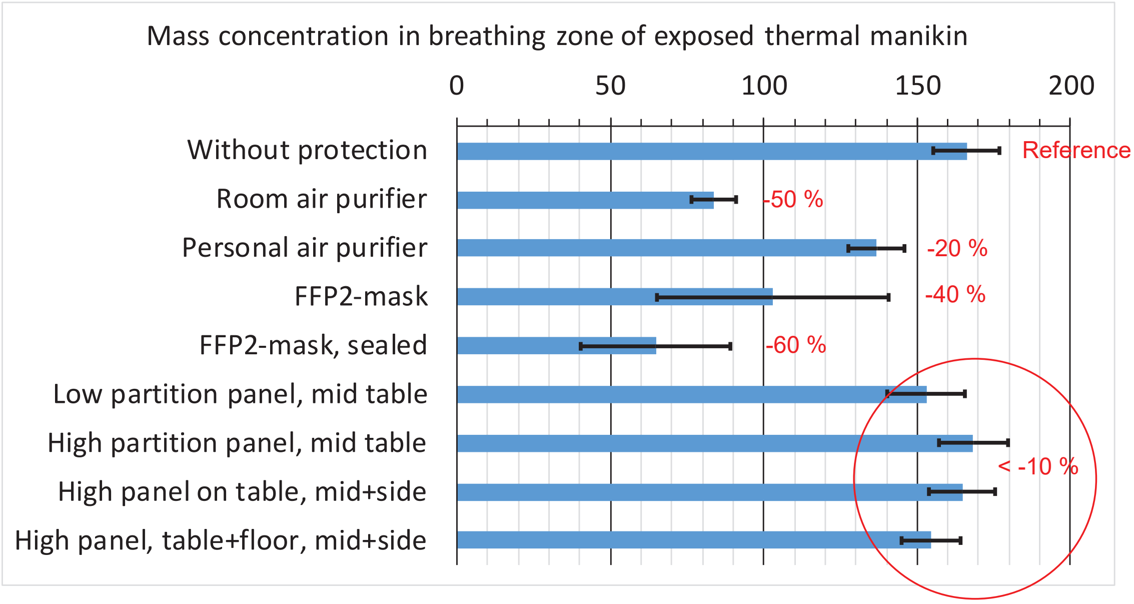
7

Results – temporal concentration characteristics



8

Results – averaged concentration at steady conditions (1000 values)



Conclusions

- Room air purifier reduced the average concentration level by **50%**.
- Personal air purifier reduced the average by **20%**.
- FFP2-mask had **40%** decrease on the concentration.
- Partition panels had **negligible** effects on the concentration.
- Room air purifier and FFP2-masks seem effective against exhaled aerosols in well-mixed conditions.

Workshop: Airborne cross infection and engineering solutions

Discussion on minimum ventilation rates for infection control

Yuguo Li 李玉國
Department of Mechanical Engineering, and
Faculty of Architecture
The University of Hong Kong

Thank you

Mr hard-working and smart students/post-docs (since 2003), and collaborators

HKU Mech Eng: Zhang Nan, Wang Qun, Cheng Pan, Jia Wei, Edwin Dung, Jack Chan, Zhao Pengcheng, Li Ao and many others

Former team: Qian Hua, Hang Jian and Xiao Shenglan, Liu Li, Wei Jianjian and Lei Hao

HKU/CUHK Medicine: Hui-Ling Yen, Ben Cowling, Gabriel Leung, Malik Peiris, KY Yuen, Vincent Cheng, David Lung, David Hui

CDCs: Kang Min, Ding Zhen, Hu Shixiong and many colleagues

HKSAR: Kenneth Leung, Lin Zhang, Niu Jianlei, Jimmy Fung and Alexis Lau

To RGC, HMRF, NSFC, HKU and WHO for supporting us in studying environment control of infection since 2003.

Two questions

Nature of dilution, and relationship with exposure/infection

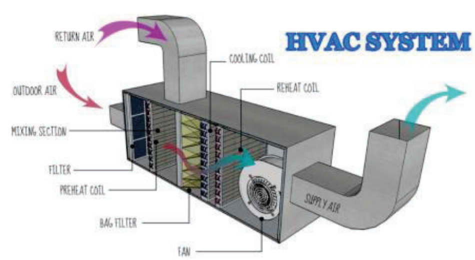
Q1: Why infection need a different standard?

Risk assessment, heterogeneity, technologies

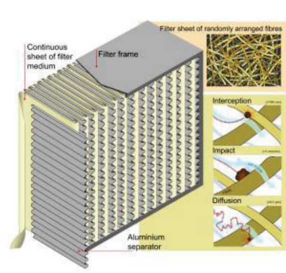
Q2: What are suitable criteria for the required dilution?

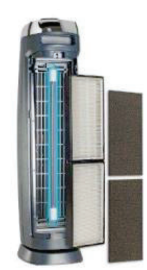
Infectious aerosols (IEs) differ from CO_2 and PM2·5

- *One Emission*
  - Everyone exhales CO_2, and multiple sources for PM2.5, but **only one individual exhales IEs in most settings**
  - IEs are only emitted when source person is present.
- *Removal by quadruplet* 四胞胎
  - CO_2 by ventilation q_v and absorption/adsorption
  - PM2.5 also by settling q_s and filtration $\eta_f q_f$, but not absorption/adsorption
  - IEs also by deactivation q_r



Internet images





We have quadruplets of clean air 洁净空气四胞胎

$$q_c = q_v + q_s + q_r + \eta_f q_f = \sum_{j=1}^{4} q_{cj}$$

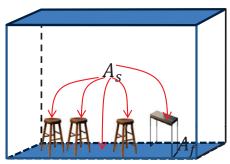
Internet image

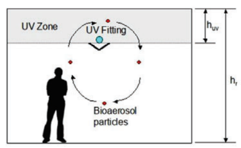
Clean air

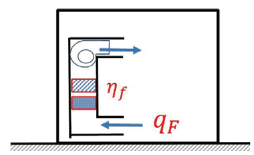
Quadruplets
四胞胎

Outdoor air Ventilation q_v	Indoor settling q_s	Deactivation q_r	Filtration $\eta_f q_f$

Inter-room air flows can also introduce "clean air" for infectious aerosols in multi-zone spaces







Noakes et al

Examples: six outbreak venues

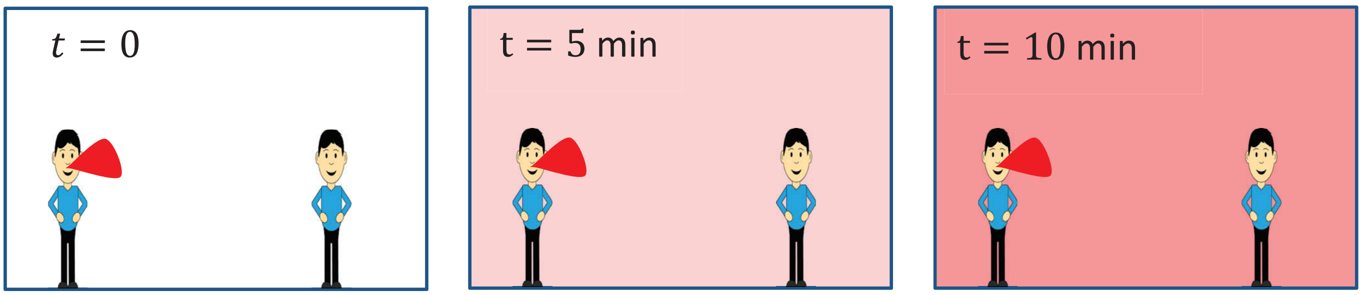
- Spacious space (courtroom and church hall): significant contribution from natural decay and settling.
- Crowed space (bus 1, 2):negligible contribution from natural decay and settling

	Parameters	courtroom	church hall	bus 1	bus 2	restaurant 1	restaurant2
outbreak and venue	attack rate (%)	33.3	86.7	15.2	11.8	10.2	28.9
	no. of susceptible	9	60	46	17	88	76
	exposure time (min)	180	150	200	60	72.4	57
	air volume per person (m^3)	**16.7**	**13.5**	**1.3**	**1.3**	4.9	5.2
air flow rate (L/s per person)	**ventilation**	1.8	2.6	1.8	3.4	0.9	1.7
	filtration	0.0	0.0	0.0	0.0	5.5	0.0
	deactivation	2.9	2.4	0.2	0.2	0.9	0.9
	settling	1.4	1.1	0.1	0.1	0.4	0.4
	clean-air flow rate	6.1	6.1	2.1	3.7	7.7	3.1

Clean-air still does not fully characterize the room air dilution ability

Li et al. Threshold dilution of airborne infection in buildings. To be submitted

Spaciousness means dilution

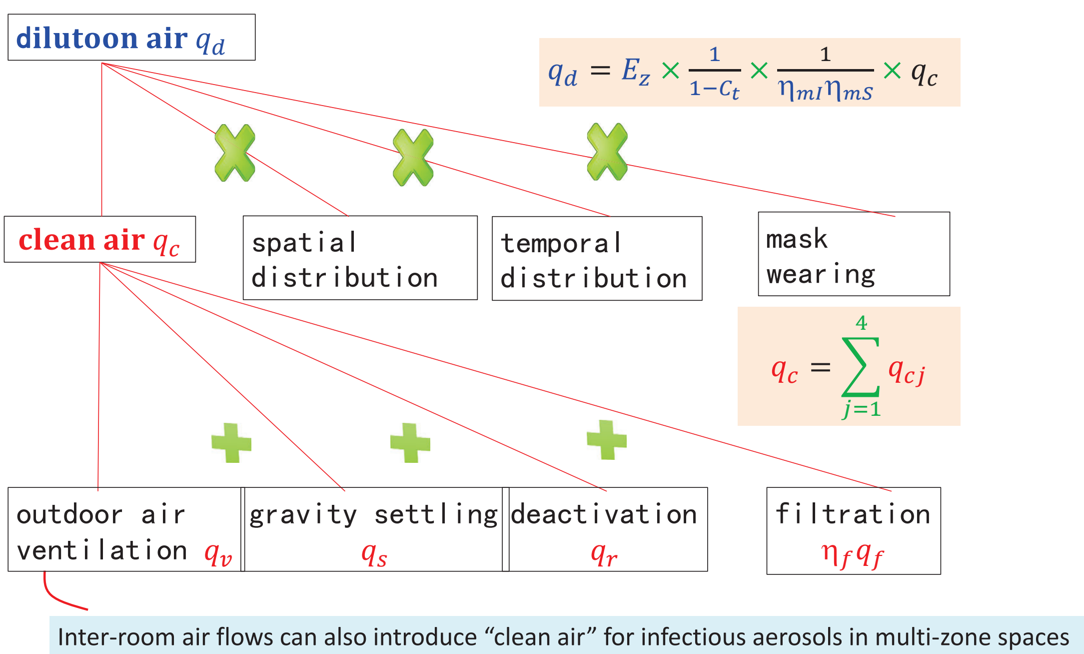


Li et al. Threshold dilution of airborne infection in buildings. To be submitted

Quadruplets of clean air + triplets of non- q_c factors

triplets of non- q_c factors
三胞胎

quadruplets of clean air
四胞胎



Internet images

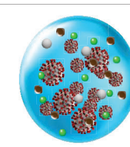
Dilution-air flow rate should be determined in outbreak investigations

- Spaciousness can introduce significant dilution ability
- A crowded space with 1.5 m^3/p introduces negligible dilution

	Parameters	courtroom	church hall	bus 1	bus 2	restaurant 1	restaurant2
outbreak and venue	attack rate (%)	33.3	86.7	15.2	11.8	10.2	28.9
	no. of susceptible	9	60	46	17	88	76
	exposure time (min)	180	150	200	60	72.4	57
	air volume per person (m^3)	**16.7**	**13.5**	**1.3**	**1.3**	4.9	5.2
air flow rate (L/s per person)	ventilation	1.8	2.6	1.8	3.4	0.9	1.7
	filtration	0.0	0.0	0.0	0.0	5.5	0.0
	deactivation	2.9	2.4	0.2	0.2	0.9	0.9
	settling	1.4	1.1	0.1	0.1	0.4	0.4
	clean-air flow rate	6.1	6.1	2.1	3.7	7.7	3.1
	dilution air per person	8.1	8.1	2.2	4.1	9.0	5.4

Li et al. Threshold dilution of airborne infection in buildings. To be submitted

A generalized Wells-Riley equation: individual heterogeneity, spatial non-uniformity, temporal variation, and multi-virion aerosols



$$\bar{p}_i = \frac{1}{N_\sigma}\sum_{i=1}^{N_\sigma}\left(1 - e^{-\sum_{n=1}^{\infty}[1-(1-r_i)^n]\int_{t_{1,i}}^{t_{2,i}} q_{in,i}(t)\sum_{j=1}^{J} c_{D,j}(\boldsymbol{x},t)\frac{\lambda_j^n e^{-\lambda_j}}{n!}dt}\right)$$

$$\bar{c}_{D,j} = \frac{1}{q_{d,j}}\sum_{k=1}^{N_I} L_{D,j,k}$$

$$\frac{N_\iota}{N_\sigma} = 1 - e^{-\frac{N_I Q}{q_D}\bar{q}_{in}\overline{\Delta t}}$$

Achieved (effective) dilution-air flow rate $q_{d,a}$

$$q_{d,a} = \frac{q_D}{N_\sigma} = \frac{E_z q_c}{1 - C_t}$$

$$C_t = \frac{1 - e^{-n\Delta t}}{n\Delta t}$$

N_σ , $\overline{\Delta t}$ human behavior
$\bar{q}_{in}$ physiology
Q virology
N_ι epidemiology
q_D building environment

Jia W. et al. (2022). Individual heterogeneity and airborne infection: Effect of non-uniform air distribution. Building and Environment, 226, 109674.
Li et al. A generalized Wells-Riley equation for multi-virion aerosols. To be submitted

Dilution air is a unified concept for removal of infectious aerosols

- Steady and uniform Wells-Riley equation can be used. $p_i = \frac{N_\iota}{N_\sigma} = 1 - e^{-\frac{N_I Q}{q_D}\bar{q}_{in}\bar{\Delta}t}$
- With **an acceptable risk level (threshold),** the threshold dilution q_D or q_d can be determined if quantum emission is known.

How to determine the infectious quantum emission of the population?

Two questions

Nature of dilution, and relationship with exposure/infection

Q1: Why infection need a different standard?

Risk assessment, heterogeneity, technologies

Q2: What are suitable criteria for the required dilution?

What risk?

- no infection (everyone in a room is safe),
- no epidemic (someone might be infected, but most people are safe),
- no pandemic?

Should different settings differ in dilution requirement？

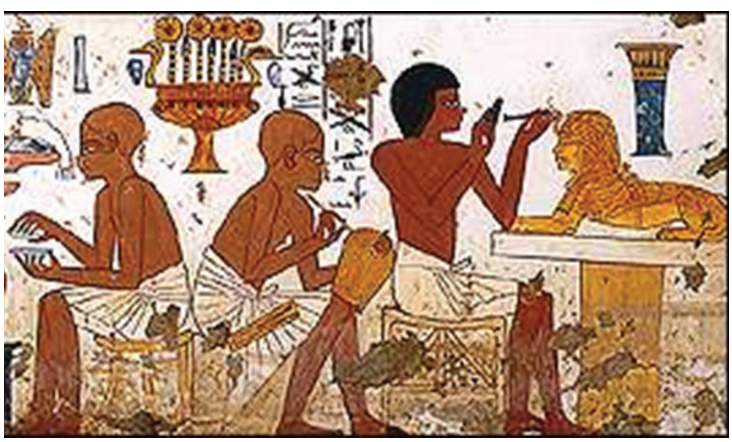
43rd AIVC conference, 4-5 October 2023, Copenhagen
WS: Airborne cross infection and engineering solutions

Mitigation of airborne transmission of respiratory viruses by ventilation - past, present and future

Arsen K. Melikov
ISIAQ Fellow, ASHRAE Fellow, Life member

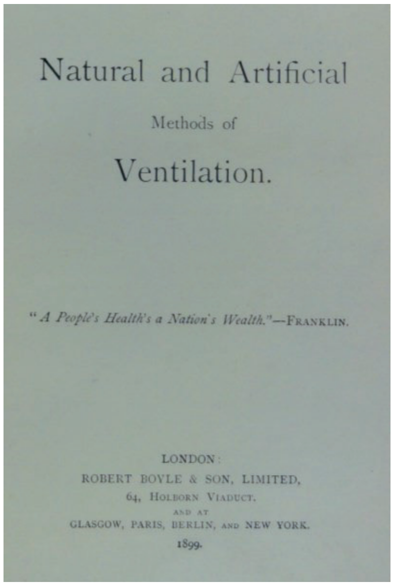
International Centre for Indoor Environment and Energy, DTU Sustain, Technical University of Denmark
akme@dtu.dk

Ventilation and Airborne Transmission: In the Past



Ancient Egyptians used natural ventilation to remove dust and to reduce respiratory diseases of stone carvers working indoors.

Ventilation and Airborne Transmission: In the Past



Natural and Artificial

Methods of

Ventilation.

"A People's Health's a Nation's Wealth."—FRANKLIN.

LONDON:
ROBERT BOYLE & SON, LIMITED,
64, HOLBORN VIADUCT,
AND AT
GLASGOW, PARIS, BERLIN, AND NEW YORK.
1899.

Chapter X.

How Infection is Spread

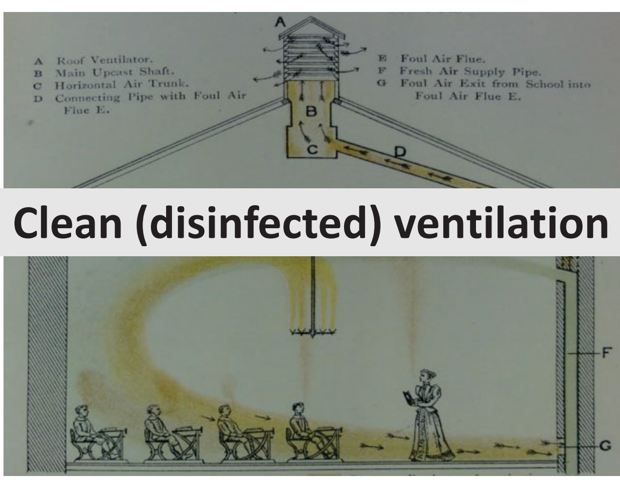
"The report on the influenza epidemic presented to Parliament by the Local Government Board indicates the extreme importance of **proper ventilation** – especially in schools – which is pronounced to be **the only real safeguard against that disease**."

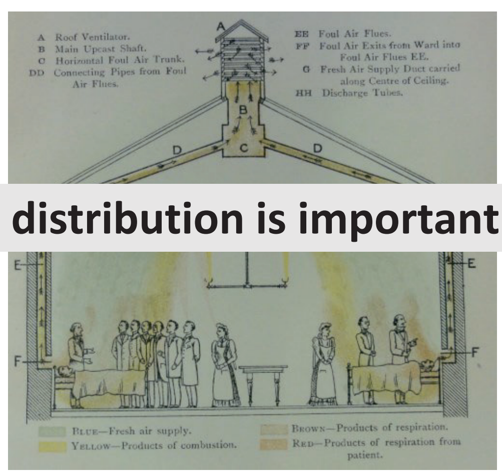
3

Ventilation and Airborne Transmission: In the Past

Book: Natural and Artificial Methods of Ventilation

Robert Boyle & Son Limited, London 1899





Clean (disinfected) ventilation air distribution is important!

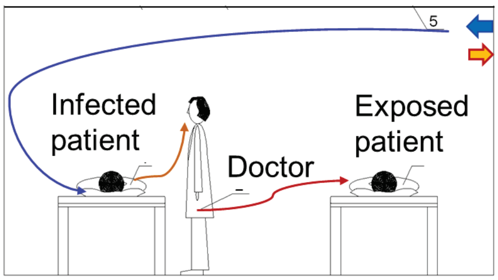
4

Ventilation and Airborne Transmission: At Present

REHVA & ASHRAE guidelines: Increase ventilation rate!

↳ May generate directional flow and may increase transmission!

➢ *Bolashikov, Melikov et al. 2012, HVAC&R Res.; Pantelic & Tham, 2013, HVAC&R Res.,*



Air distribution:

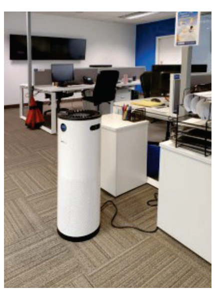
- **reduces** concentration of infectious agents and
- **spreads** infectious agents

Increase of ventilation rate leads to problems:

- Expensive: rebuilding of existing systems/huge new systems
- High velocities: draught, resuspension of particles/viruses
- Energy consumption is increased

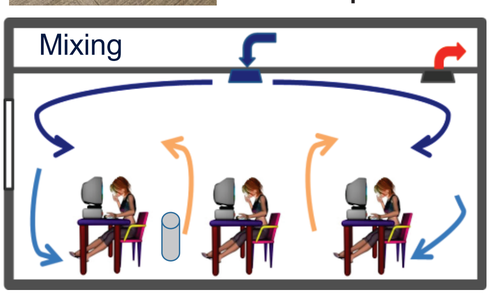
5

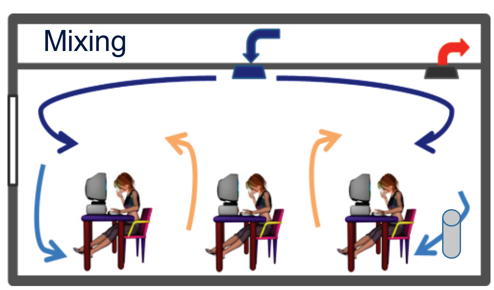
Reduction of Airborne Transmission by Air Cleaners



Performance of air cleaners depends:

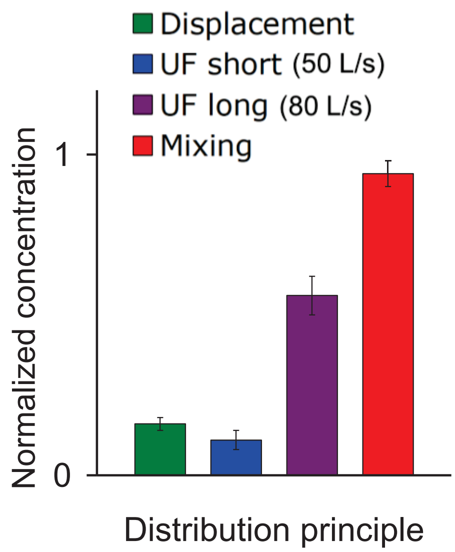
- Design of air cleaner
- Capacity of air cleaner & generated flow
- Positioning in space
- Background air distribution
- Location of infected occupant
- Occupants' activity



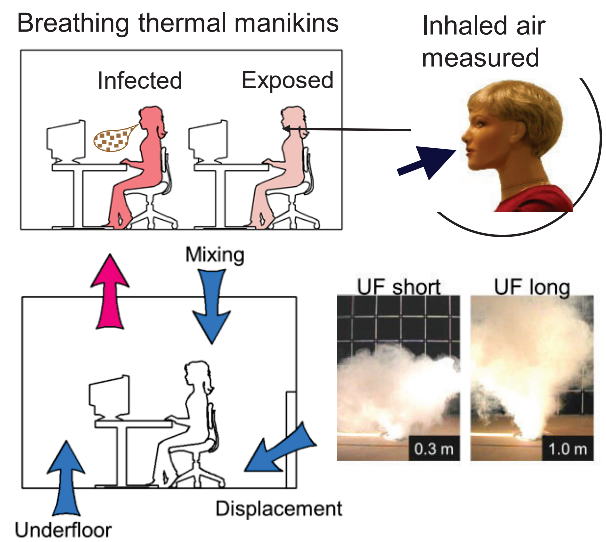


6

Airborne Transmission: Importance of Air Distribution



Cermak and Melikov, J. of Ventilation 2006



7

Ventilation and Airborne Transmission: In the Future

Past and present ventilation:

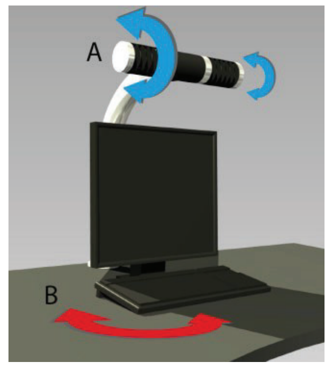
- Reduces long-range airborne transmission
- Distancing & face masks needed for reduction of short range transmission
- Present ventilation requirements lead to increase of energy use

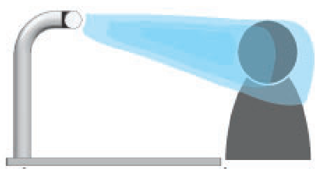
Future ventilation:

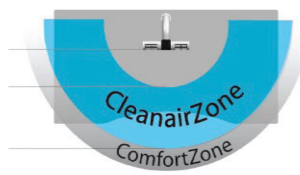
- Focus on reduction of short range transmission
- Reduced ventilation rate, small HVAC systems, energy savings

8

Advanced Air Distribution: Personalised Ventilation







Melikov, Indoor Air J. 2004

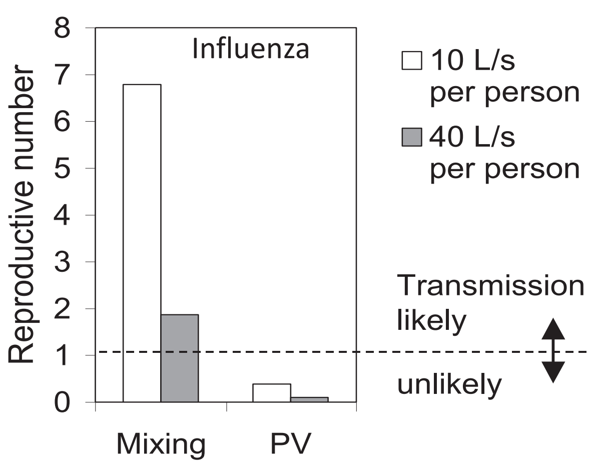
Curtesy to "Exhausto" (Denmark)

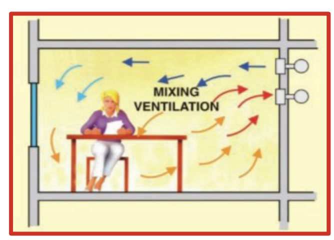
9

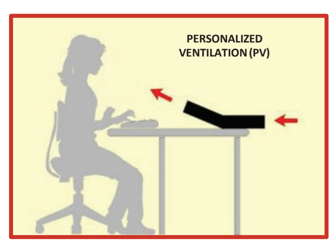
Personalized Ventilation vs. Mixing Ventilation

R_{A0} - reproductive number of secondary infections that arise when a single infectious case is introduced into a population where everyone is susceptible

[*Rudnick and Milton, 2003*]





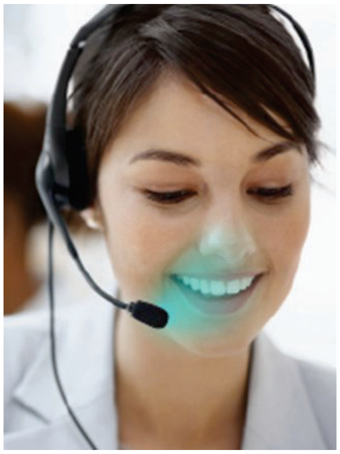


➢ *Cermak & Melikov, HVAC&R 2007*

10

Ventilation & Air Cleaning

Headset Incorporated Personal Ventilation



Mode 1: Clean air supply

Inhaled clean air: 90%

Mode 2: Exhaled air removal

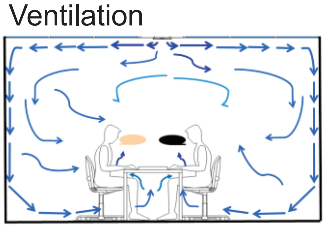
Exhaled air captured: 80%

Bolashikov et al. HB 2003; Zhu et al. Indoor Air 2008; Bolashikov et al. S&T for the Built Environment 2015

11

Reduction of Airborne Transmission: Approaches

Ventilation

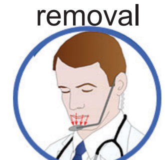


Ventilation+ Air Cleaner

Clean air supply

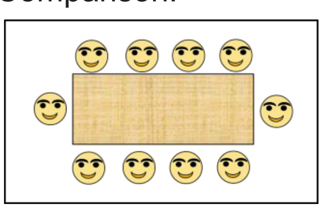
Bolashikov et al. 2003; Zhu et al. 2008

Exhale air removal

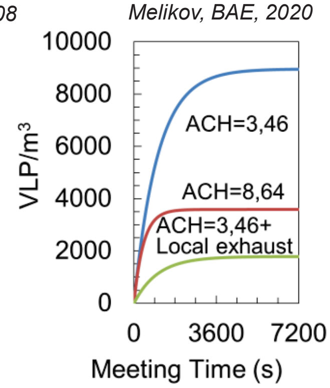


Bolashikov et al. 2015 Melikov, BAE, 2020

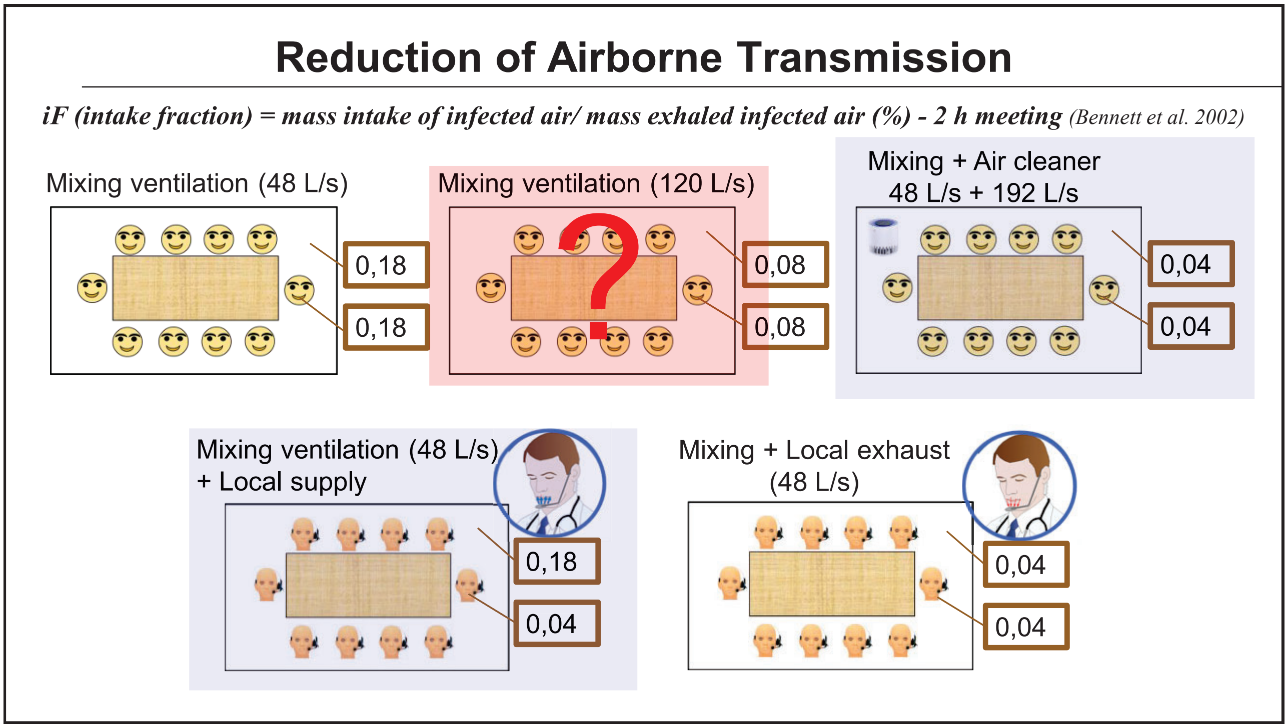
Comparison:



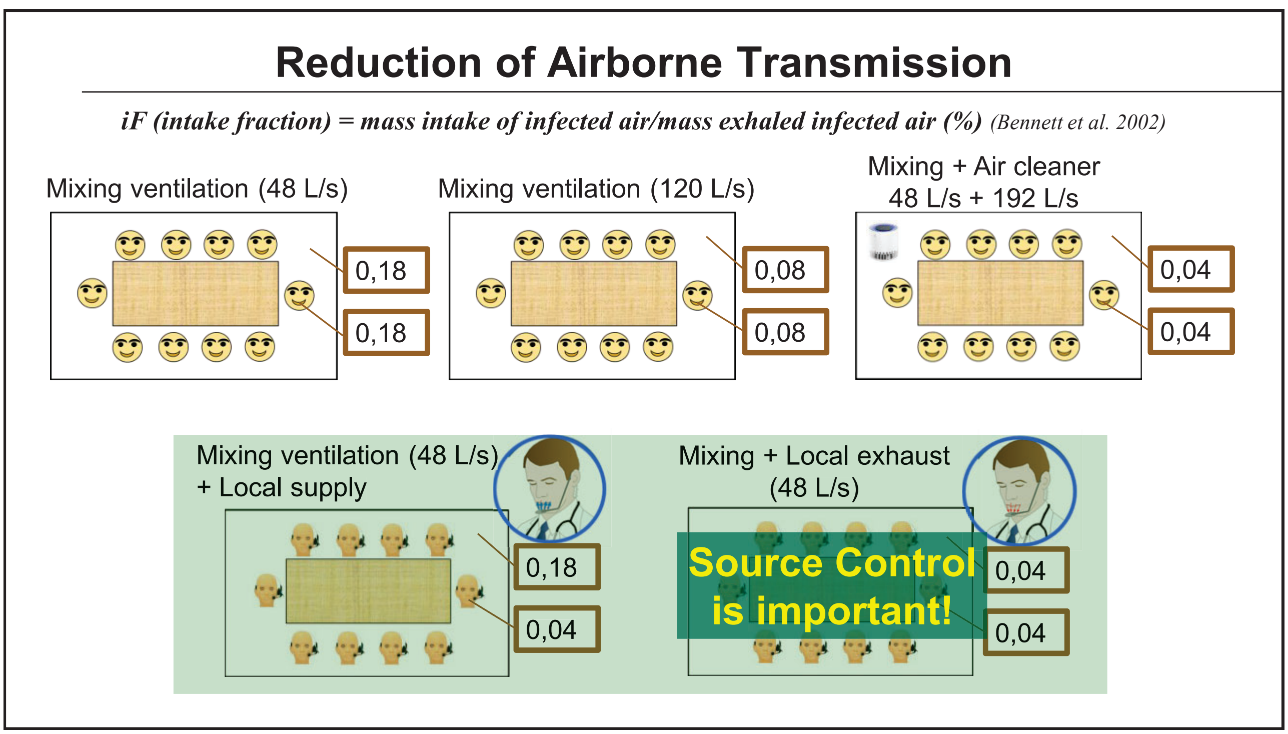
- Meeting room, 10 occupants
- 20 m^2, 50 m^3, Low Polluting Building
- Category III: 48L/s; Category I:120 L/s
- One infected occupant
- 2850 virus laden particles/exhalation (VLP)
- Calculations for 2 hours meeting time
- Local exhaust/supply efficiency: 80%
- Air cleaner efficiency: 100%



12


Reduction of Airborne Transmission
iF (intake fraction) = mass intake of infected air/ mass exhaled infected air (%) - 2 h meeting (Bennett et al. 2002)
Mixing ventilation (48 L/s)
0,18
0,18
Mixing ventilation (120 L/s)
?
0,08
0,08
Mixing + Air cleaner
48 L/s + 192 L/s
0,04
0,04
Mixing ventilation (48 L/s)
+ Local supply
0,18
0,04
Mixing + Local exhaust
(48 L/s)
0,04
0,04

13


Reduction of Airborne Transmission
iF (intake fraction) = mass intake of infected air/mass exhaled infected air (%) (Bennett et al. 2002)
Mixing ventilation (48 L/s)
0,18
0,18
Mixing ventilation (120 L/s)
0,08
0,08
Mixing + Air cleaner
48 L/s + 192 L/s
0,04
0,04
Mixing ventilation (48 L/s)
+ Local supply
0,18
0,04
Mixing + Local exhaust
(48 L/s)
Source Control
is important!
0,04
0,04

14

Reduction of Airborne Transmission: Future Ventilation Design

Future solutions

- Increase system size?
- Increase volume of spaces?
- Increase of ventilation rate?

} **Not feasible** { Increased cost / Poor operation / Increased energy consumption

Focus on

- Source control (exhaled air removed close to face)
  - Reduction (not increase!) of ventilation rate
- Clean air supply to the breathing zone
  - Advanced ventilation
  - Air disinfecting clothing

G.Settels, Penstate Univ.

43rd AIVC conference, 4-5 October 2023, Copenhagen

NS: Airborne cross infection and engineering solutions

Focus on the Air Distribution and the Occupant!

THERE IS A LOT TO BE DONE!

Thank you

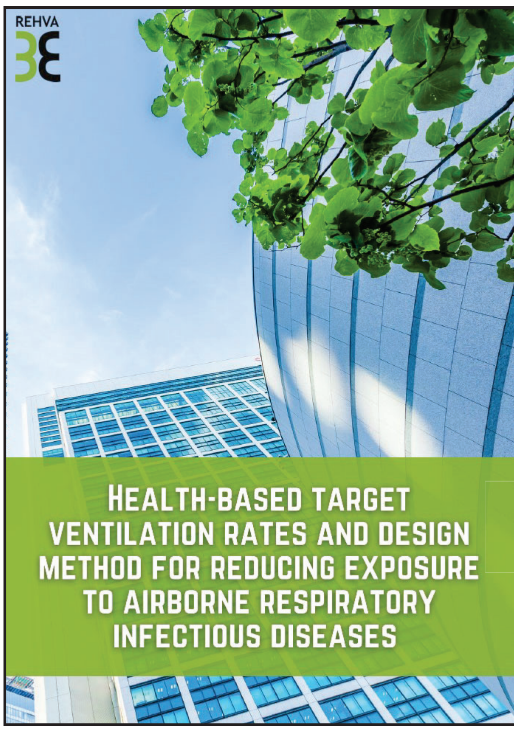
Arsen K. Melikov
ASHRAE Fellow, Life member

International Centre for Indoor Environment and Energy, DTU Sustain, Technical University of Denmark
akme@dtu.dk

POINT SOURCE VENTILATION EFFECTIVENESS IN INFECTION RISK-BASED VENTILATION DESIGN

Jarek Kurnitski
Tallinn University of Technology, Aalto University,
REHVA Technology and Research Committee

1



Target outdoor air ventilation rates *Q* (L/s) calculated using the number of persons in room *N* (-) and the room volume *V* (m^3)

Space category	Ventilation rate, L/s
Classroom	Q = 10(N-1) – 0.24V
Office	Q = 23(N-1) – 0.24V
Assembly hall	Q = 30(N-1) – 0.24V
Meeting room	Q = 40(N-1) – 0.24V
Restaurant	Q = 40(N-1) – 0.24V
Gym	Q = 70(N-1) – 0.24V

Design ventilation rate supplied by the ventilation system:

$$Q_s = \frac{Q}{\varepsilon_b}$$

ε_b **point source ventilation effectiveness** for the breathing zone (-) (contaminant removal effectiveness, ventilation factor)

https://www.rehva.eu/activities/post-covid-ventilation

2

2

INFECTION RISK MODELING

- Standard airborne disease transmission Wells-Riley model calibrated to COVID-19 with the correct source strength (quanta emission rates)
- Viral load emitted is expressed in terms of the quanta emission rate (quanta/h). One quantum is defined as the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons
- The probability of infection (*p*) is related to the number of quanta inhaled (*n*):

$$p = \frac{N_c}{N_s} = 1 - e^{-n} = 1 - e^{-\frac{IqQ_bD}{Q}} = 1 - e^{-CQ_bD}$$

p	probability of infection for a susceptible person (-)
N_c	number of disease cases
N_s	number of susceptible persons in the room
I	number of infectious persons (-)
n	number of quanta inhaled (quanta)
q	quanta emission rate per infectious person (quanta/(h pers))
Q_b	volumetric breathing rate of an occupant (m^3/h)
Q	outdoor air ventilation rate for the breathing zone (m^3/h)
D	duration of the occupancy (h)
C	average quanta concentration in the room (quanta/m^3)

QUANTA CONCENTRATION *C* UNDER STEADY STATE

Pollutant/quanta mass balance

$$Iq = C_e\lambda_v V + C\lambda_{rest}V$$

Q_s C_o=0 Q_s C_e C C_i C_{i+1} C_n Iq

C_e	quanta concentration in the extract air (quanta/m^3)
C	average quanta concentration in the breathing zone (quanta/m^3)
C_0	quanta concentration in the supply air (quanta/m^3)
V	volume of the room (m^3)
λ_v	outdoor air change rate, i.e., removal rate due to ventilation (1/h)
λ_{rest}	other removal mechanisms than ventilation (1/h)

Point source ventilation effectiveness is defined:

$$\varepsilon_b = \frac{C_e - C_0}{C - C_o}$$

ventilation rate supplied by the ventilation system $Q_s = \lambda_v V$ (m³/h)

$$C = \frac{Iq}{\varepsilon_b Q_s + \lambda_{rest} V}$$

$$p = 1 - e^{-\frac{IqQ_b D}{\varepsilon_b Q_s + \lambda_{rest} V}}$$

TALTECH TALLINNA TEHNIKAÜLIKOOL

INFECTION RISK CONTROL CONCEPT BASED ON R AND PRE-SYMPTOMATIC PERIOD

- Considering that N_s susceptible persons are exposed to *C*, the **event reproduction number *R*** (new disease cases per infectious person) can be calculated

$$R = \frac{pN_s}{I}$$

- *R* based on pre-symptomatic period of 2.5 days: 9/22.5=0.4 in offices and 2/22.5=0.09 in meeting rooms (Kurnitski et al. 2023 https://doi.org/10.1016/j.enbuild.2023.113386)
- For given *R* value, ventilation rate for the breathing zone *Q* can be solved from equation of *p* because:

$$Q = \varepsilon_b Q_s$$

Q target ventilation rate for the breathing zone = outdoor air ventilation rate at fully mixing

TALTECH TALLINNA TEHNIKAÜLIKOOL

AVERAGE CONCENTRATION C VS. LOCAL C_i

- Probability of infection can be calculated at each measured location *i*. Pollutant/quanta mass balance applied for each measurement point with concentration C_i:

$$Iq = C_e \lambda_v V + C_i \lambda_{rest} V$$

- Local air quality index is defined:

$$\varepsilon_{P,i} = \frac{C_{e-} C_0}{C_i - C_0}$$

- Substituting C_e and taking into account that ventilation rate supplied by the ventilation system $Q_s = \lambda_v V$ one obtains:

$$C_i = \frac{Iq}{\varepsilon_{P,i} Q_s + \lambda_{rest} V}$$

$$p_i = 1 - e^{-\frac{IqQ_bD}{\varepsilon_{P,i}Q_s + \lambda_{rest}V}}$$

TAL TECH | TALLINNA TEHNIKAÜLIKOOL

R IS THE SUM OF FRACTIONS OF THE EVENT REPRODUCTION NUMBER R_i

- Considering that $N_{s,i}$ susceptible persons are exposed to C_i at location *i*, the fraction of the event reproduction number R_i (new disease cases per infectious person) can be calculated

$$R_i = \frac{p_i N_{s,i}}{I}$$

- The event reproduction number forms from the exposure of all susceptible persons

$$R = \sum_i R_i$$

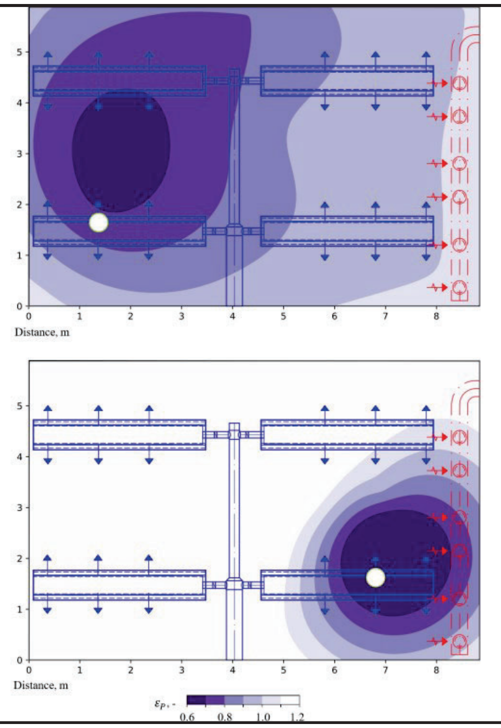
- For given R value, ventilation rate supplied by the ventilation system Q_s can be iteratively solved. Finally:

$$\varepsilon_b = \frac{Q}{Q_s}$$

TAL TECH | TALLINNA TEHNIKAÜLIKOOL

RESULTS

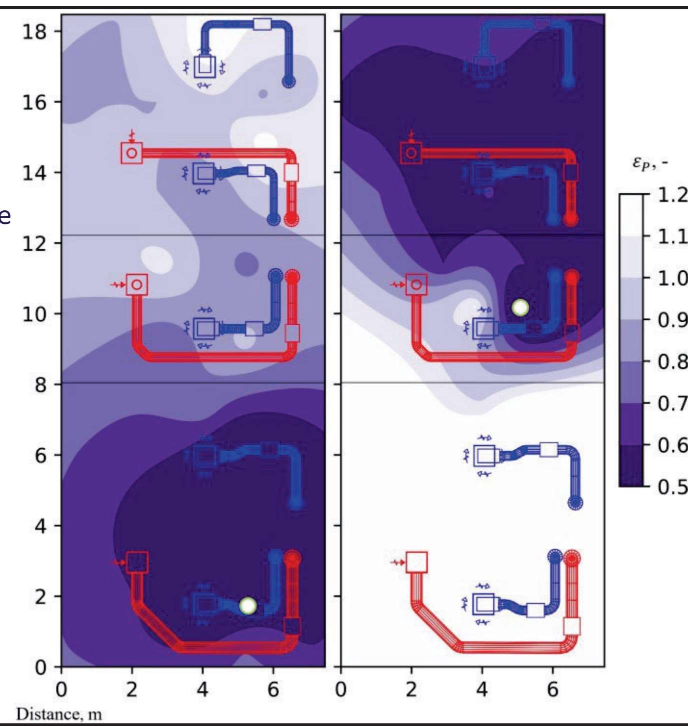
- Examples of tracer gas measurements
- Meeting room of 52.5 m² with active chilled beams and 3.0 L/(s m²) ventilation
- Local air quality index values with left and right locations of point source
- Concentrations/ventilation effectiveness depends on the source location



TAL TECH TALLINNA TEHNIKAÜLIKOOL

RESULTS

- Local air quality index values with two locations of point source in the large teaching space of 129.5 m² with 4 L/(s m²)
- The larger room the larger differences



TAL TECH TALLINNA TEHNIKAÜLIKOOL

RESULTS

- No difference in small rooms
- Up to 26% difference in large rooms with large concentration differenses
- Calculation from average concentration provides conservative result

Room	Measurement	ε_b	ε_b, avg	Q_s, L/s	Q_s, avg, L/s
Classroom 30.5	Meas. No 1	0.99	0.99		
m^2, 13 persons	Meas. No 2	1.89	1.88		
	Average	1.44	1.43	70	70
	%		-0.4%		0.4%
Teaching space	Meas. No 1	0.77	0.76		
129.5 m^2,	Meas. No 2	0.81	0.77		
50 persons	Average	0.79	0.76	513	532
	%		-3.6%		3.7%
Gym 173.5 m^2,	Meas. No 1	0.56	0.53		
12 persons	Meas. No 2	1.80	1.53		
	Average	1.18	1.03	548	627
	%		-12.6%		14.5%
School gym	Meas. No 1	0.74	0.52		
217.5 m^2, 25	Meas. No 2	0.36	0.35		
pers.	Average	0.55	0.44	**2695**	**3401**
	%		-20.8%		**26.2%**
Meeting room	Meas. No 1	0.86	0.86		
52.5 m^2, 12	Meas. No 2	1.18	1.14		
persons	Average	1.02	1.00	404	412
	%		-2.0%		2.1%
Open plan	Meas. No 1	0.50	0.34		
office	Meas. No 2	0.74	0.64		
173 m^2, 17 pers.	Average	0.62	0.49	**406**	**511**
	%		-20.5%		**25.8%**

TAL TECH TALLINNA TEHNIKAÜLIKOOL

CONCLUSIONS

- Point source ventilation effectiveness was calculated from average and local tracer gas concentrations
- Calculation from average concentration is straightforward, but provides conservative results (= higher ventilation rate to be supplied)
- Calculation from local concentrations and individual risk of probabilities needs iteration but provides more accurate results in spaces with large concentration differences
- Max difference 26% in the airflow rate (school gym and open plan office)
- Infection risk based ventilation design is proposed to be addressed in the ongoing revision of EN 16798-1

TAL TECH TALLINNA TEHNIKAÜLIKOOL

Acoustic method for measurement of airtightness – Field testing on three different existing office buildings in Germany

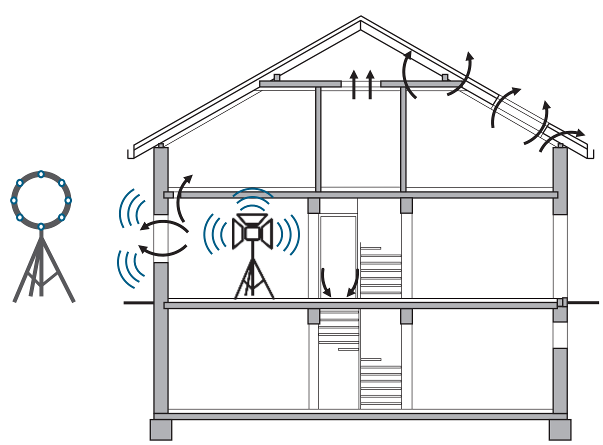
Björn Schiricke, **Benedikt Kölsch**
Solar Research – German Aerospace Center (DLR)

DLR

Acoustic Approach

DLR

- **Objective**
  Identify leak locations in building envelopes quickly
- **Assumption**
  Sound takes predominantly the
  same paths as air in fan pressurization method
- **Equipment**
  - Speaker
  - Microphone array
- **Advantages**
  - Independent from pressures and temperatures
  - Scanning of large areas possible
- **Previous testing**
  - Successful on known leaks



Field testing on three different office buildings

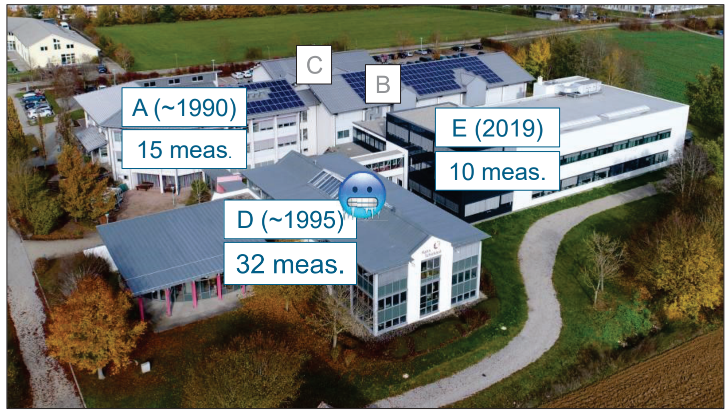
DLR

Testing this method…

- Large building complex
- Different building types
- Unknown leaks

Measurements evaluated

- 57 measurements (in 37 rooms)
- Smoke sticks in 3 rooms for validation



Measurement setup

DLR

Speakers inside

High frequency speakers
15 - 120 kHz

Mid and low frequency speakers
0.05 - 16 kHz

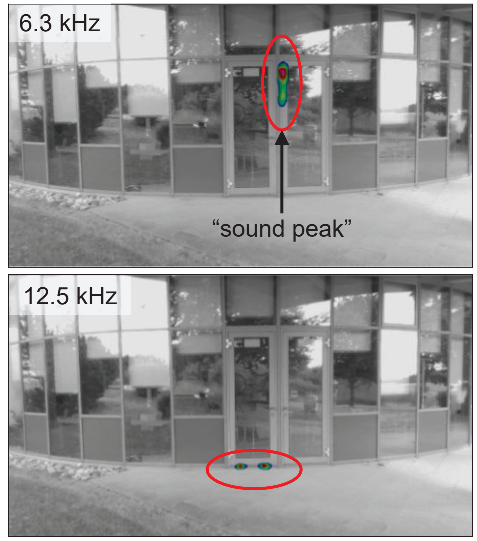
White noise signal
85 dB for 4 s

Microphone array outside

48 microphones
0.2 - 60 kHz

Video camera
1920 × 1080 px

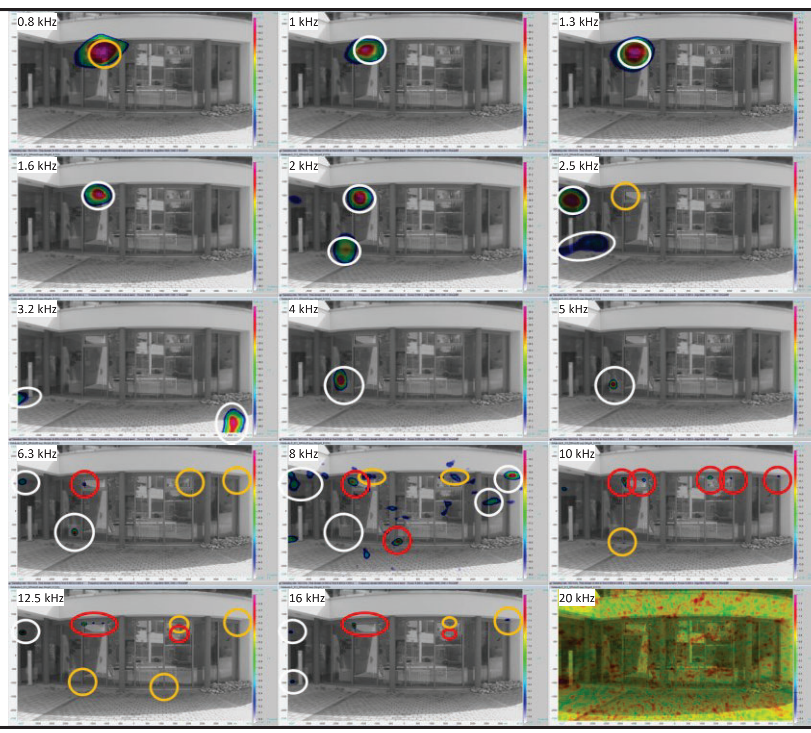
Leak detection on facades



- Analysed in 16 third-octave frequency bands
  0.8 – 25 kHz
- Different potential leaks are found
  in different frequency bands

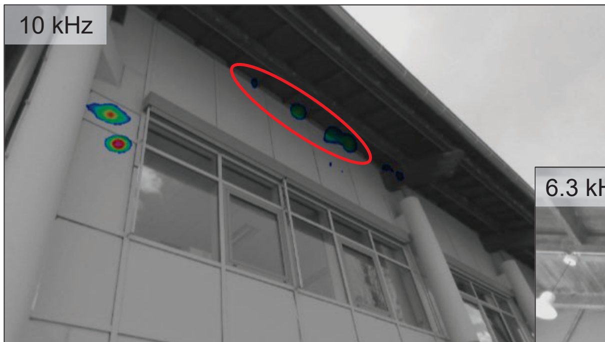
bjoern.schiricke@dlr.de, AIVC Copenhagen, 04.10.2023

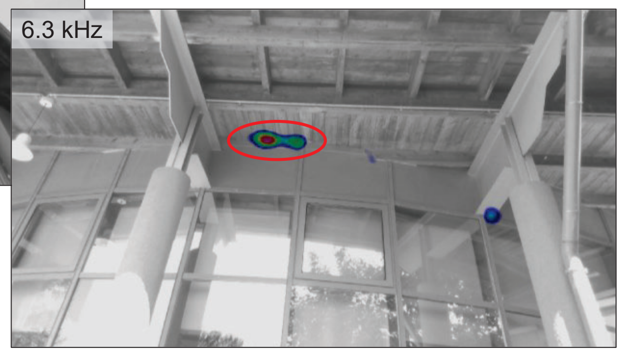
Visualisation of potential leaks



bjoern.schiricke@dlr.de, AIVC Copenhagen, 04.10.2023

Examples





Transition from the wall to the roof

Examples – confirmed by **visual inspection**

Cover protrudes and
the window seal is faulty

Examples – confirmed by visual inspection

Cracks in the plaster inside and outside

Examples – confirmed by visual inspection

Mould

Examples – confirmed by **smoke stick**

DLR

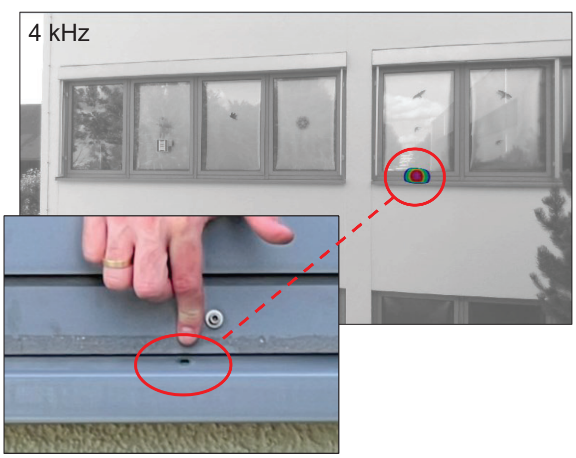
Hole in window seal

bjoern.schiricke@dlr.de, AIVC Copenhagen, 04.10.2023

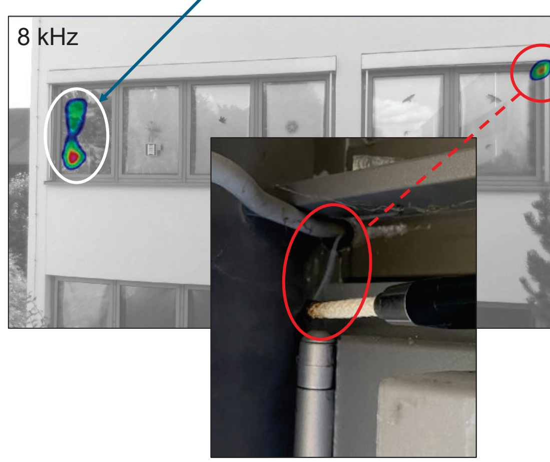
Examples – confirmed by **smoke stick**

DLR

Vibration / reflection



Hole in window frame



Cable fairlead to the blind

bjoern.schiricke@dlr.de, AIVC Copenhagen, 04.10.2023

Categorisation of the acoustic signals

DLR

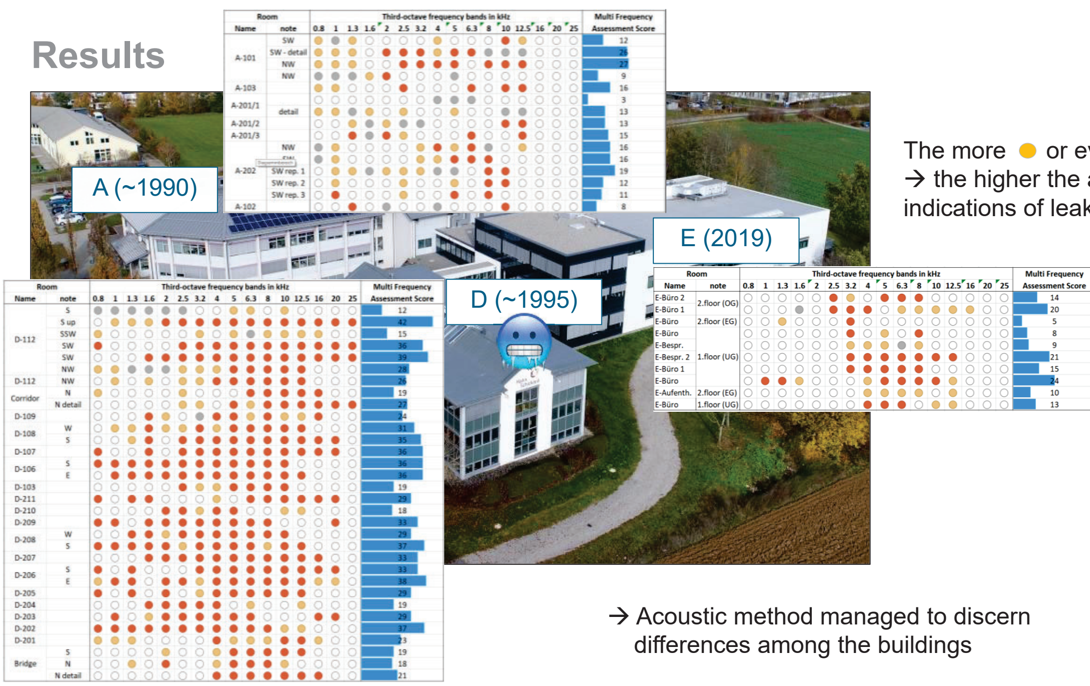
Colour Code	Acoustic Assessment Score	Evaluation of acoustic signals	Description of subjective criteria
○	0	very unlikely leakage	Peak of signal is at implausible location (e.g. on a window pane or facade panel, or outside the area under consideration)
●	1	unlikely leakage	
🟡	2	likely leakage	
🔴	3	very likely leakage	

Room		Third-octave frequency bands in kHz																Multi Frequency
Name	note	0.8	1	1.3	1.6	2	2.5	3.2	4	5	6.3	8	10	12.5	16	20	25	Assessment Score
E-Büro 2	2.floor (OG)	○	○	○	○	○	🔴	🟡	○	🔴	🔴	🔴	○	○	○	○	○	14
E-Büro 1		○	○	○	●	○	🔴	🔴	🔴	○	🟡	🟡	🟡	🟡	🟡	○	○	20
E-Büro	2.floor (EG)	○	○	🟡	○	○	○	🔴	○	○	○	○	○	○	○	○	○	5
E-Büro	1.floor (UG)	○	○	○	○	○	○	🔴	○	🟡	○	🔴	○	○	○	○	○	8
E-Bespr.		○	○	○	○	○	○	🟡	🟡	🟡	●	🟡	○	○	○	○	○	9
E-Bespr. 2		○	○	○	○	○	○	🔴	🔴	🔴	🔴	🔴	🔴	🔴	○	○	○	21
E-Büro 1		○	○	○	○	○	○	🔴	🔴	🔴	🔴	🔴	○	○	○	○	○	15
E-Büro		○	🔴	🔴	🟡	○	○	○	🟡	🔴	🔴	🔴	🔴	🟡	○	○	○	24
E-Aufenth.	2.floor (EG)	○	○	○	○	○	○	○	🟡	🟡	🟡	🟡	○	🟡	○	○	○	10
E-Büro	1.floor (UG)	○	○	○	○	○	○	○	🔴	🔴	🔴	○	🟡	🟡	○	○	○	13

The more 🟡 or even 🔴 → the higher the acoustic indications of leaks

Results

DLR



The more 🟡 or even 🔴
→ the higher the acoustic indications of leaks

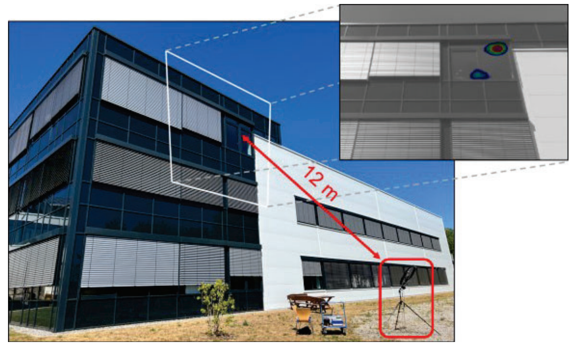
→ Acoustic method managed to discern differences among the buildings

Summary and Outlook

Achievements

- Significant number of potential leaks localized
- Scanning of large areas possible
- Large distances were demonstrated (3. floor)
- Managed to discern differences among the three buildings

→ **Successful demonstration of acoustic approach to leak detection**

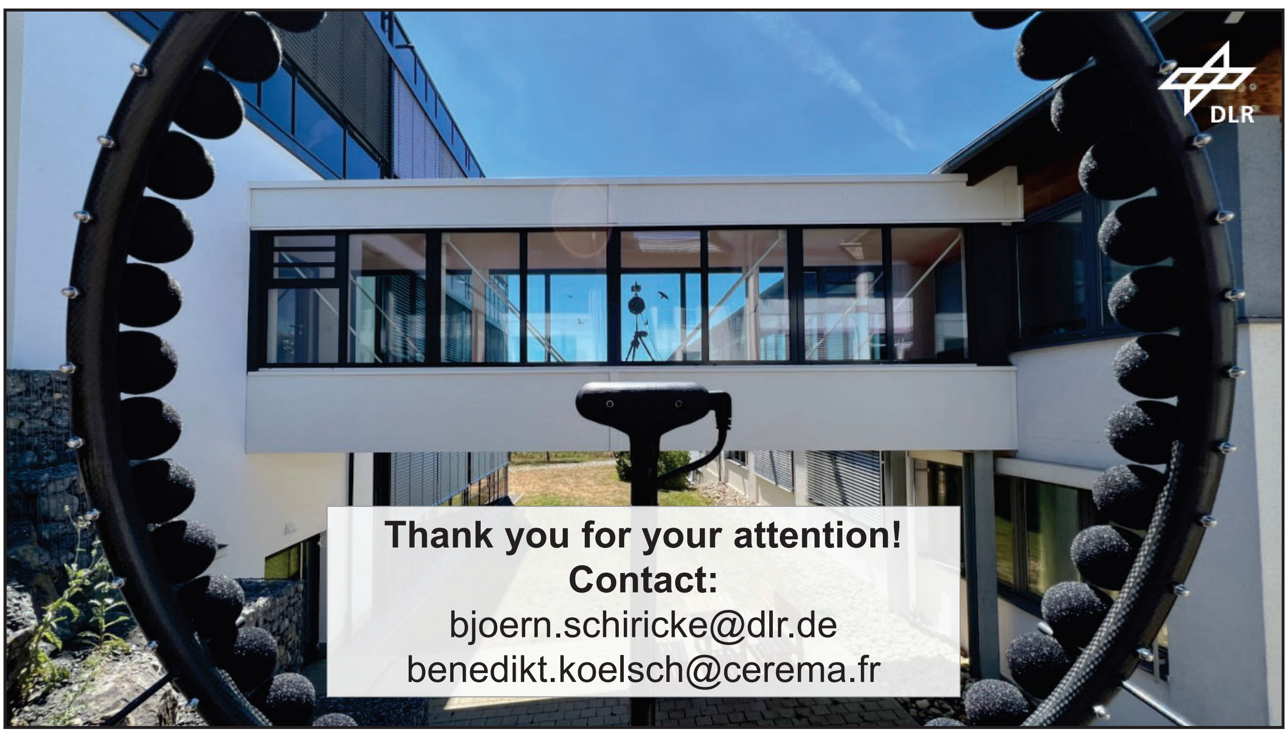


Outlook

- Automation of data analysis
- Compact visualisation of potential leaks
- Laboratory test stand
  - Systematic investigation of various leakage setups
  - Infer the type and size of leaks (e.g. out of spectral data)

→ **New research projects ongoing**

15



16

Imprint

Topic: Acoustic method for measurement of airtightness – field testing on three different existing office buildings in Germany

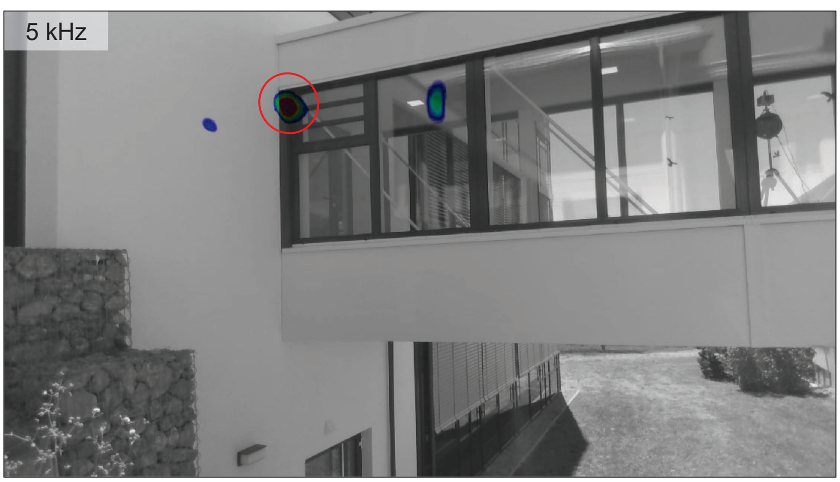
Date: 2023-10-04

Author: Björn Schiricke

Institute: Solar Research

Image credits: All images “DLR (CC BY-NC-ND 3.0)” unless otherwise stated

Examples – confirmed by **visual inspection**

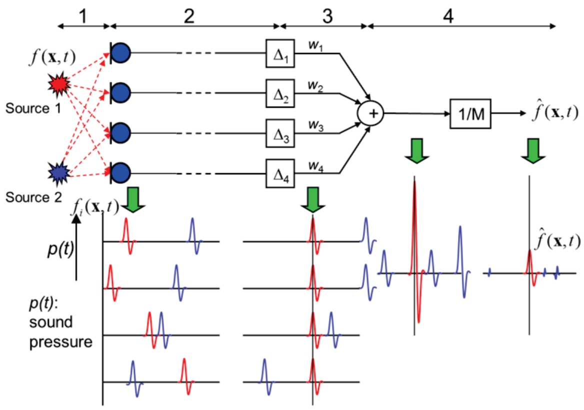


Tilt window and hole in steel structure

Examples – confirmed by visual inspection

Window seals are damaged

Delay and Sum Beamforming



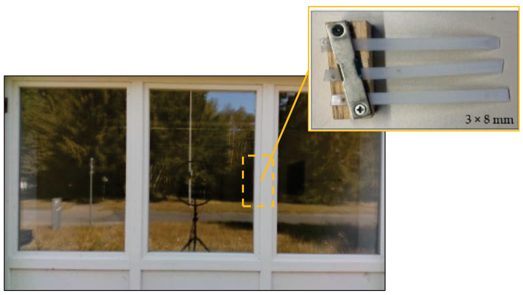
1. Sound arrives at microphones.
2. Signals have phase differences → Offset can be calculated by sound velocity, distances between microphones and to the sound source.
3. Depending on the focus point, signal is shifted by the delay time difference.
4. All signals are added up and normalized with number of microphones.

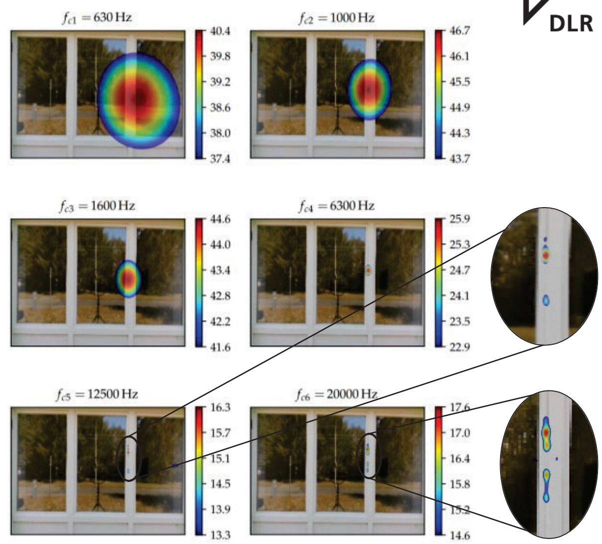
Background information

DLR

Previous testing *

- Single window frame
- With known leaks





* Kölsch et al: “Detection of Air Leakage in Building Envelopes using Microphone Arrays”, AIVC 2021 in Athens

DLR

University of Nottingham
UK | CHINA | MALAYSIA

43rd AIVC

Pulse tests in highly airtight Passivhaus standard buildings

Xiaofeng (Ken) Zheng

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

1

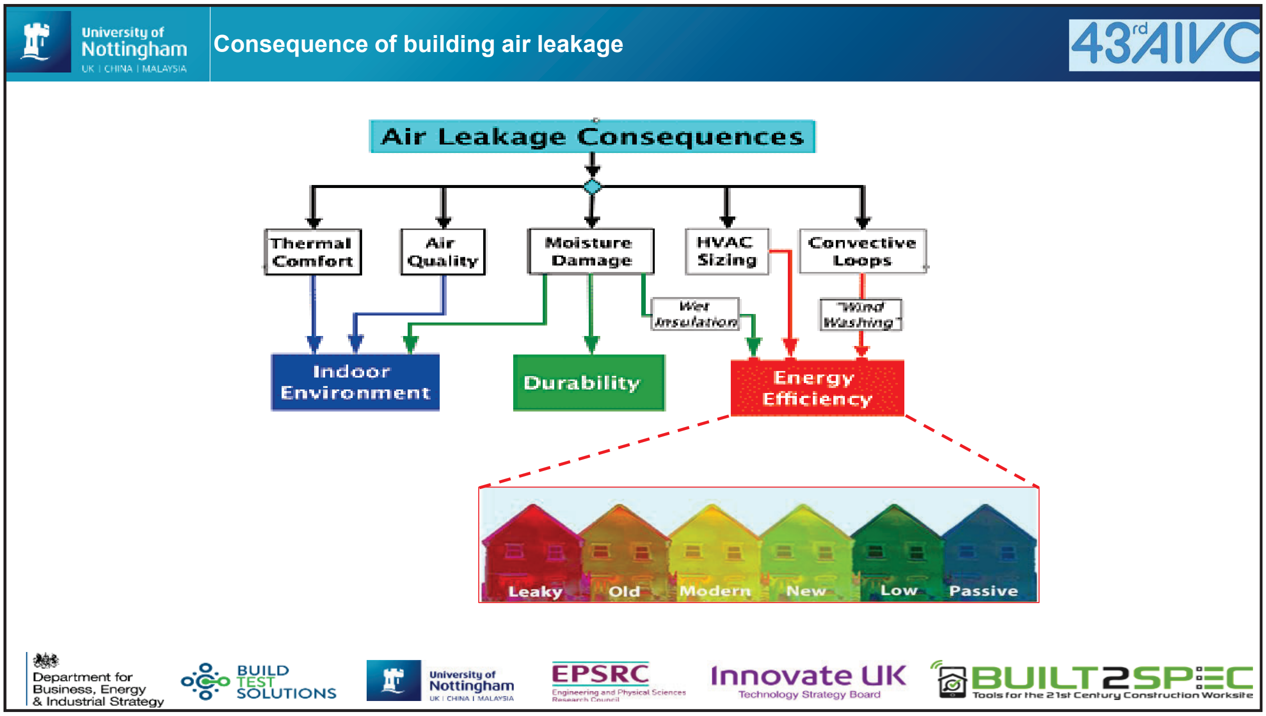
University of Nottingham
UK | CHINA | MALAYSIA

43rd AIVC

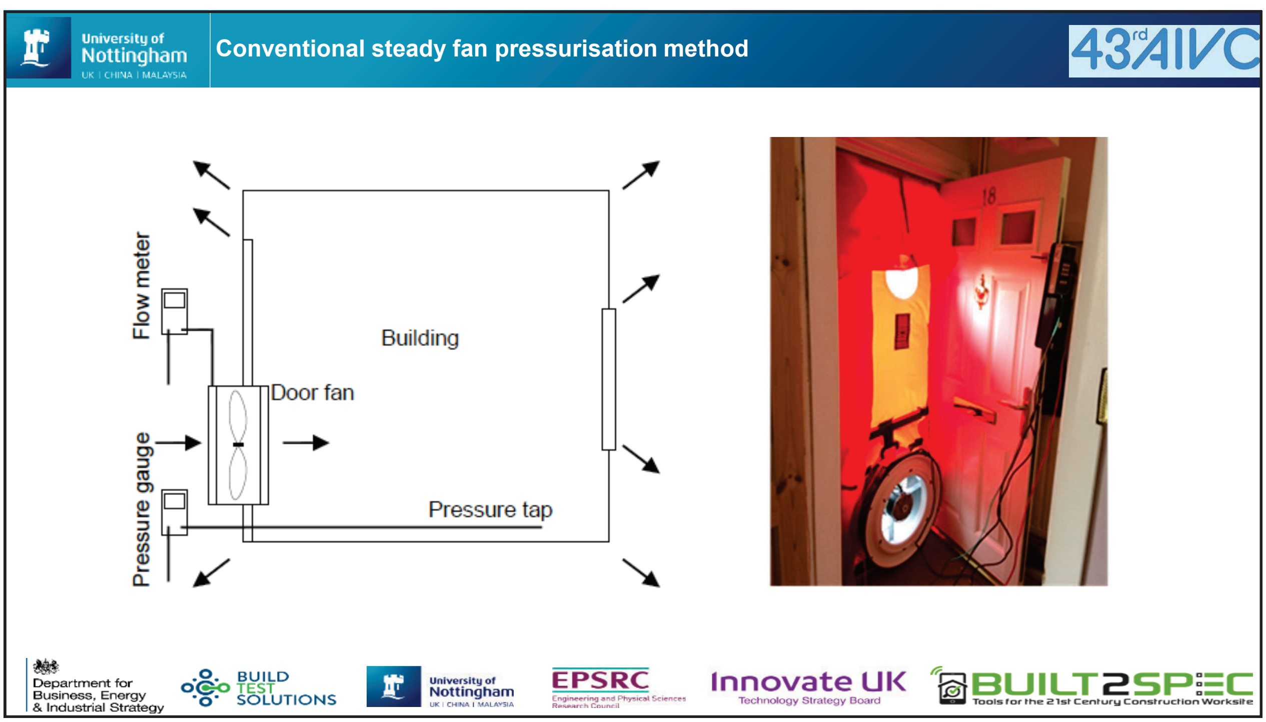
Outline:

- Background
- Fundamental of the Pulse technique
- Challenges for testing Passivhaus
- Case study buildings
- Test results

2


University of Nottingham
UK | CHINA | MALAYSIA
Consequence of building air leakage
43rd AIVC
Air Leakage Consequences
Thermal Comfort
Air Quality
Moisture Damage
HVAC Sizing
Convective Loops
Wet Insulation
Wind Washing
Indoor Environment
Durability
Energy Efficiency
Leaky
Old
Modern
New
Low
Passive
Department for Business, Energy & Industrial Strategy
BUILD TEST SOLUTIONS
University of Nottingham
EPSRC
Engineering and Physical Sciences Research Council
Innovate UK
Technology Strategy Board
BUILT2SPEC
Tools for the 21st Century Construction Worksite

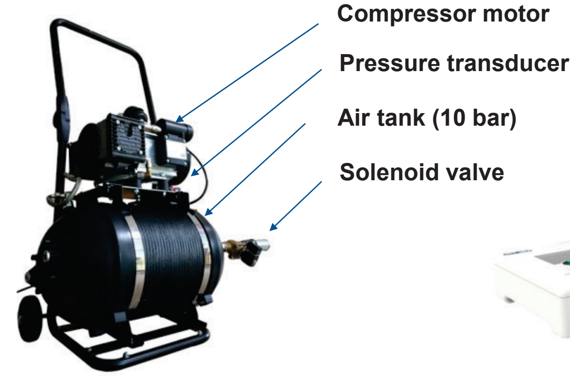
3


University of Nottingham
UK | CHINA | MALAYSIA
Conventional steady fan pressurisation method
43rd AIVC
Flow meter
Pressure gauge
Building
Door fan
Pressure tap
Department for Business, Energy & Industrial Strategy
BUILD TEST SOLUTIONS
University of Nottingham
EPSRC
Engineering and Physical Sciences Research Council
Innovate UK
Technology Strategy Board
BUILT2SPEC
Tools for the 21st Century Construction Worksite

4

Fundamental of the Pulse technique

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.



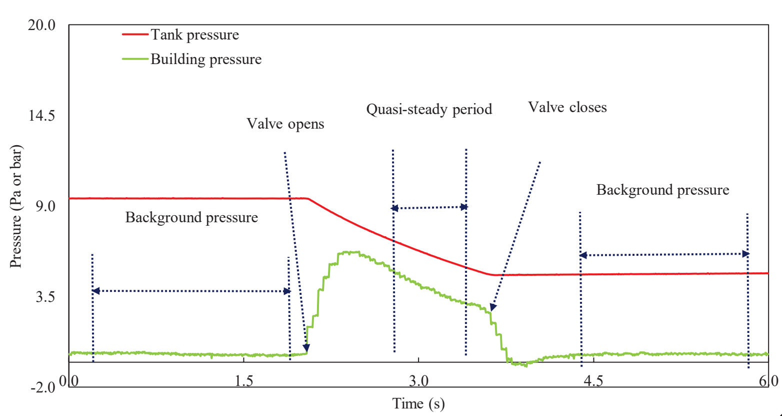
Tank unit

Control unit

University of Nottingham UK | CHINA | MALAYSIA

Fundamental of the Pulse technique

43rd AIVC



Steady $Q_{device}=Q_{building}$

Pulse $Q_{compressibility}$

⇩

$Q_{device}=Q_{building}+Q_{compressibilit}$

Historical development

Technique	Year	Funding source	Nottingham academics/researchers	External involvement
Piston Technique	2001	Internal funding	**Etheridge** & Carey	-
	2002-2006	EPSRC Industrial Case Award (PhD)	**Etheridge** & Cooper	Airflow Developments Ltd
	2010	Swedish Energy Agency	**Cooper** & Etheridge	University of Gavle, Sweden
Nozzle Technique	2010-2011	EPSRC First Grant	**Cooper** & Zu	Letters of support from industry
	2013-2015	Innovate UK (TSB) consortium - Scaling Up Retrofit	**Cooper**, Riffat, Gillott & Zheng	NEF, Elmhurst, EPS Ltd, Air & Gas Ltd, & ANDtr
	2014-2018	EU Funding (Horizon 2020) – Commissioning of buildings	**Cooper**, **Wood** & Zheng	'Built2Spec' consortium of 20 partners in 8 EU countries
	2017-2018	Innovate UK: High Integrity enclosure testing	**Wood** & Zheng	Build Test Solutions Ltd (lead)
	2017-2019	BEIS -PULSE: Rapid Verification and Validation of Air Infiltration in New and Existing Buildings	**Wood**, Gillott, Zheng & Pasos	Build Test Solutions Ltd (lead)
	2019-2021	Internal funding: wind impact, Passivhaus and non-residential buildings	**Wood**, Zheng & Hsu	Build Test Solutions Ltd

Background of this study

Ministry of Housing, Communities & Local Government

The Future Homes Standard

2019 Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for new dwellings

Introducing an alternative to the blower door test

5.11. Currently, airtightness is commonly tested using the blower door method. To provide an alternative method of airtightness testing, we are seeking views on introducing the Pulse test as an approved airtightness testing methodology. The Pulse test dynamically measures building air leakage directly at low pressure.

5.12. The Pulse test is performed at a pressure differential of 4Pa as opposed to 50Pa, which is more representative of conditions that properties are likely to experience.

5.13. A constant conversion factor has been identified to convert measurements performed at a pressure differential of 4Pa to 50Pa in SAP.

5.14. The effectiveness of the test in very airtight dwellings has yet to be demonstrated. Therefore, we want to seek views on introducing the Pulse test as an approved method of airtightness testing for new dwellings with a designed airtightness of between 1.5 $m^3/m^2.h$ and the maximum allowable airtightness value in Approved Document volume 1. This is the range that a 58.5l Pulse unit has been demonstrated to perform at in the field trial, which can be accessed via the link below.

- 2018 Submission to MHCLG
- 2019 Public Consultation
- 2020 Majority voted yes
- 2025 In effect

Background of this study

Limited to: >1.5 m³/h/m² @50 Pa

11 properties have been Pulse tested between October 2019 and January 2020

@50 Pa

0.29 m³/h/m² to 1.19 m³/h/m²

0.48 ACH to 1.27 ACH

@4 Pa

0.05 m³/h/m² to 0.31 m³/h/m²

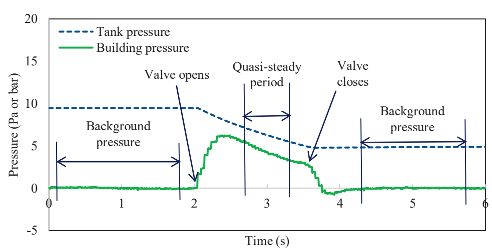
0.07 ACH to 0.33 ACH

Department for Business, Energy & Industrial Strategy | BUILD TEST SOLUTIONS | University of Nottingham UK | CHINA | MALAYSIA | EPSRC Engineering and Physical Sciences Research Council | Innovate UK Technology Strategy Board | BUILT2SPEC Tools for the 21st Century Construction Worksite

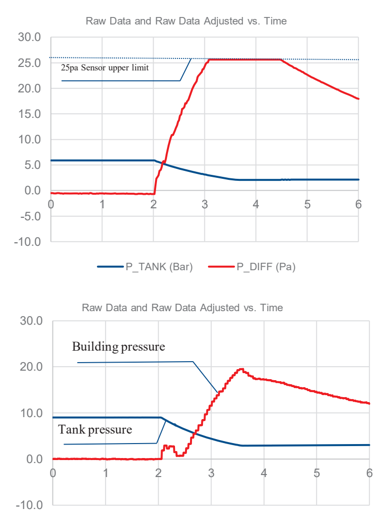
University of Nottingham UK | CHINA | MALAYSIA

Challenges for testing Passivhaus buildings

43rd AIVC



Good Pulse shape



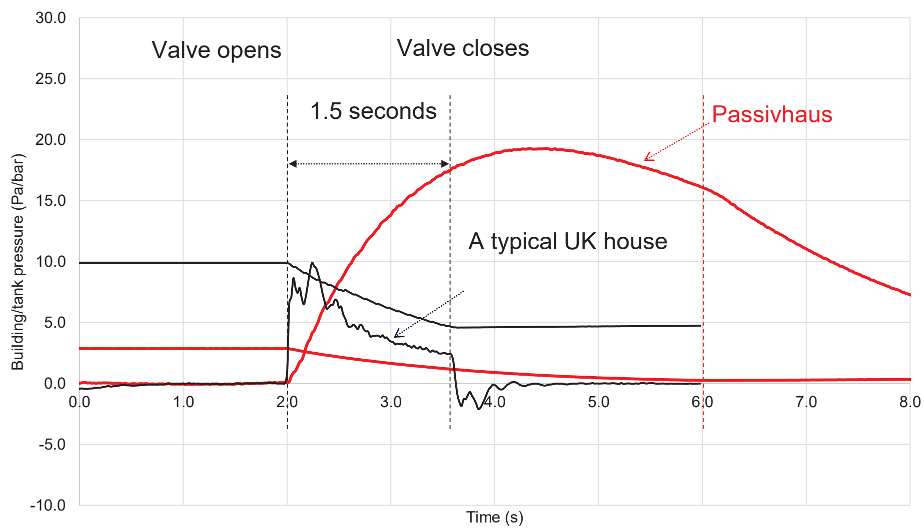
Incomplete or unusable Pulse shapes

Department for Business, Energy & Industrial Strategy | BUILD TEST SOLUTIONS | University of Nottingham UK | CHINA | MALAYSIA | EPSRC Engineering and Physical Sciences Research Council | Innovate UK Technology Strategy Board | BUILT2SPEC Tools for the 21st Century Construction Worksite

University of Nottingham UK | CHINA | MALAYSIA

Challenges for testing Passivhaus buildings

43rd AIVC



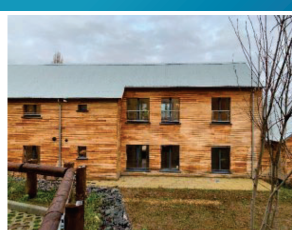
Department for Business, Energy & Industrial Strategy | BUILD TEST SOLUTIONS | University of Nottingham | EPSRC Engineering and Physical Sciences Research Council | Innovate UK Technology Strategy Board | BUILT2SPEC Tools for the 21st Century Construction Worksite

11

University of Nottingham UK | CHINA | MALAYSIA

Case study buildings

43rd AIVC



Flat (New Build)

Terraced house (New Build)

Detached house (Retrofit)

Detached house (New Build)

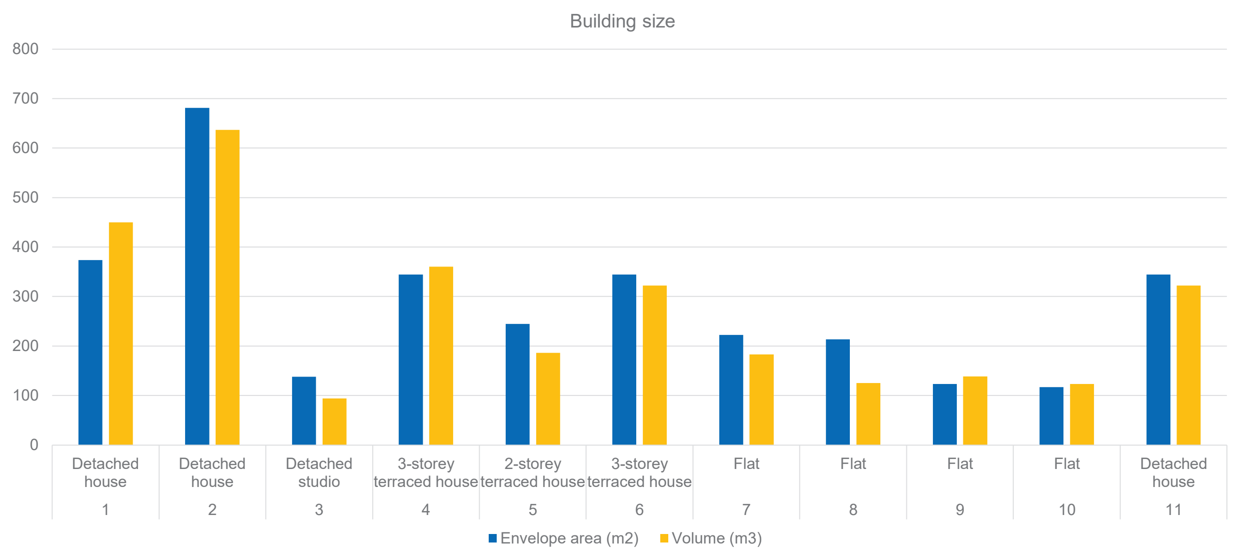
Department for Business, Energy & Industrial Strategy | BUILD TEST SOLUTIONS | University of Nottingham | EPSRC Engineering and Physical Sciences Research Council | Innovate UK Technology Strategy Board | BUILT2SPEC Tools for the 21st Century Construction Worksite

12

University of Nottingham UK | CHINA | MALAYSIA

Case study buildings

43rd AIVC



Department for Business, Energy & Industrial Strategy · BUILD TEST SOLUTIONS · University of Nottingham UK | CHINA | MALAYSIA · EPSRC Engineering and Physical Sciences Research Council · Innovate UK Technology Strategy Board · BUILT2SPEC Tools for the 21st Century Construction Worksite

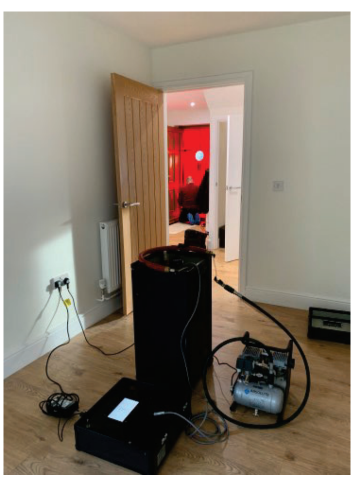
13

University of Nottingham UK | CHINA | MALAYSIA

Challenges in minimising the difference in building preparation

43rd AIVC

The installation of both methods can lead to a difference in the measured building envelope due to the different way of installation:

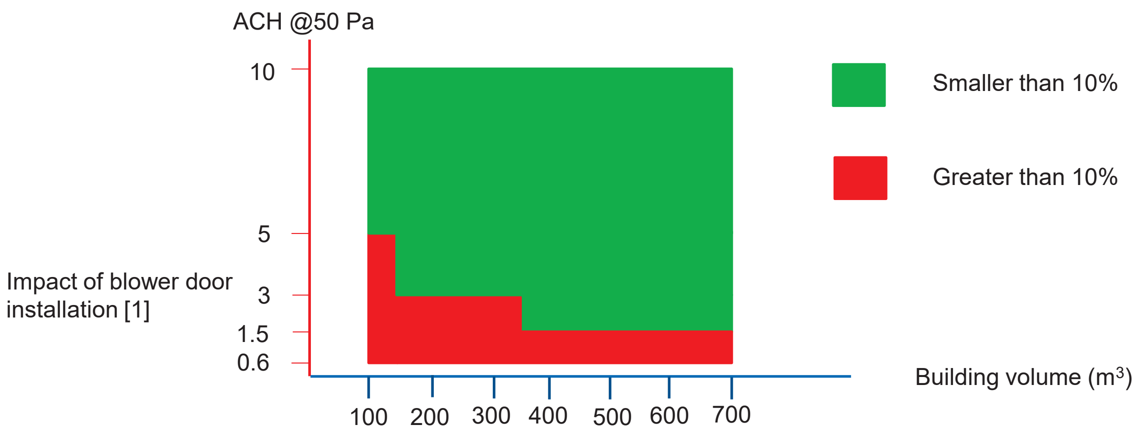


- Difference in the fenestration opening
- This difference is more obvious when the opening is in an irregular shape, the frame is angled, or the door has lots of fittings in the frame.

Department for Business, Energy & Industrial Strategy · BUILD TEST SOLUTIONS · University of Nottingham UK | CHINA | MALAYSIA · EPSRC Engineering and Physical Sciences Research Council · Innovate UK Technology Strategy Board · BUILT2SPEC Tools for the 21st Century Construction Worksite

14

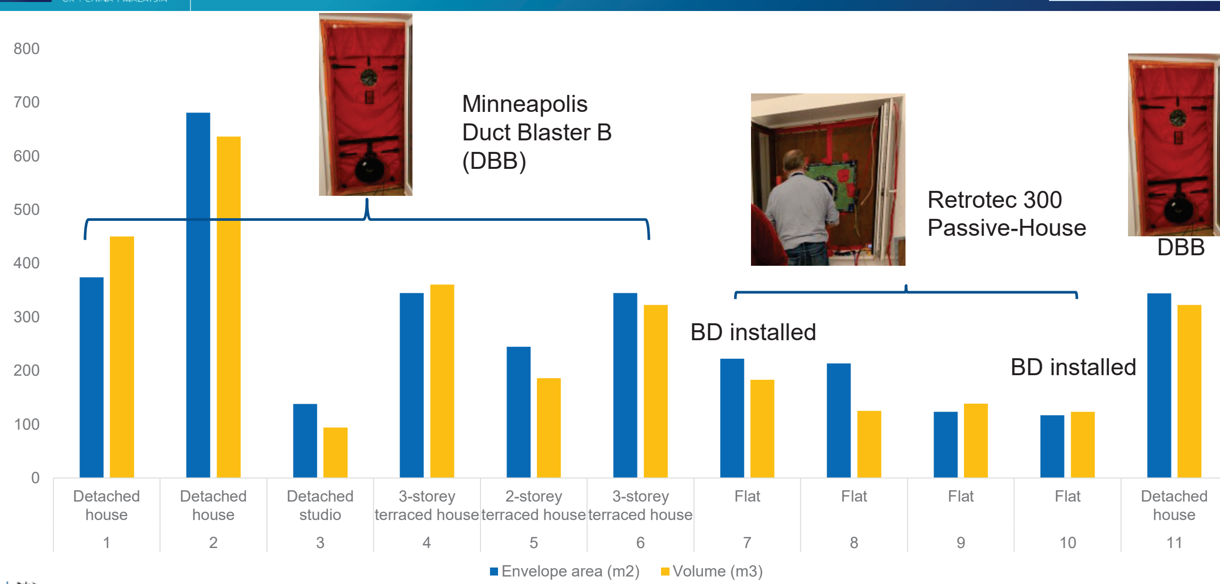
Challenges in minimising the difference in building preparation



[1] X.F. Zheng, Y.S. Hsu, A.V. Pasos, L. Smith, C.J. Wood. A progressive comparison of the novel pulse and conventional steady state methods of measuring the airtightness of buildings. Energy & Buildings 261 (2022) 111983.

15

Test setup



16

University of Nottingham
UK | CHINA | MALAYSIA

Building preparation

43rd AIVC

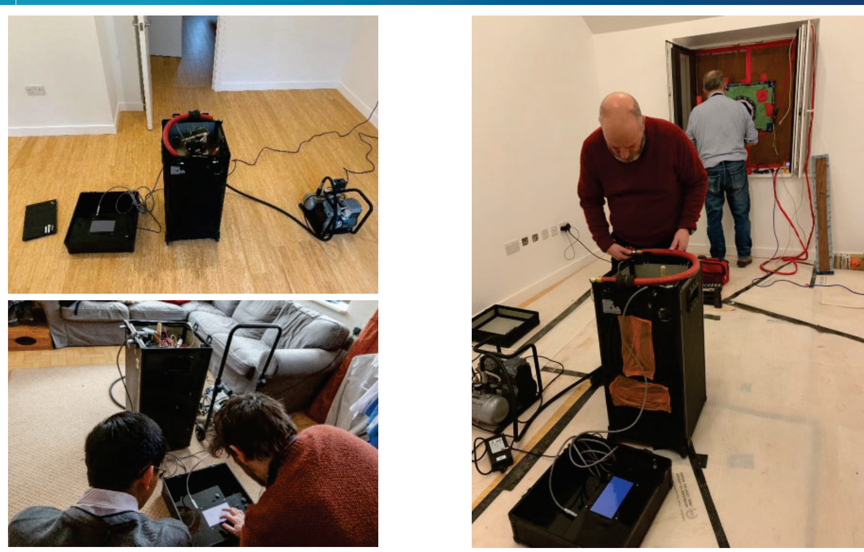
Department for Business, Energy & Industrial Strategy | BUILD TEST SOLUTIONS | University of Nottingham UK | CHINA | MALAYSIA | EPSRC Engineering and Physical Sciences Research Council | Innovate UK Technology Strategy Board | BUILT2SPEC Tools for the 21st Century Construction Worksite

17

University of Nottingham
UK | CHINA | MALAYSIA

Setup and testing

43rd AIVC



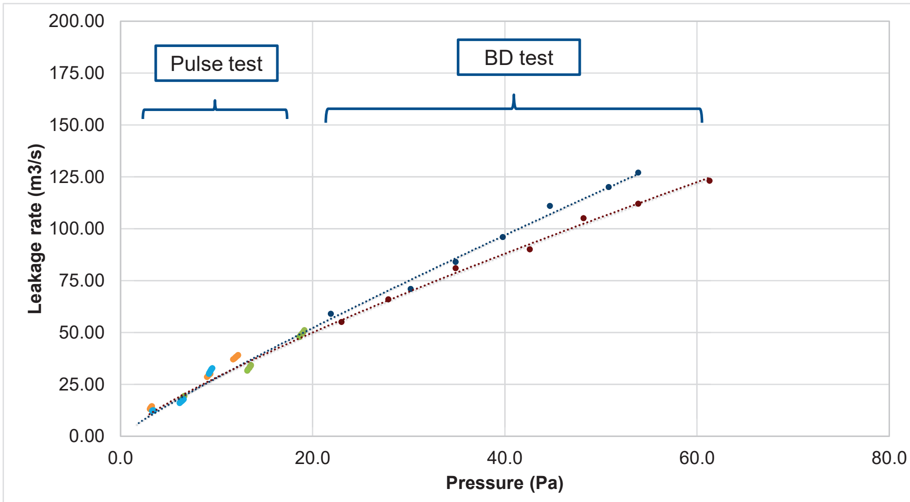
Department for Business, Energy & Industrial Strategy | BUILD TEST SOLUTIONS | University of Nottingham UK | CHINA | MALAYSIA | EPSRC Engineering and Physical Sciences Research Council | Innovate UK Technology Strategy Board | BUILT2SPEC Tools for the 21st Century Construction Worksite

18

University of Nottingham UK | CHINA | MALAYSIA

Leakage-pressure curves

43rd AIVC



University of Nottingham UK | CHINA | MALAYSIA

Test results at 4 Pa

43rd AIVC

Property ID	N4 (BDT)	N4 (Pulse)	N4 Difference	N4 Percentage Difference
001	0.11	0.09	0.024	27%
002	0.14	0.13	0.004	3%
003	0.11	0.10	0.01	10%
004	0.13	0.20	-0.066	33%
005	0.05	0.06	0.004	7%
006	0.12	0.14	-0.014	10%
007	0.08	0.09	-0.008	9%
008	0.04	0.05	0.004	7%
009	0.11	0.11	0.002	2%
010	0.11	0.11	0.000	0%
011	0.36	0.31	0.053	17%

DBB by Zheng

300 PH by PJ

Department for Business, Energy & Industrial Strategy · BUILD TEST SOLUTIONS · University of Nottingham · EPSRC Engineering and Physical Sciences Research Council · Innovate UK Technology Strategy Board · BUILT2SPEC Tools for the 21st Century Construction Worksite

Test results at 50 Pa

Property ID	N50 (BDT)	N50 (Pulse) extrapolated	N50 Difference	N50 Percentage Difference
001	0.57	0.74	-0.163	22%
002	0.80	1.34	-0.549	41%
003	0.78	0.66	0.119	18%
004	0.73	0.82	-0.082	10%
005	0.45	0.50	-0.050	10%
006	0.78	0.74	0.044	6%
007	0.46	0.56	-0.095	17%
008	0.29	0.40	-0.112	28%
009	0.67	0.63	0.038	6%
010	0.65	0.80	-0.144	18%
011	1.19	1.53	-0.337	22%

DBB by Zheng

300 PH by PJ

Findings

- The Pulse technique can measure the airtightness of Passivhaus standard building, with an extended valve opening time.
- It can be challenging to achieve a like-for-like comparison between two methods due to the different way of testing.
- With the difference in the building envelope condition minimised, they provide comparable test results.

Many thanks!

Xiaofeng.Zheng@nottingham.ac.uk

2023 AIVC conference "Ventilation, IEQ and health in sustainable buildings"

Correlation analysis between ACH50 and Air permeability considering the floor area of a residential buildings

2023. 10. 04

INHA UNIVERSITY
Choi, Su-Ji
Jo, Jae-Hun
(Email: jhjo@inha.ac.kr)

CONTENTS

1. Introduction

- **Typical residential building types in Korea**
  - Residential building types in large Asian cities ➔ Apartment building
  - More than 500 units will be built, consisting of 3 to 7 unit types

https://www.google.com/search?q=apartment+building+in+asia

1. Introduction

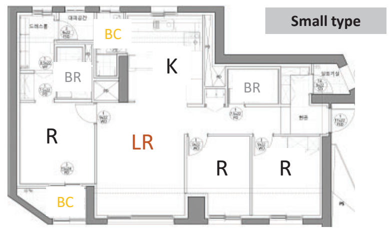
- **The floor plan of residential building**
  - The floor area is different, but the internal configuration is similar
  - Small type($66m^2$ ~ $95.7m^2$)/ Medium type($99m^2$~$128.7m^2$)/ Large type($132m^2$~$161.7m^2$)

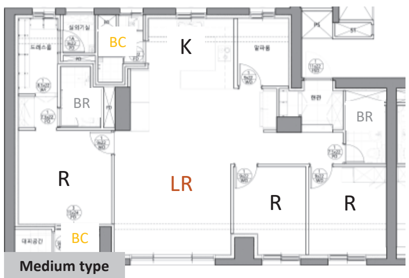
1. Introduction

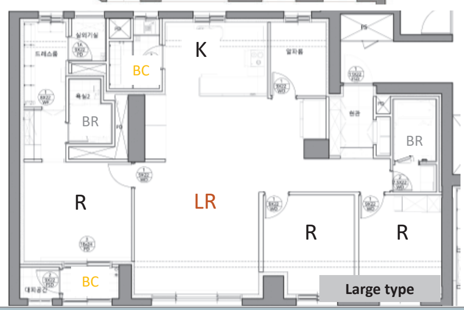
▪ **The floor plan of residential building**

Similar structure and construction methods

- 3 Bedroom(R)
- 1 Living room(LR)
- 1 Kitchen(K)
- 2 Bathroom(BR)
- 2 Balcony(BC)
- 1 Entrance door
- 1 Ventilation system





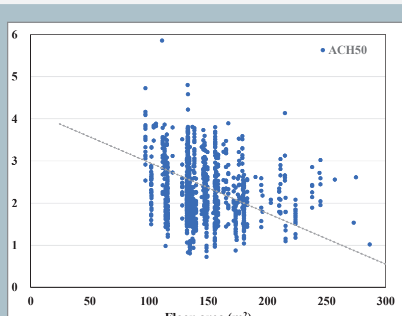


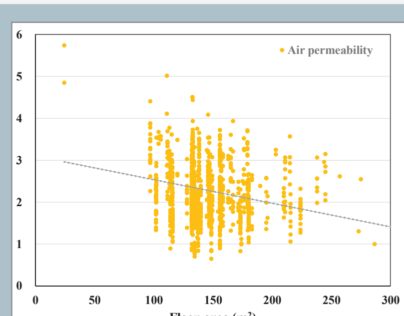
1. Introduction

▪ **ACH50 & air permeability according to the floor area**

- The same airtightness techniques and construction details were applied
- Large floor area → ACH50 is tighter than air permeability
- Small floor area → ACH50 is looser than air permeability

➔ **The potential air leakage sources are similar, but there are many difference in values**





Kyung-Hwan, J et al., 2020; https://db.baip.co.kr/

2023 AIVC conference

1. Introduction

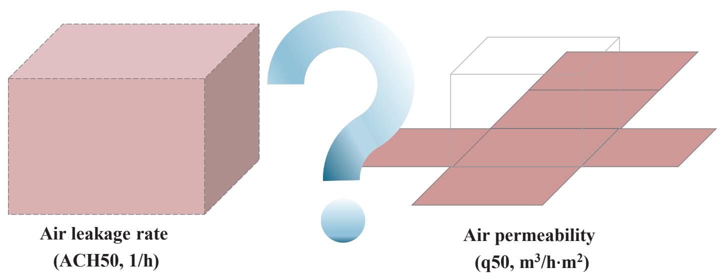
• 6

- **Purpose of this study**

To properly evaluate the level of airtightness,
it is necessary to understand the characteristics of
ACH50 and air permeability

➔ **Analyze each characteristic by comparing ACH50 and air permeability**

➔ **Analyze the conversion ratio between ACH50 and air permeability**

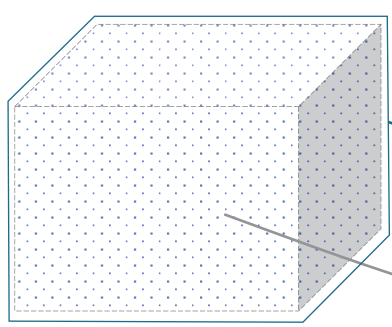


2023 AIVC conference

2. Airtightness Expression

• 7

- **ACH50 & Air permeability**
  - ACH50 : how many times the air in a room is leak out when a pressure of 50 Pa is applied to the building envelope
  - Air permeability: The amount of leakage through the building envelope

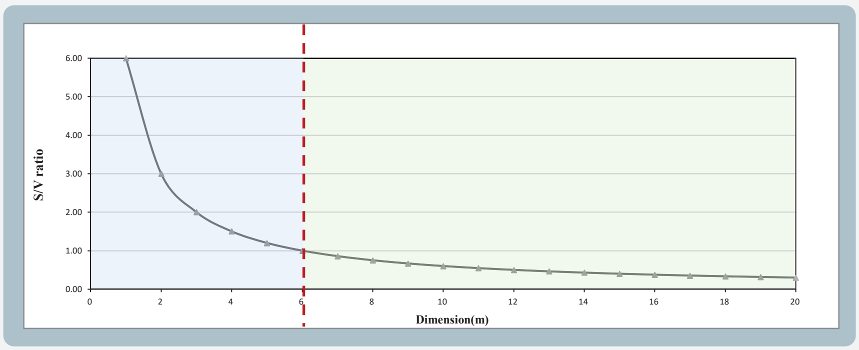


$$ACH50(n50) = \frac{CMH50}{V}$$

$$Air\ permeability(q50) = \frac{CMH50}{S}$$

2. Airtightness Expression

- **ACH50 & Air permeability**
  - Growth rate: Volume > Surface area → Differences occur depending on the size of the building
  - S/V ratio change
    - Dimension < 6 → Air permeability appears to be tighter than ACH50
    - Dimension > 6 → ACH50 appears to be tighter than air permeability



Surface area > Volume | Surface area < Volume

3. Field Measurement of Airtightness in Residential Buildings

- **Field measurement summary**

Classification	Small type	Medium type	Large type
Building Use		Multi-unit dwelling	
Construction year		2017	
Construction type		Reinforced concrete structure, Flat slab	
Number of Unit	24	24	24
Floor area(m^2)	101.76~102.21	134.56~137.56	173.18

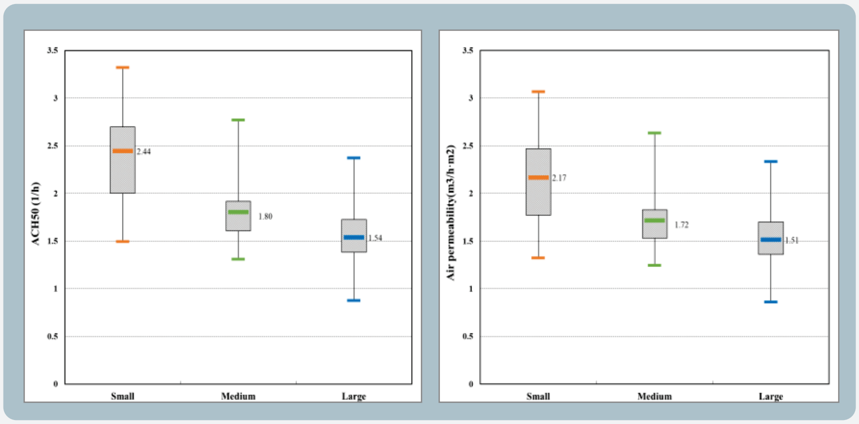
✓ Classification by floor area
- Small type
- Medium type
- Large type

✓ Blower door test
- ISO 9972

✓ Random sampling
- 24 units were selected(total 274 units)

3. Field Measurement of Airtightness in Residential Buildings

- **Field measurement results**
  - Air permeability is lower than ACH50
  - Airtightness decreases as floor area increases
  - The change rate of ACH50 is larger than air permeability



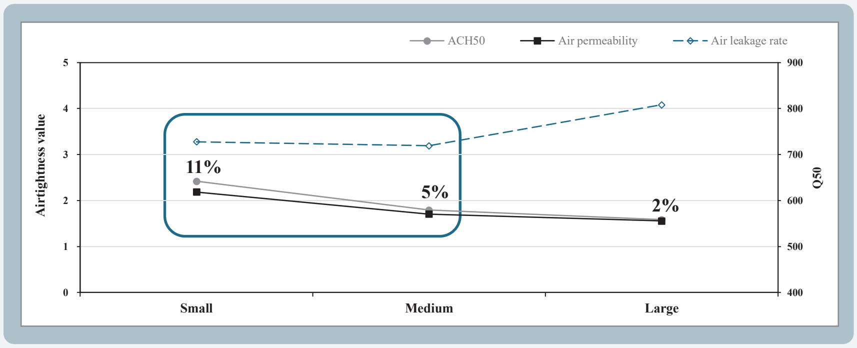
3. Field Measurement of Airtightness in Residential Buildings

- **Airtightness according to the floor area**
  - Comparing the change rate → The difference is especially noticeable for small type

➔ Q is similar, but the difference is larger due to the difference in area and volume

  - The rate of change in ACH50 is greater than air permeability

➔ Air permeability is more suitable for airtightness evaluate



2023 AIVC conference

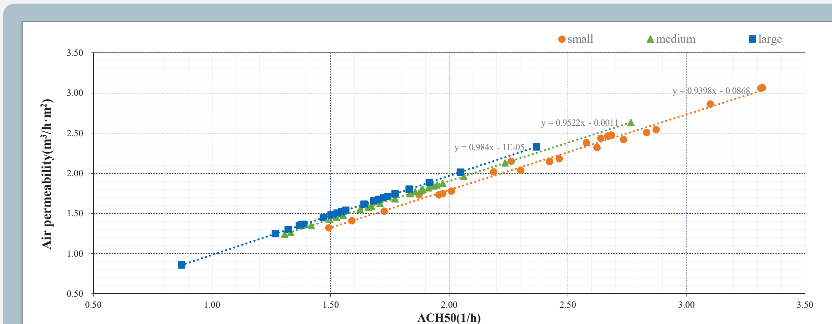
4. Correlation Analysis Between ACH50 and Air Permeability

- **Correlation of ACH50 and Air permeability**
  - ACH50 and air permeability are linearly related

    : Correlation coefficients is close to 1

➔ Indicates a strong positive correlation

➔ More difference in small type



2023 AIVC conference

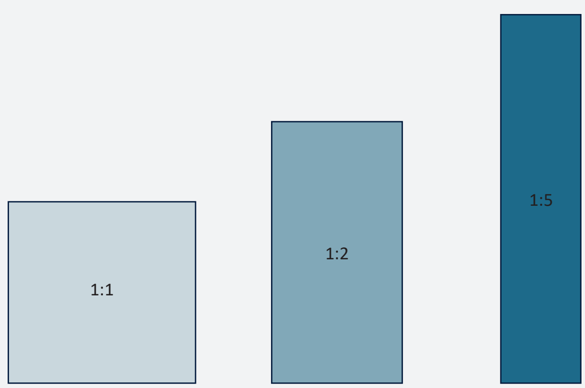
4. Correlation Analysis Between ACH50 and Air Permeability

- **Analysis the s/v ratio by floor area considering aspect ratio**
  - Model summary

    : Constant height

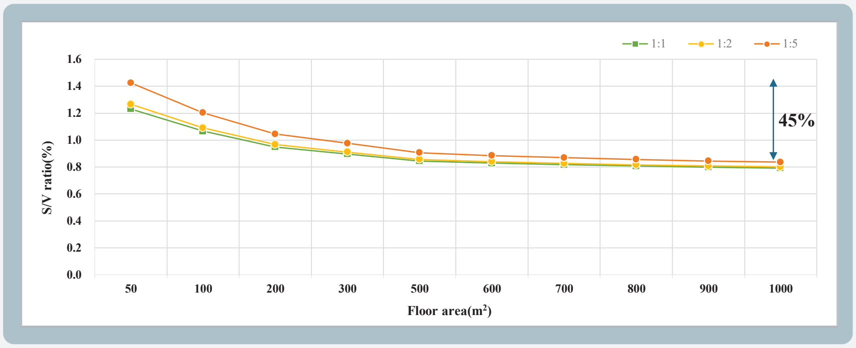
    : Change only the aspect ratio with the same area

Classification	
Building Use	Multi-unit dwelling
Building height	3
Floor area(m^2)	50 ~ 1000
Floor type	1:1, 1:2, 1:5



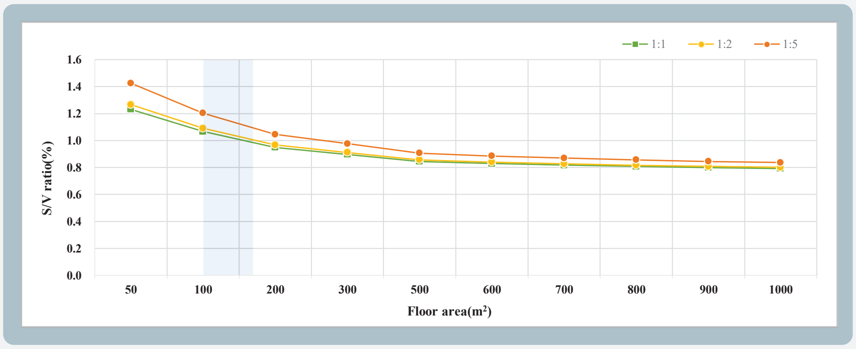
4. Correlation Analysis Between ACH50 and Air Permeability

- **Analysis the s/v ratio by floor area considering aspect ratio**
  - The s/v ratio ranged
    : 50m² : 1.23 ~ 1.43, 1000m² : 0.79 ~ 0.84, 100m² ~ 200m²: 1
  - The smaller the difference in aspect ratio, the lower the s/v ratio
  - The lower the floor area, the more it is affected by the aspect ratio



4. Correlation Analysis Between ACH50 and Air Permeability

- **Analysis the s/v ratio by floor area considering aspect ratio**
  - In the measured data, the s/v ratio corresponds to 1
  - ➔ The data range of floor are is from 101.76 to 173.18
  - The residential building does not have a wide range of floor area in Korea
  - ➔ The conversion ratio between ACH50 and air permeability is close to 1
  - The floor area be <100 m² or >200 m²
  - ➔ It is necessary to evaluate the airtightness results considering the s/v ratio by floor area



5. Conclusions

In this study, the characteristics of ACH50 and air permeability were analyzed to compare the airtightness of buildings of various sizes.

1. The change rate of ACH50 is greater than air permeability and air permeability is more suitable for airtightness evaluate due to its stability

2. The s/v ratio tended to decrease as the floor area increased, the difference in aspect ratio became smaller

3. In Korea, the s/v ratio is close to 1. However, since the s/v ratio varies depending on the floor area, it is necessary to convert the airtightness expression by considering the floor area

→ ***Although the s/v ratio of Korean residential buildings is close to 1, the same standard should not be applied because of the difference in change***

→ ***Airtightness is related to the flow rate through the envelope, additional consideration of component affecting the air flow rate is required for airtightness evaluation***

Airtightness predictive model from measured data of residential buildings in Spain

Irene Poza Casado, GIR Arquitectura & Energía
Pilar Rodríguez-del-Tío, Dpto. Estadística e Investigación Operativa
Miguel Fernández-Temprano, Dpto. Estadística e Investigación Operativa
Miguel Ángel Padilla-Marcos, GIR Arquitectura & Energía
Alberto Meiss, GIR Arquitectura & Energía

Universidad de Valladolid

43rd AIVC -11th TightVent & 9th venticool Conference: *Ventilation, IEQ and health in sustainable buildings*
October 4-5, 2023 Aalborg University, Copenhagen, Denmark

1

Building and Environment 223 (2022) 109435

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

An envelope airtightness predictive model for residential buildings in Spain

Irene Poza-Casado [a], Pilar Rodríguez-del-Tío [b], Miguel Fernández-Temprano [b], Miguel-Ángel Padilla-Marcos [a], Alberto Meiss [a,*]

[a] *GIR Arquitectura & Energía, Dpto. Construcciones Arquitectónicas, Ingeniería del Terreno y Mecánica de los Medios Continuos y Teoría de Estructuras, Universidad de Valladolid. E.T.S. de Arquitectura, Avenida Salamanca, 18, 47014, Valladolid, Spain*
[b] *Dpto. Estadística e Investigación Operativa, E. de Ingenierías Industriales - Sede Doctor Mergelina, Paseo Prado de la Magdalena 3-5, 47011, Valladolid, Spain*

ARTICLE INFO

Keywords:
Predictive model
Airtightness
Blowerdoor
Dwellings
Database
Statistical analysis

ABSTRACT

The need for airtightness control is a reality given its impact on buildings' energy use and Indoor Air Quality (IAQ). For the past few years, this fact has resulted in energy performance regulations establishment that involves airtightness requirements in many countries in Europe and North America. In this sense, efforts should not only be focused on new buildings, but also existing ones. Considering that around 90% of the built stock in the EU is expected to still be standing in 2050 and that almost 75% of the buildings are energy inefficient, attention must be paid to retrofitting actions.

Airtightness predictive models have become useful in the decision-making process and to estimate input values in energy performance simulation tools. So far, several predictive models have been developed in different countries. However, specific construction systems and practices lead to a lack of consensus regarding the impact of different factors on airtightness performance. Therefore, the applicability of existing models is limited to their specific contexts.

This paper presents a predictive model for envelope airtightness, which was developed from a database that contains a fully characterised representative sample of the residential building stock in Spain. A General Linear Model (GLM) was considered to assess significant variables related to the age of the building, typology, building state, construction system, and dimensions. As a result, a predictive model is presented and validated. Overall, even if some limitations were identified, the relevance of the model proposed is warranted from the statistical point of view. The airtightness predictive model presented offers a procedure for airtightness estimation of residential buildings in Spain.

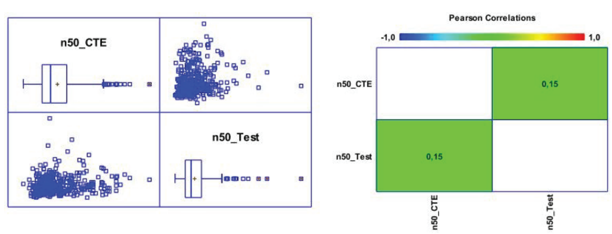
Poza-Casado, Irene, Pilar Rodríguez-del-Tío, Miguel Fernández-Temprano, Miguel-Ángel Padilla-Marcos, and Alberto Meiss. 2022. "An Envelope Airtightness Predictive Model for Residential Buildings in Spain." Building and Environment 223(July):109435. doi: 10.1016/j.buildenv.2022.109435

2

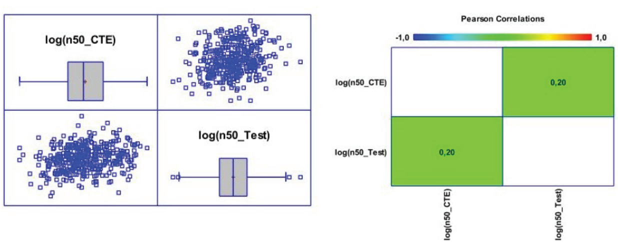
Structure

- Context
- Motivation
- Sample and airtightness
- Statistical model development
- Results
- An application example
- Conclusions and challenges

Context



Correlation analysis between the n50 values obtained from pressurization tests and reference values



Correlation analysis between the logarithms of the n50 values obtained from pressurization tests and reference values

- Inaccurate reference values to prove compliance with building regulations

Motivation

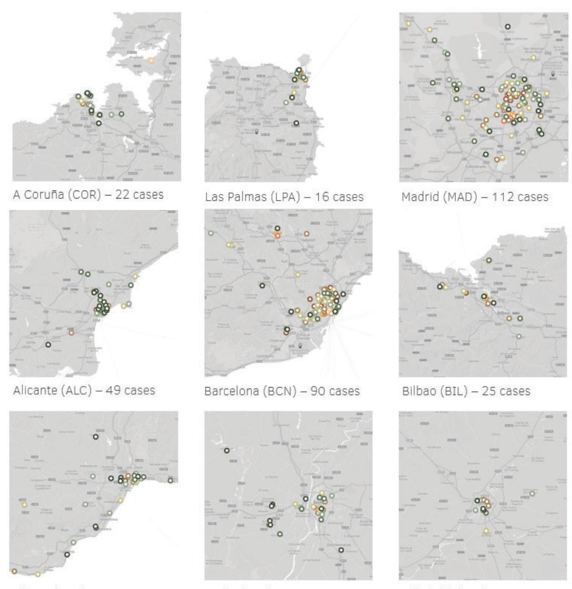
Importance of predictive models:

- Estimate the airtightness from building characteristics
- Evaluate the impact of potential improvements
- Controlling costs and time in the decision-making process
- Estimate input values in EP simulation tools
- Understand the factors that most impact airtightness

<u>**airtightness estimation cannot substitute on-site testing**</u>

Sample and airtightness

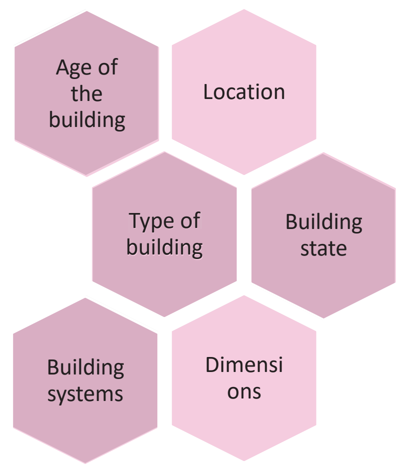
- Dataset: 400 dwellings
  - Representative of the existing built stock
  - Typology, age, climate zone
- Airtightness: Blower Door tests
- Characterization
  - Identification information
  - Configuration
  - Construction of the envelope
  - Building systems



Statistical model development

- General Linear Model (GLM)
- Qualitative and quantitative variables
- Iterative procedure
- Main effects and interactions

$$Y = \beta_0 + \sum_{i=1}^{p} \beta_i X_i + \sum_{i<j} \tau_{ij}(X_i X_j) + \varepsilon$$



Final variables

Climate zone	Period of construction	Typology	Number of bathrooms	Retrofitting state	Type of ceiling
• Winter severity • Summer severity	• Before 1980 • After 1980	• Single family • Multi family	• 0…5	• Original • Retrofitted	• No false ceiling • False ceiling only wet romos • False ceiling

Window permeability	Window material	Shutter position	Heating system	Share of Windows	Share of opaque envelope
• Class (UNE-EN 12207) • 0-4	• Aluminium • PVC • Wood • Steel • Wood • Steel	• Non integrated • Internal • External • No shutter	• No heating • Heating units • Underfloor • Ducts	• Quantitative	• Quantitative

Results

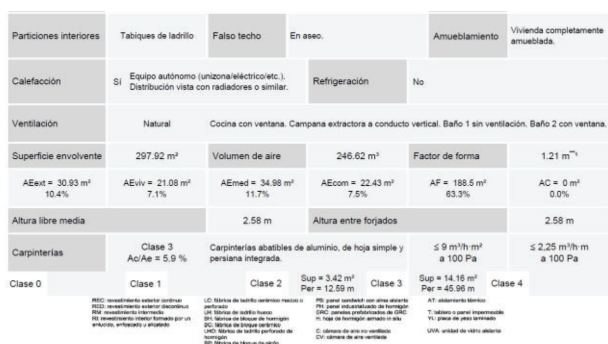
- 12 main effects and 2 interactions
- Significant variables in line with previously developed models
- Included singularities of the Spanish national built stock
- The model can explain 42.9% of the variability of the response
- Robust model in spite of limitations
  - Influence of supervision and workmanship
  - Size and representativeness of the sample

Table 5: Equation of the final GLM predictive model for airtightness.

Parameter	Coefficient	Parameter	Coefficient
Intercept	0.273	Shutter position. P04	0a
Retrofitting state. Original	0.137**	False ceiling. FC0	-0.313***
Retrofitting state. Retrofitted	0a	False ceiling. FC1	-0.264***
Climate zone. A3	0.346**	False ceiling. FC2	0a
Climate zone. B4	0.545***	Typology. Multifamily	0.412**
Climate zone. C1	0.273	Typology. Single-family	0a
Climate zone. C2	0.630***	Heating system. No heating	0.074
Climate zone. C3	0.053	Heating system. Underfloor heating	-0.041
Climate zone. D2	0.575***	Heating system. Ducts	0.261***
Climate zone. α3	0a	Heating system. Other systems	0.173
Period of construction. Before 1980	-0.329***	Heating system. Heating units	0a
Period of construction. Since 1980	0a	Number of bathrooms. 0	0.610**
Window permeability. Class 0 or 1	0.596***	Number of bathrooms. 1	0.347***
Window permeability. Class 2	0.322***	Number of bathrooms. 2	0.183
Window permeability. Class 3	0.255***	Number of bathrooms. 3	0.090
Window permeability. Class 4	0a	Number of bathrooms. 4 or 5	0a
Window material. Steel	0.071	Share of windows	0.045***
Window material. Aluminium	0.074	Share of opaque envelope	0.003
Window material. Wood	0.298***	Period of construction. Before 1980 * Share of opaque envelope	0.010***
Window material. PVC	0a	Period of construction. After 1980 * Share of opaque envelope	0a
Shutter position. P01	0.195*	Typology. Multifamily * Share of opaque envelope	-0.009**
Shutter position. P02	0.144**	Typology. Single-family * Share of opaque envelope	0a
Shutter position. P03	-0.123		

a. This parameter is set to 0 as it corresponds to the reference class of the variable.
* stands for p-value ≤ 0.1, ** for p-value ≤ 0.05 and *** for p-value ≤ 0.01

An application example



Climate zone	Period of construction	Typology	Number of bathrooms	Retrofitting state	Type of ceiling
• C1	• Before 1980	• Multi family	• 2	• Original	• No false ceiling

Window permeability	Window material	Shutter position	Heating system	Share of Windows	Share of opaque envelope
• Class 3	• Aluminium	• External	• Heating units	• 5,89%	• 4,48%

Parameter	Coefficient
Period of construction. Before 1980 * Share of opaque envelope	0.010***
Period of construction. After 1980 * Share of opaque envelope	0a
Typology. Multifamily * Share of opaque envelope	-0.009**
Typology. Single-family * Share of opaque envelope	0a

Estimated value:

$$n_{50} = 3,081\ h^{-1}$$

$$\log n_{50} = 0,273 + \sum variables + \left(0,003 \cdot \left(\frac{\sum area_{opaque\ env}}{\sum area_{total\ env}} \cdot 100\right)\right) + \left(0,045 \frac{\sum area_{windows}}{\sum area_{total\ env}} \cdot 100\right) + \left(\sum interactions\right) + \varepsilon$$

Parameter	Coefficient
Intercept	0.273
Retrofitting state. Original	0.137**
Retrofitting state. Retrofitted	0a
Climate zone. A3	0.346**
Climate zone. B4	0.545***
Climate zone. C1	0.273
Climate zone. C2	0.630***
Climate zone. C3	0.053
Climate zone. D2	0.575***
Climate zone. α3	0a
Shutter position. P01	0.195*
Shutter position. P02	0.144**
Shutter position. P03	-0.123

Parameter	Coefficient
Period of construction. Before 1980	-0.329***
Period of construction. Since 1980	0a
Window permeability. Class 0 or 1	0.596***
Window permeability. Class 2	0.322***
Window permeability. Class 3	0.255***
Window permeability. Class 4	0a
Window material. Steel	0.071
Window material. Aluminium	0.074
Window material. Wood	0.298***
Window material. PVC	0a

Parameter	Coefficient
Shutter position. P04	0a
False ceiling. FC0	-0.313***
False ceiling. FC1	-0.264***
False ceiling. FC2	0a
Typology. Multifamily	0.412**
Typology. Single-family	0a
Heating system. No heating	0.074
Heating system. Underfloor heating	-0.041
Heating system. Ducts	0.261***
Heating system. Other systems	0.173
Heating system. Heating units	0a
Number of bathrooms. 0	0.610**
Number of bathrooms. 1	0.347***
Number of bathrooms. 2	0.183
Number of bathrooms. 3	0.090
Number of bathrooms. 4 or 5	0a

Conclusions and challenges

- Valuable knowledge
- Added value:
  - Origin of representative data
  - Full characterization of the cases
  - Standardised procedures
  - Both quantitative and qualitative variables and interactions
- Current reference values to prove compliance do not consider important variables

Thank you!

irene.poza@uva.es

*Funding: MOVILIDAD INVESTIGADORES E INVESTIGADORAS UVa-BANCO SANTANDER 2023

Bridging The Mechanical / Enclosure Gap AIVC 2023

4-5 October 2023, Conference, Copenhagen– 43rd AIVC conference

1

David de Sola, AIA, LEED BD+C,
Principal, 3iVE

Nathaniel Fanning, CEM
Associate Principal,
Energy and Infrastructure Service Leader,
Fitzemeyer & Tocci

2

LEARNING OBJECTIVES

- Develop an informed understanding of the symbiotic relationship between high-performance exterior enclosures and the corresponding high-performance mechanical systems in a building.
- Enhance understanding of the ways building interventions and metrics can be used to inform mechanical systems.

The Issue

Enclosure Design and Evaluation is Designed by Architects and Constructed mainly of CSI Division 7 and 8 Trades

Mechanical Design is Designed by HVAC Engineers and constructed by CSI Division 15-23 Tradess

WE DON'T KNOW EACH OTHER

OR EACH OTHER'S WORK

5

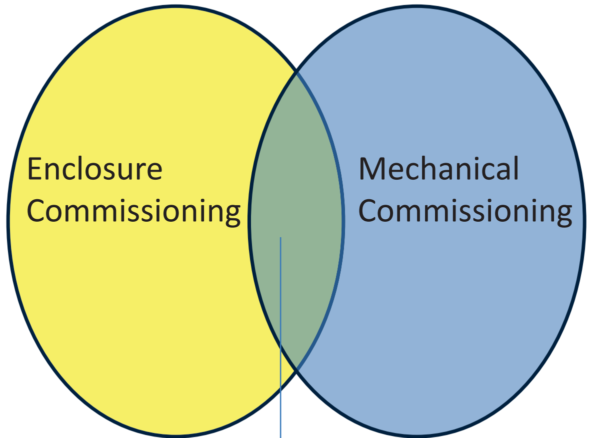
US COMMISSIONING PROCESS

A systematic verification, documentation, applied to all activities during the design, construction, and functional performance testing of the Building Enclosure. It is to confirm that the Owner's Project Requirements (OPR) and the Basis of Design (BoD) are built in accordance with the contract documents.

Enclosure Commissioning

Mechanical Commissioning

6



- Air Leakage
- Durability
- Candidate Evaluation
- Energy Efficiency

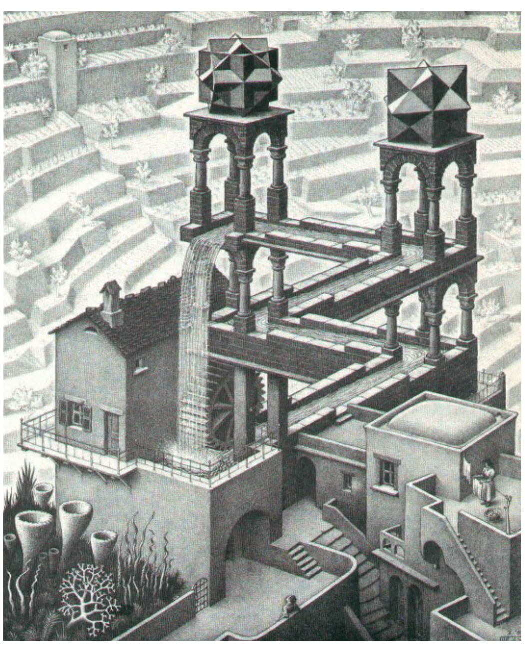
Why Do Mech Engineers Care about Building Envelope?

Infrastructure Sizing

1. Air Leakage
2. Insulation Values
3. Glazing Values

ENCLOSURE THINGS

- Air-Tight Detailing
- Constructability
- Durability

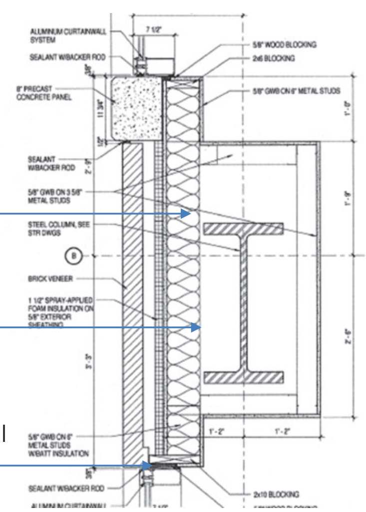


BECx EVALUATION:

Insulation:
Good idea.
BUT…
Is the wall balanced? Is there a risk of condensation?

Can the insulation be installed?

Will sealant work here? How long will it last?



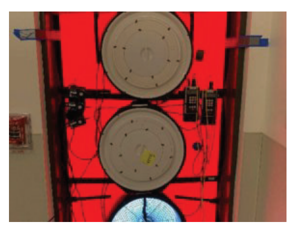
Mechanical Assessment Findings

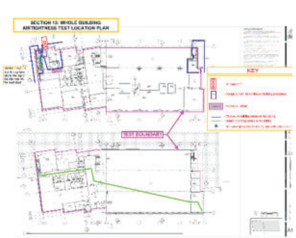
Air Leaks

1. Windows
2. Doors
3. Dampers

11

Whole Building Air Testing





12

How Tight Will the Building Be According to Codes and Sustainability Standards?

Standard	Requirement CFM@75 Pascal/ ft2
2009 IECC International Energy Conservation Code	.55
2012 IECC	.25
R-2000*	.13
LEED IV Multi-Family **	.09
Passivhaus	.05

Table 1: Standards and Requirements for Air Leakage
•*Standard for Energy Efficiency in New Construction developed by Natural Resources Canada
•**50 Pascal, 2 Point Option, IECC Climate Zone 5-7
•*Table References: Genge, C. 2014; USGBC, 2018; USGBC LEED BD+C Homes Air Infiltration 2018*

13

How Tight Can We Count On?

Case	Building Type	Measured Air Leakage Rate at 75 PA
1	Elementary School 2018	.06
2	Library 2020	.06
3	University Academic Building 2016	.09
4	Elementary School 2020	1.2*

14

Where Do Building Leak?

- Roof/wall intersections
- Bulkhead leakage into attic spaces
- Overhead doors, mainly at base and sides, not between sections
- Masonry Block /f loor slab intersections
- Curtain wall / floor slab intersections
- Unsealed walls above ceiling lines
- Doors and windows (both thermally broken and unbroken)
- **Ductwork and pipe penetrations**
- **Underground steam lines**
- **Exhaust and make-up air fans with one-way dampers**

15

DURABILITY: WHY WE SHOULD ALL CARE

- Climate change requires it
- Migration of people to less inhabitable locations
- Energy and Environmental impacts of construction

16

INSTITUTIONAL DURABILITY

Table 2
Categories of Design Service Life for Buildings
(See Clauses 5.2.3 and 6.2.)

Category	Design service life for building	Examples
Temporary	Up to ten years	• non-permanent construction buildings, sales offices, bunkhouses • temporary exhibition buildings
Medium life	25 to 49 years	• most industrial buildings • most parking structures*
Long life	50 to 99 years	• most residential, commercial, and office buildings • health and educational buildings • parking structures below buildings designed for long life category*
Permanent	Minimum period, 100 years	• monumental buildings (eg, national museums, art galleries, archives) • heritage† buildings

CSA 478 19 Guideline on Durability in Buildings

17

THE CASE FOR DURABILITY TO OWNERS

- Exchange of resources for function over time
- Accreditation for Sustainable Program
- Impacts of Economic Investment in Equipment / Years in Service

18

DURABILITY: SOUNDS GOOD. HOW DO I GET IT?

- Start With Robust Materials
- Deploy Them Appropriately
- Understand their interaction with their neighbors
- Understand how details are constructed

ENCLOSURE DURABILITY CONSIDERATIONS

- Does material work for climate?

- Fauna
- Flora

21

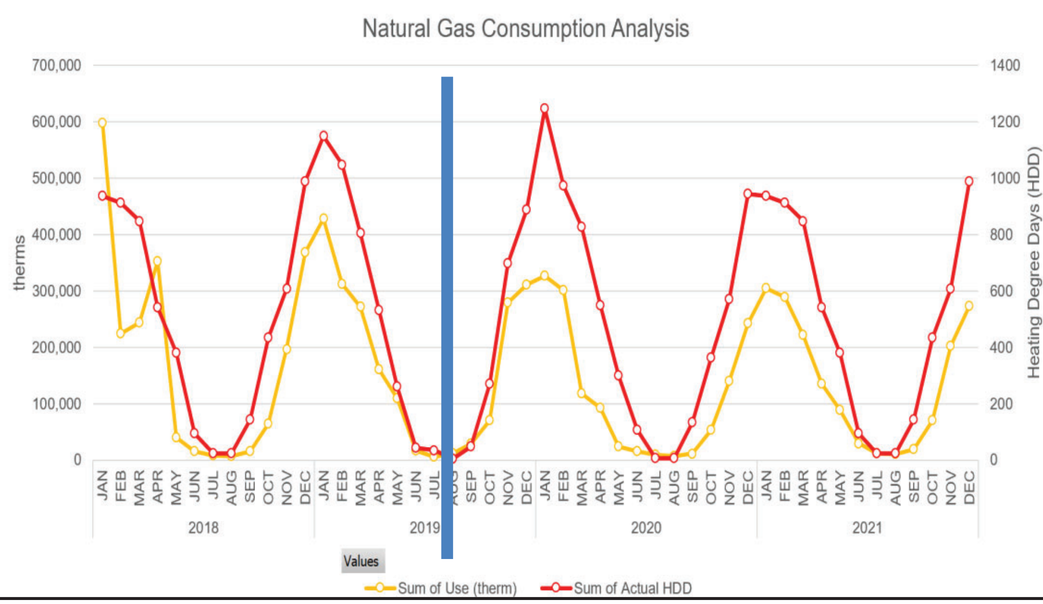
- Is sufficiently skilled labor available to achieve Design Intent?

22

- Are the materials sufficiently durable for their placement?

23

Mechanical and Building Envelope Upgrade Results



24

DISCUSSION

25

THANK YOU

David de Sola, AIA, LEED BD+C
Principal, 3iVE

Nathaniel Fanning, CEM
Associate Principal,
Energy and Infrastructure
Service Leader,
Fitzemeyer & Tocci

26

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings
October 4-5 2023 Copenhagen Denmark

Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback

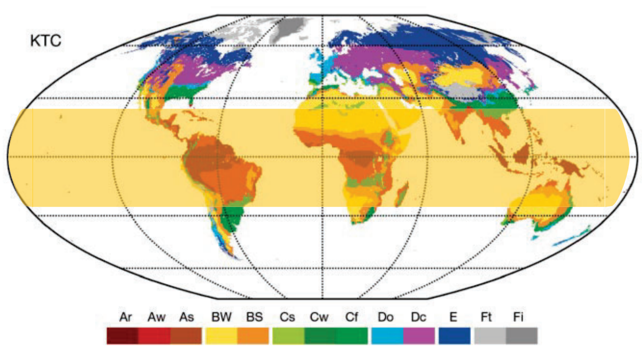
Topical Session 1C: Windows and ceiling fans occupant behaviour model coupling methodology with building energy models A tropical case study

Maareva PAYET * , LEU Réunion / La Reunion University - PIMENT, France
Maxime BOULINGUEZ**, LEU Réunion / La Réunion University - PIMENT, France

*mp@leureunion.fr
** maxime.boulinguez@univ-reunion.fr

DEFINITION OF HUMID TROPICAL CLIMATE

FEATURES and ISSUES



According to Koppen-Trewartha
- Average monthly temperature > 18°C
- Rainfall threshold > 60mm over several months

The surface area of Aw subclass territories has increased since 1965-1994

(Belda et al. 2014)

50% of the population in the intertropical zone forecasted by 2050

(University f James Cook , Australia, 2014)

75% of the population in urban areas

(Rodrigues et al., 2019)

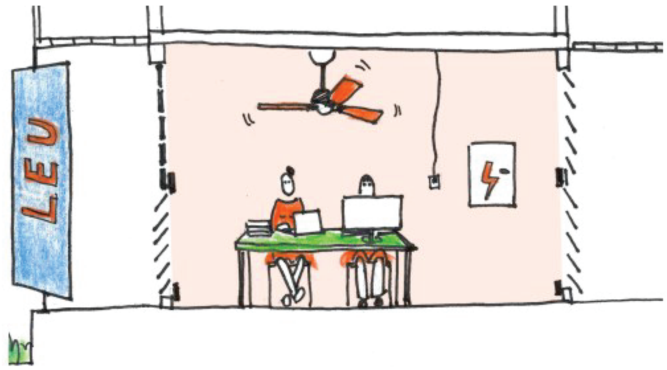
MIXED MODE BUILDINGS

DEFINITIONS

Passive cooling systems -> Openings
Low-energy cooling systems -> Ceiling Fans
High-energy mechanical systems -> HVAC

Zoned Mixte Mode Building
(Brager, 2006)

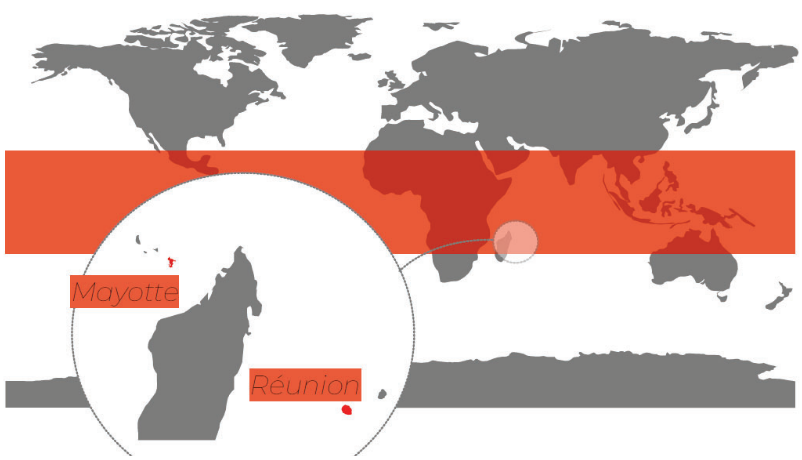
Different controls *(Raja, 2014)*



3

CASE STUDY IN REUNION ISLAND

ILET DU CENTRE OFFICE BUILDING



4

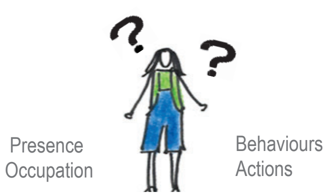
CASE STUDY IN REUNION ISLAND

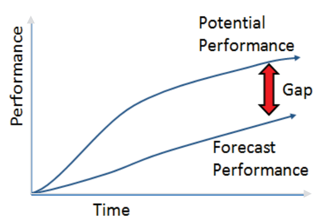
ILET DU CENTRE OFFICE BUILDING OVERVIEW

310 m²
Two open plan floors (NV)
Singles offices (NV or AC)
Meeting rooms (AC)
IT room (AC).

USER BEHAVIOUR IN MIXED MODE BUILDINGS

RESEARCH QUESTIONS





Environmental factors

Personnal factors

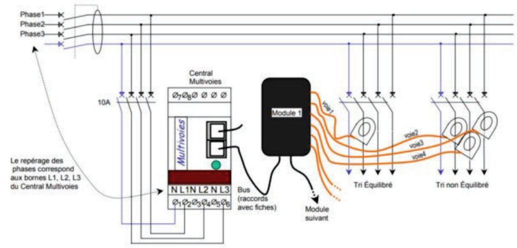
How to assess user behavior in mixed-mode buildings operating with ventilation ?

How to estimate the presence of users on openings and ceiling fans during the design phase ?

1- Model behaviours based on measured data
2- Integrate these behavioural models into a building model

CASE STUDY IN REUNION ISLAND

ILET DU CENTRE OFFICE BUILDING FIELD MEASUREMENTS

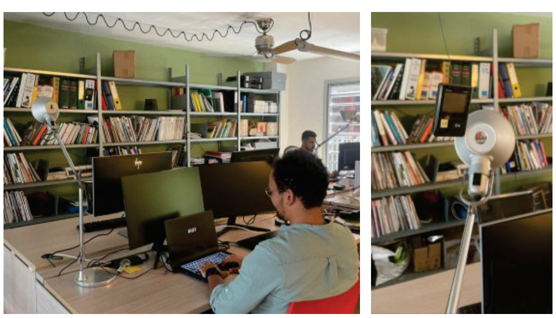


- 37 **position sensors** NODON (ENOCEAN)
- Irregular timestamp
- 2 states [**0 ou 1**]

- Energy meters OMEGAWATT
- 1 min timestamp
- Ceiling fan power [W] and offices plug [W]

CASE STUDY IN REUNION ISLAND

ILET DU CENTRE OFFICE BUILINDG FIELD MEASUREMENTS



- 9 TESTO 174H temp/rh sensors
- Regular timestamp
- Air Temperature (+/- 0.5°C) et relative humidity (+/- 3 %HR)

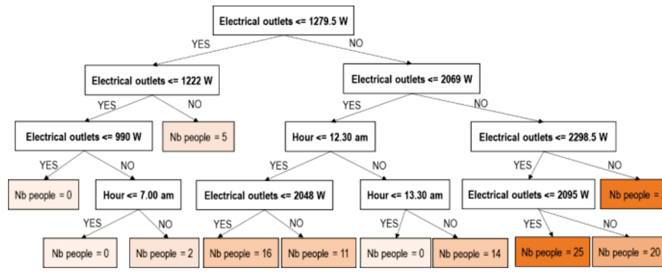
- Meteorological station

(Less than 1km far from site)

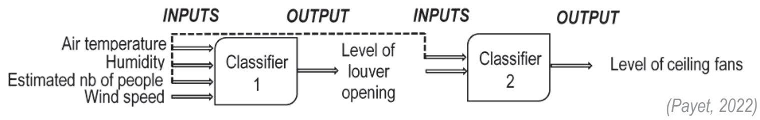
OCCUPATION AND BEHAVIOURS MODELS

CLASSIFICATION METHODS

Occupation model
(Decision Tree)



Ceiling fans and openings models
(Random forest)

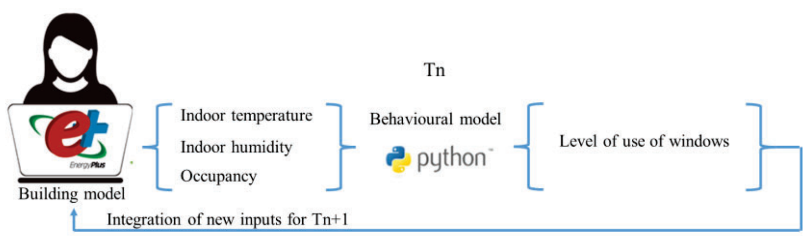


(Payet, 2022)

Payet, M., David, M., Lauret, P., Amayri, M., Ploix, S., Garde, F., 2022. *Modelling of occupant behaviour in non-residential mixed-mode buildings: The distinctive features of tropical climates.* Energy and Buildings 259, 111895. https://doi.org/10.1016/j.enbuild.2022.111895

IMPLEMENTING BEHAVIOURAL MODELS IN ENERGYPLUS

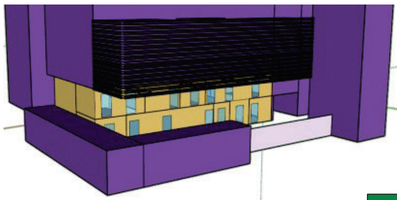
PYTHON PLUGIN METHOD



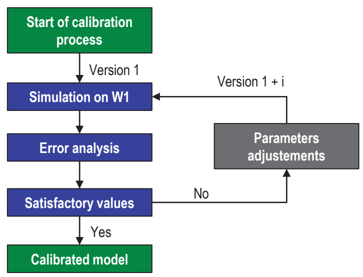
Method	Ease of implementation	Flexibility
Direct modelling	++++	+
Code customization	++	++
Customization of Core code	+	+++
Co-simulation	++	++++
Python plugin	+++	++++

BUILDING ENERGY MODEL

VALIDATION (based on indoor conditions)



Week simulated	Step	From	To	Season	Internal heat gains from users
W1	Calibration	20/12/2020	27/12/2020	Summer	No
W2	Validation	01/12/2020	08/12/2020	Summer	Yes
W3	Validation	06/07/2020	13/07/2020	Winter	Yes
W4	Validation	05/10/2020	12/10/2020	Mid-season	Yes



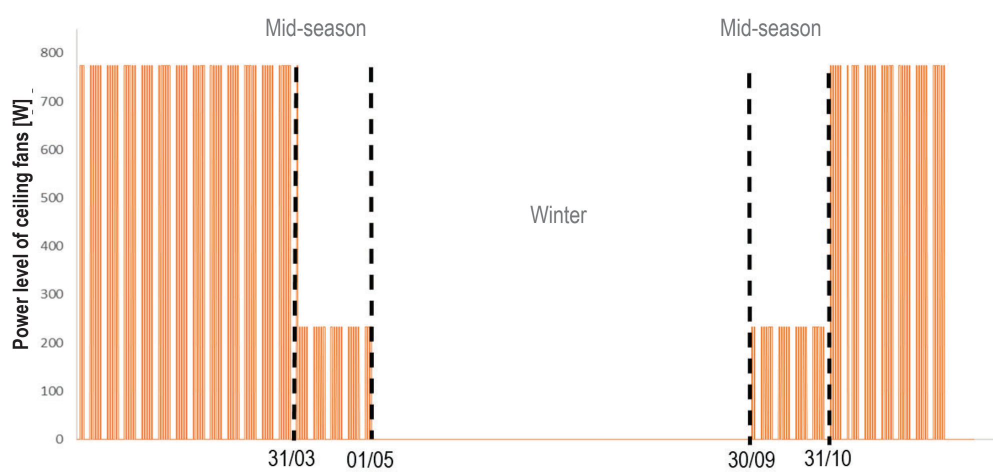
Validation results	Standards
NMBEh ≤ 5.3 %	NMBEh ≤ 10 %
CV(RMSE)h ≤ 6.6 %	CV(RMSE)h ≤ 30 %
MADh ≤ 2.8 °C	(Baba, 2022)
MBEh ≤ 1.2 °C	(Baba, 2022)

- ASHARE Guideline 14 (Measurement and Energy Demand)
- Int. Measurement & Verification protocol recommanded by French Energy Agency ADEME
- Mean Bias Error & Mean Absolute Deviation

11

CONVENTIONAL DESIGN OFFICE MODEL FOR CEILING FAN USE

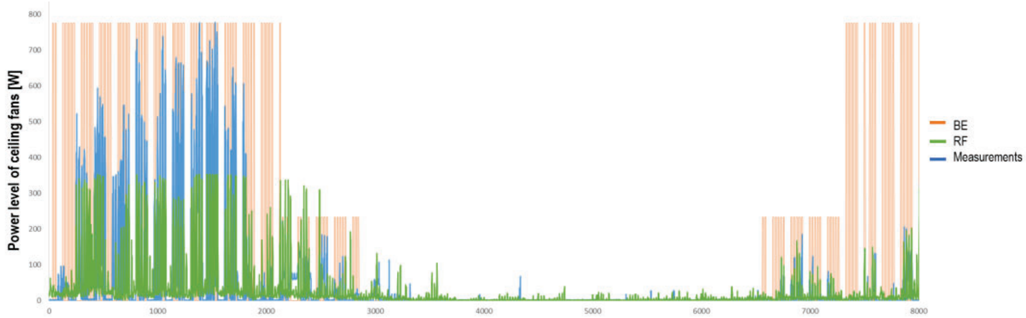
BASELINE METHOD

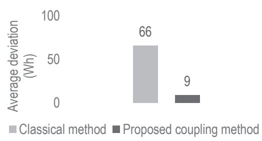


12

COMPARISON WITH OUR RESULTS

PROPOSED COUPLING METHOD NOTED in GREEN / baseline orange





Skill Score: assessing the value of a new model compared with a reference model

$SS_{\text{Typical design office model / Coupling method proposed}} = 63\ \%$

TO CONCLUDE

LIMITS OF THE PRESENT WORK

- Lack of generalisation capabilities
- Only NV + CF has been modeled so far (no AC+CF)
- Better estimate Ceiling Fans use but still need to improve related energy use for each predicted class

PERSPECTIVES

- Extend field measurement studies to other building types and user categories to better teach models
- Add a level of complexity for mixed-mode cooled building with AC
- Investigate new way to estimate class energy use (seasonal class / monthly class, add model input parameter(s))

Thank you for your attention

Further readings:

Payet, M., 2022. *Simulation du comportement des usagers dans les bâtiments tertiaires à faible consommation énergétique, en zone tropicale (phdthesis).* University of la Reunion.

Payet, M., David, M., Lauret, P., Amayri, M., Ploix, S., Garde, F., 2022. *Modelling of occupant behaviour in non-residential mixed-mode buildings: The distinctive features of tropical climates.* Energy and Buildings 259, 111895. https://doi.org/10.1016/j.enbuild.2022.111895

LAB PIMENT · LEU REUNION · anrt association nationale recherche technologie · Cifre

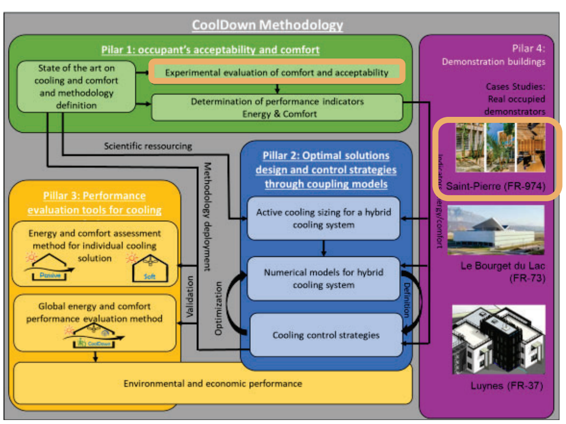
An innovative approach to better understand hot discomfort, based on the measurement of global human responses, including physiological and sensory indicators

Application to end-users of mixed mode cooled buildings under tropical climate conditions

43rd AIVC -11th TightVent & 9th venticool Conference, October 4-5, 2023, Aalborg Univ., Copenhagen, Dk

Gwénaëlle Haese, Maxime Boulinguez, Pierre Bernaud, Anthony Couzinet

Context and objectives



3 main objectives in the task « Experimental evaluation of comfort and acceptability » of the CoolDown project

1. Measure physiological response directly on humans to better understand the origin of thermal discomfort.
2. Identify the link between office climatic conditions, perceived comfort and human physiological response.
3. Optimize and experimentally validate predictions from comfort models.

Buildings

Saint-Pierre, La Réunion
Average annual daytime temperatures
[7 a.m. to 6 p.m.] > 23°C

Hot period, expected daily temperature amplitude of 24 to 34°C with a relative humidity > 75%

"**Ilet du Centre**" building (IDC): large double floor open space office building built in 2008.

> Bioclimatic design primarily based on natural cross ventilation with louvres openings and double protection facades acting as fixed shadow devices (described by Payet et al. (2022)).

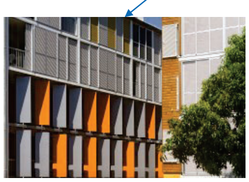
"**CoArchitectes**" (COA): first floor of an old basic concrete residential house on the city's seaside.

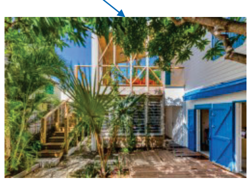
> Recently renewed and extended as an office building.
> No natural cross ventilation in all spaces, 2/3 of the building with single-sided openings, therefore equipped with AC units and ceiling fans.
> Limited solar impact thanks to a second floor and very dense nearby vegetation.

Subjects

21 volunteers ♀ 11 ♂ 10

25 to 52 (mean age: 35.2 ± 9.1)





IDC building:
SU1-8

COA building:
SU9-21

Architects, engineers and landscape designers

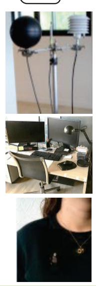
Sensitized to the AEC industry's environmental impact and having a basic-to-good understanding of comfort components and their impact on energy use and carbon emission in buildings

Methodology

Innovative approach
Combined measures on 21 subjects in their offices

Environmental measures

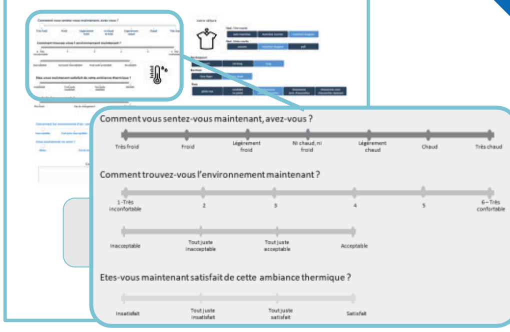
- Meteorological data
- Air temperature, relative humidity, radiation and air velocity in office spaces
- Air temperature, relative humidity at each desk
- Air temperature, relative humidity (subjects' micro-climate)



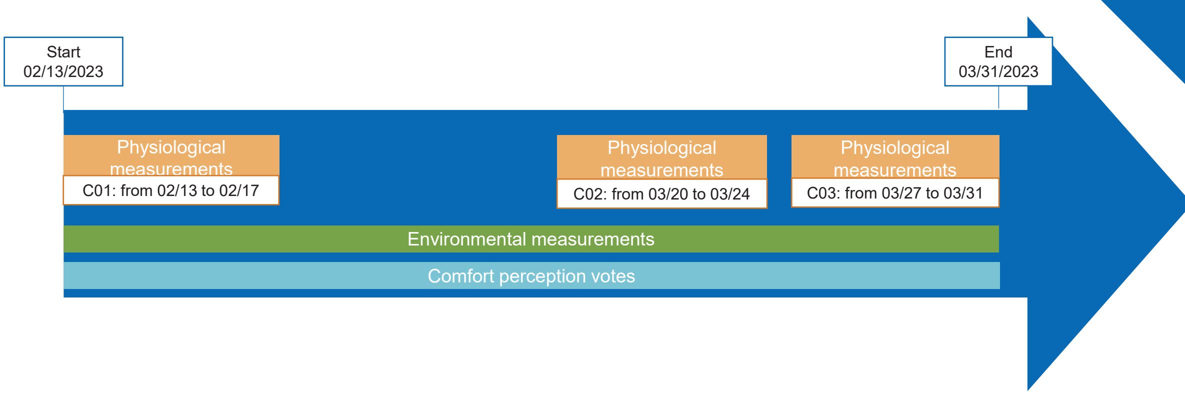
Physiological measures

- Skin temperature
- Core temperature
- Heart rate

Comfort perception measures



Experimental campaigns



Data acquisition

Questionnaire

Q1	Q2	Q3	Q4	Q5	Q6

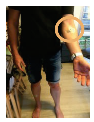
- Sensory questionnaires on clothing, activity, thermal sensation, perception of thermal comfort, level of acceptability and satisfaction
- 1 to 6 times per day

Smart watch

Heart rate

- Heart rate recorded by a connected watch,
- Acquisition of beats per minute in one-second time steps

Thermo-buttons



Temperature - shin	Temperature - forearm	Temperature - chest	Temperature - core

- Skin temperatures measured using thermo-buttons attached to the tibia, torso and forearm with biomedical dressings
- Measured every 5 minutes

Mereen database

Meteorological data

- From French weather stations located at Saint-Pierre, La Réunion
- Data at hourly intervals

Hygro-buttons

Temperature - pin	Radiation - pin	Relative humidity - pin

- Temperature and relative humidity close to the participant measured by a hygro-button attached to clothes
- At 5-minute time intervals (pin)

T°/RH box

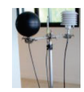
Temperature box	Relative humidity box

- Temperature and relative humidity from the recording of the PULSE comfort box
- Measured at 10-minute intervals.

Measurement station

Temperature - station	Relatiev humidity - station	Air velocity - station	Radiation - station

- Temperature, relative humidity, radiation, air velocity in the office measured by comfort measurements stations
- At 15-second time intervals



Data collection and quality

Synchronization of the data from the different sources of measurements

→ 935 lines, corresponding to the **935 questionnaires** obtained from the 21 participants over the 3 campaigns.

Subject	Date	Time	Q1	Q2	Q3	Q4	Q5	Q6	Temperature - shin	Temperature - foremarm	Temperature - chest	Temperature - core	Heart rate	Mean skin temperature	Meteorological data	Temperature - station	Relatiev humidity - station	Air velocity - station	Radiation - station	Temperature - pin	Radiation - pin	Relative humidity - pin	Temperature box	Relative humidity box
SU1	02/13/2023	10:00																						
SU21	03/31/2023	18:15																						

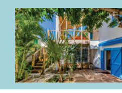
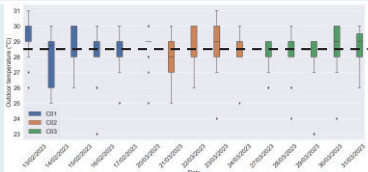
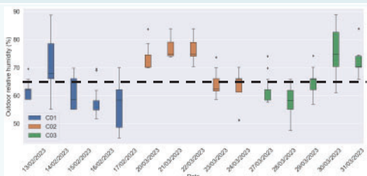
Column groups: Questionnaire (Q1–Q6); Thermo-buttons (Temperature - shin, foremarm, chest, core); Smart watch (Heart rate); Calculated (Mean skin temperature); Mereen database (Meteorological data); Measurement station (Temperature, Relatiev humidity, Air velocity, Radiation - station); Hygro-buttons (Temperature, Radiation, Relative humidity - pin); T°/RH box (Temperature box, Relative humidity box).

0.5°C mean difference between the temperatures acquired by the box and the comfort stations,
3.6%mean difference for relative humidity → ***difference < uncertainty of the sensors.***

→ Missing values from the comfort stations completed with the values of the boxes:
- 55 missing values remaining after the database cleaning for indoor temperature and indoor relative humidity measurements,
- 30 for the skin temperatures.

Outdoor and indoor conditions*

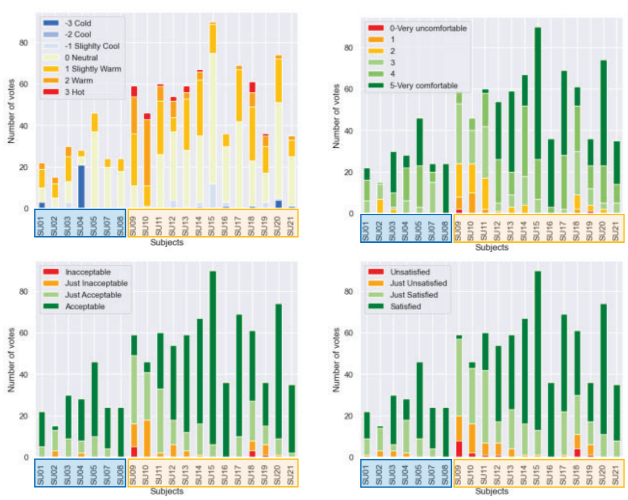
CoolDown

	Outdoor conditions		IDC Building	COA building
				
Mean **T** (°C)	28.5°C		**28.3°C** min: 25.4°C max: 29.4°C	**29.3°C** min: 23.9°C max: 31.3°C
Mean **RH** (%)	64.7%		**59.8%** min: 51.5% max: 81.8%	**67.1%** min: 50% max: 82.5%
Aeraulic conditions	**Wind** from the **SE**, at a mean **speed of 6.5 m/s** (min: 0 m/s, max: 13.4 m/s)		Windows opened 85% of the time.	

*Conditions seen by the subjects in the office buildings

Comfort perception of the occupants

CoolDown



> **Volunteers were globally satisfied (**62% satisfied and 29% just satisfied)

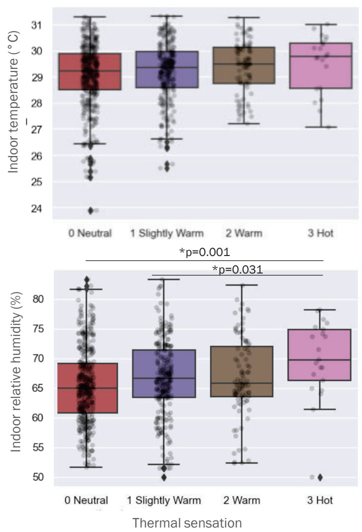
> With a thermal sensation mainly neutral (50%) or slightly warm (30%)

> Same analysis for comfort and acceptability.

> **Only COA building occupants felt “hot” and “unsatisfied”**

Data crossing

CoolDown



> The mean indoor temperature for each modality of thermal sensation is similar (about 29.5°C)

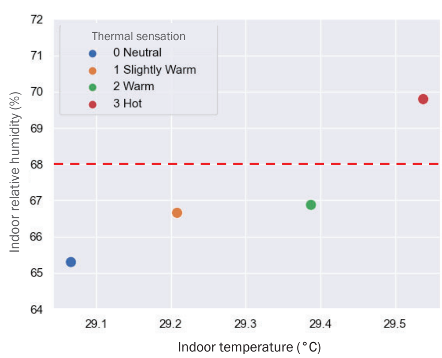
> The indoor temperature is insufficient to explain the differences between the chosen thermal sensation levels

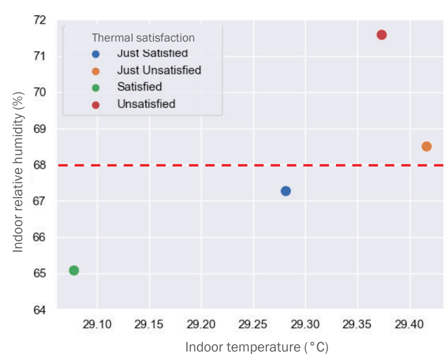
> On the contrary, the influence of the RH level is very strong on thermal sensation

> Significant differences are observed between "neutral" and "hot" and between "slightly warm" and "hot" thermal sensations

Data crossing

CoolDown



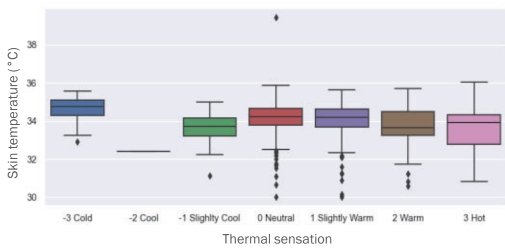


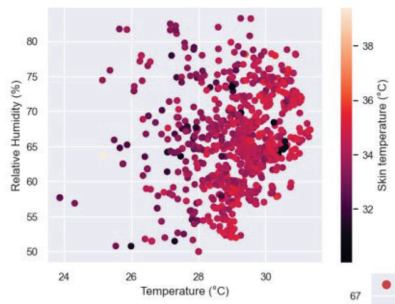
> The mean indoor temperature for each modality of thermal sensation and satisfaction is almost constant (about 29.3°C)

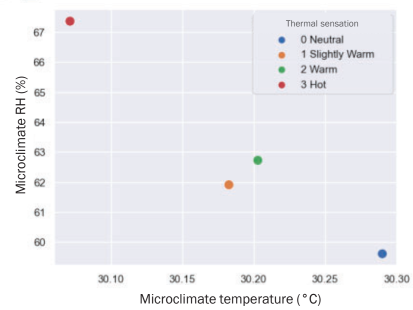
> Results confirm that **relative humidity is the main driver** of thermal sensation, comfort acceptability and satisfaction levels, indifferently of the temperature values in the observed range (28-30°C)

> Hot sensation, as well as discomfort, and unsatisfaction appear at a **threshold of 68% of relative humidity**

Data crossing







> Skin temperature seems to decrease as the thermal sensation increases

> Skin temperature arises with indoor temperatures, but relative humidity plays a role on thermal sensation as seen before

Questions:

- *Incomplete measure due to the sensor interaction with the skin: what about the sweating impact ?*
- *Which impact of sweating evaporation and skin temperature on micro-climate conditions?*
- *For now, 3-measurement points for skin temperature: more points needed?*

Future works and outlook

> New measurements campaigns starting November 2023 to gather more data and optimize the protocol and data acquisition and to validate the calibration of comfort models on the same subjects

> Study of the parametric sensitivity of the comfort models

> Individualized thermophysiological comfort model calibration for La Reunion's specific population

Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback

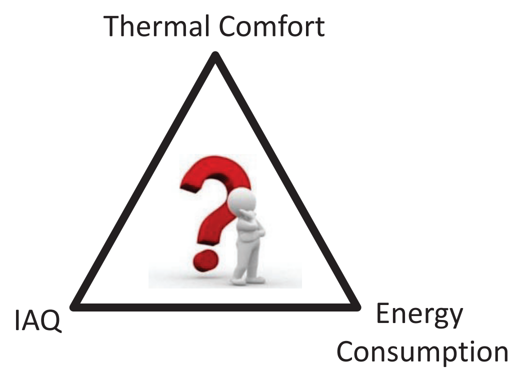
An IAQ and thermal comfort coach prototype to improve comfort and energy consumption thanks to adequate management of natural ventilation:

development and first feedback results

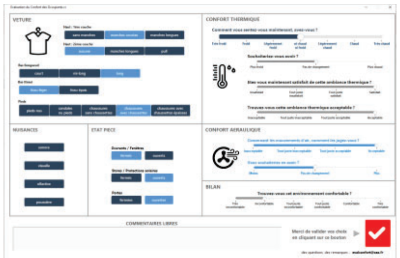
Arnaud JAY, Pierre BERNAUD, Franck ALESSI CEA Liten - INES, FRANCE

CONTEXT

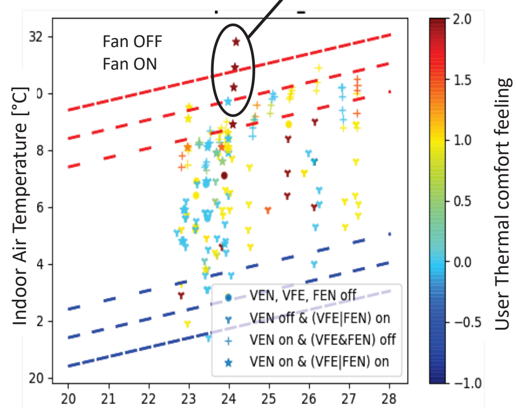
- Natural ventilation through open Windows allows to exchange easily 5 - 10 ACH for free
- But might bring some additional energy consumption or incomfort if open at inappropriate time



Wind'ose genesis



Windows open:
Inappropriate Behaviors ?



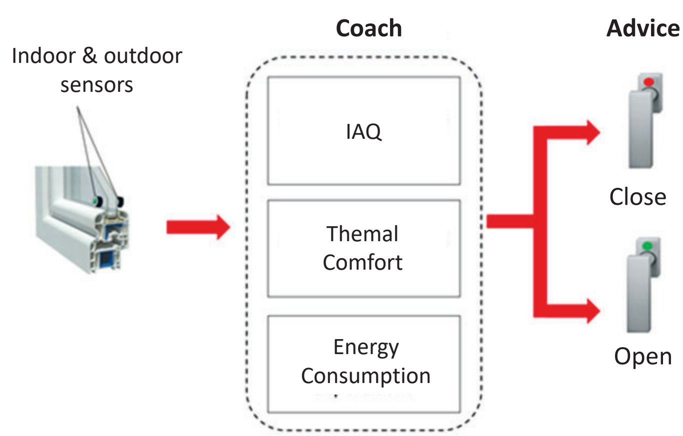
slippery average outside temperature

Interface to collect User feedback

Monitoring of Windows /Doors opening

WIND'OSE OBJECTIVE

- Coaching tool developed to help occupants to know whether it is a good option to open or close their windows.
- Coach objective is to consider the three components:
  - thermal comfort,
  - indoor air quality (IAQ)
  - energy consumption



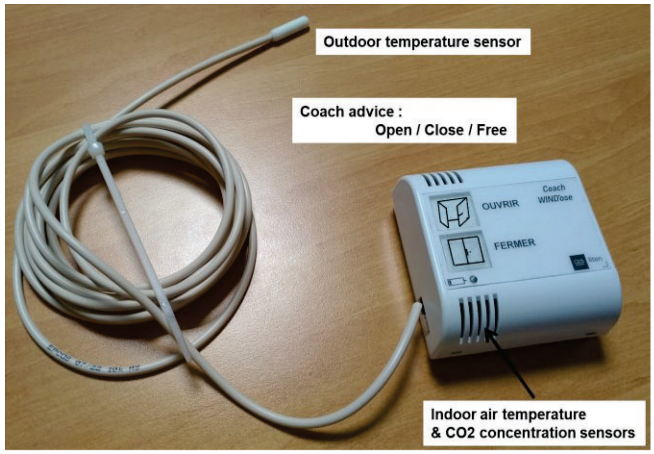
→ Based on Patent EP3971490 on "Method and system for advising on the opportunity of activating a door in order to improve the thermal comfort and/or the quality of the air"

WIND'ose an e-fAIR prototype

SPECIFICATIONS AND PROTOTYPE V1 -

2 Indoor Sensors:
- Indoor air temperature
- CO_2 concentration

1 Outdoor sensor
- Outdoor air température

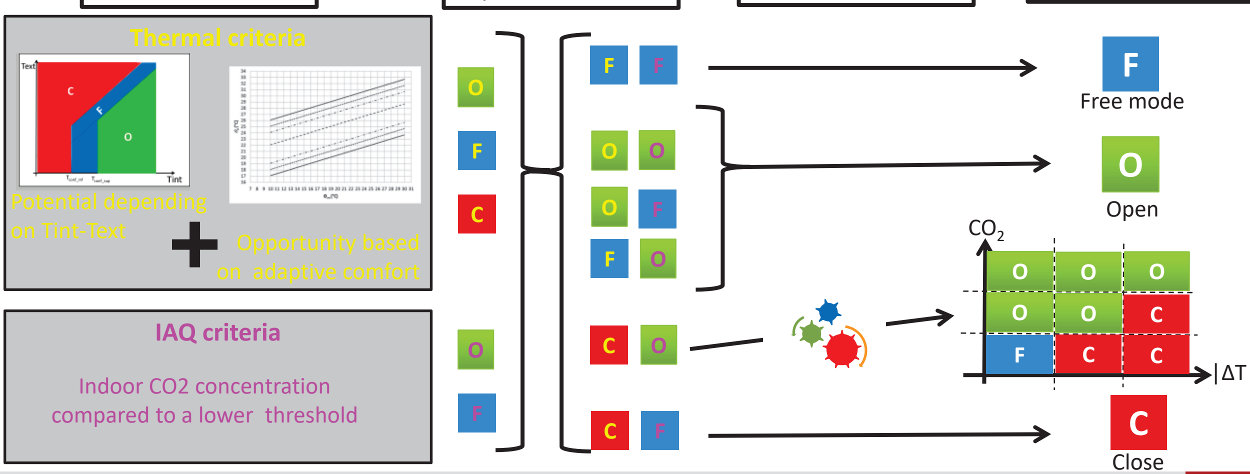


Intuitive message communicate to users

Autonomous (Energy & embedded algorithm) and easy to set up

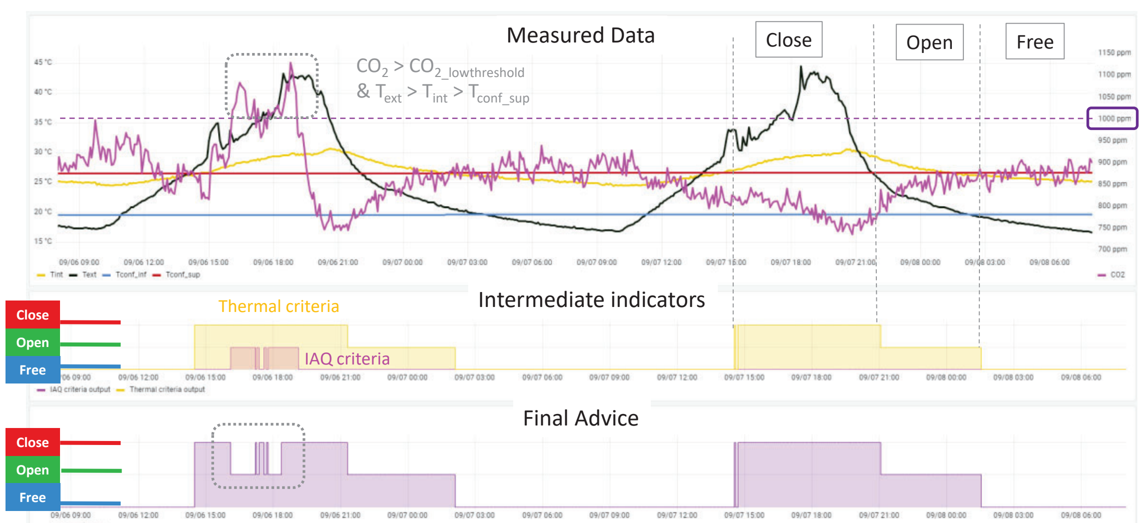
WIND'OSE ALGORITHM

1. Separate evaluation of each criteria
2. Check consistency between the 2 separate evaluations
3. If necessary – Arbitrate between criterias
4. Advice push to user



EXPERIMENTAL CAMPAIGN
SET UP ON A REAL BUILDING.

FIRST RESULTS



CONCLUSION AND PERSPECTIVE

- **Wind'ose prototype answer our 1st requirements and specifications**

- **What's next:**
  - Increase period and number of user feedback
  - Improve algorithm, and integrate specificity from
    - Mid-season
    - Winter
  - Enhance battery autonomy or integrate PV cells to get it fully autonomous.
  - Integrate other pollutants sensors.
  - …

Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback

OPEN DISCUSSION

Arnaud JAY
CEA Liten - INES

Gwénaëlle HAESE
CSTB

Maxime BOULINGUEZ
LEU Réunion / La Réunion Univ. - PIMENT

11

12

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings
October 4-5 2023
Copenhagen Denmark

Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback

Topical Session 1C:

Summer comfort and energy efficiency in hot periods:

interest of mixed mode cooling and need of occupant feedback

Arnaud JAY
CEA Liten - INES

Gwénaëlle HAESE
CSTB

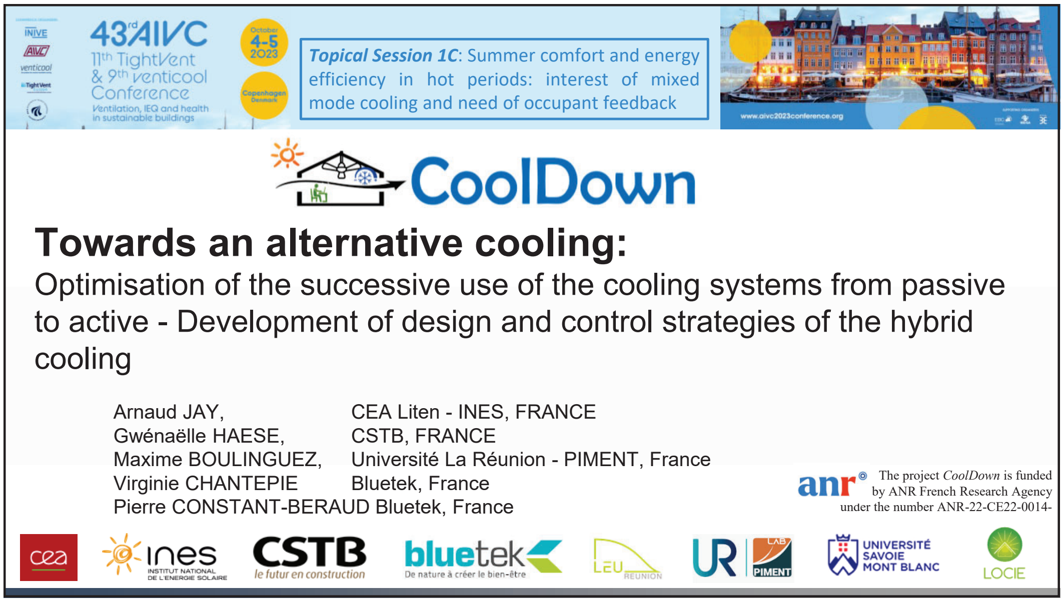
Maxime BOULINGUEZ
LEU Réunion / La Réunion Univ. - PIMENT

TOPICAL SESSION CONTENT

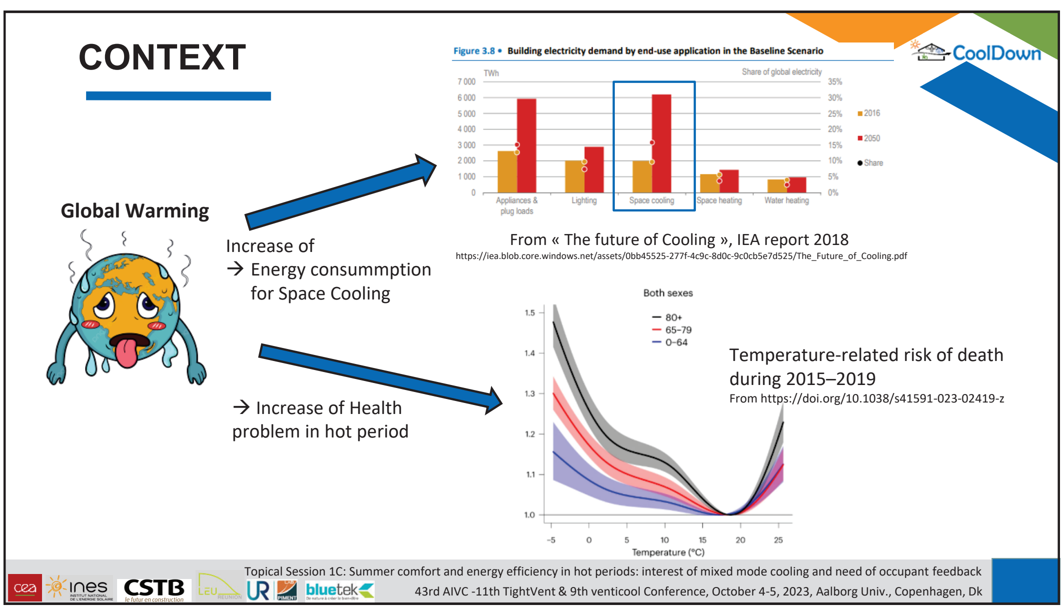
- **Towards an alternative cooling: Optimisation of the successive use of the cooling systems from passive to active - Development of design and control strategies of the hybrid cooling.**
  - Arnaud JAY, CEA Liten - INES, FRANCE
  - Gwénaëlle HAESE, CSTB, FRANCE
    Maxime BOULINGUEZ, *La Réunion University* - PIMENT, France

CoolDown

- **An innovative approach to better understand hot discomfort, based on the measurement of global human responses, including physiological and sensory indicators - application to end users of mixed mode cooled buildings under tropical climate conditions.**
  - *Gwénaëlle HAESE, CSTB, FRANCE*
    Maxime BOULINGUEZ, La Réunion University - PIMENT, France
- **Windows and ceiling fan occupant behaviour model coupling methodology with building energy models, a tropical case study.**
  - *Maxime BOULINGUEZ, La Réunion University - PIMENT, France*
- **An IAQ and thermal comfort coach prototype to improve comfort and energy consumption thanks to adequate management of natural ventilation: development and first feedback results.**
  - Arnaud JAY, CEA Liten - INES, FRANCE
- **Open discussions**

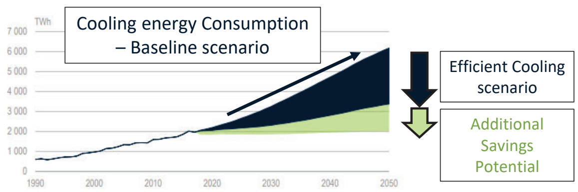

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings
October 4-5 2023
Copenhagen Denmark
Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback
www.aivc2023conference.org
CoolDown
Towards an alternative cooling:
Optimisation of the successive use of the cooling systems from passive to active - Development of design and control strategies of the hybrid cooling
Arnaud JAY, CEA Liten - INES, FRANCE
Gwénaëlle HAESE, CSTB, FRANCE
Maxime BOULINGUEZ, Université La Réunion - PIMENT, France
Virginie CHANTEPIE Bluetek, France
Pierre CONSTANT-BERAUD Bluetek, France
anr The project CoolDown is funded by ANR French Research Agency under the number ANR-22-CE22-0014-
cea
ines INSTITUT NATIONAL DE L'ENERGIE SOLAIRE
CSTB le futur en construction
bluetek De nature à créer le bien-être
LEU REUNION
UR PIMENT
UNIVERSITÉ SAVOIE MONT BLANC
LOCIE

3


CONTEXT
CoolDown
Figure 3.8 • Building electricity demand by end-use application in the Baseline Scenario
TWh
Share of global electricity
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
35%
30%
25%
20%
15%
10%
5%
0%
2016
2050
Share
Appliances & plug loads
Lighting
Space cooling
Space heating
Water heating
From « The future of Cooling », IEA report 2018
https://iea.blob.core.windows.net/assets/0bb45525-277f-4c9c-8d0c-9c0cb5e7d525/The_Future_of_Cooling.pdf
Global Warming
Increase of
→ Energy consummption for Space Cooling
→ Increase of Health problem in hot period
Both sexes
80+
65–79
0–64
1.5
1.4
1.3
1.2
1.1
1.0
-5
0
5
10
15
20
25
Temperature (°C)
Temperature-related risk of death during 2015–2019
From https://doi.org/10.1038/s41591-023-02419-z
Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback
43rd AIVC -11th TightVent & 9th venticool Conference, October 4-5, 2023, Aalborg Univ., Copenhagen, Dk

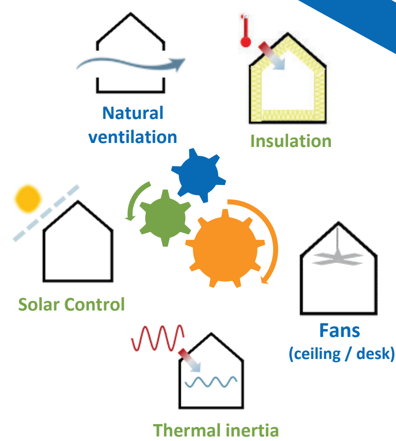
4

CONTEXT



From « The future of Cooling », IEA report 2018
https://iea.blob.core.windows.net/assets/0bb45525-277f-4c9c-8d0c-9c0cb5e7d525/The_Future_of_Cooling.pdf

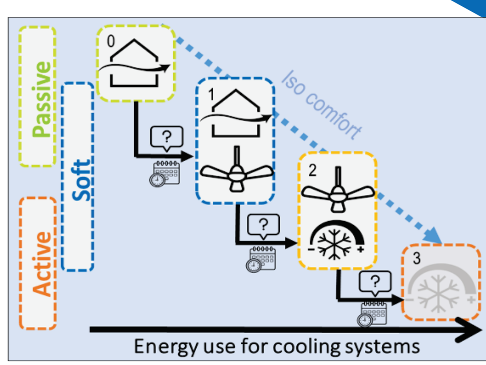
→ **Active cooling can be optimized**
AND
→ **some alternative solutions exist**



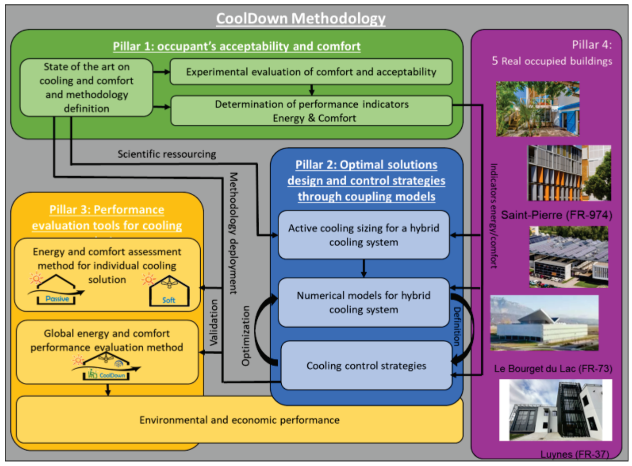
COOLDOWN OBJECTIVES

Define tools and methodology
to optimise the successive and combined use of passive, soft and active solutions
to maximize comfort for occupants
while minimising energy consumption
in summer, hot seasons or heat waves
to face the climate change impact

→ Focus on **existing office buildings**.



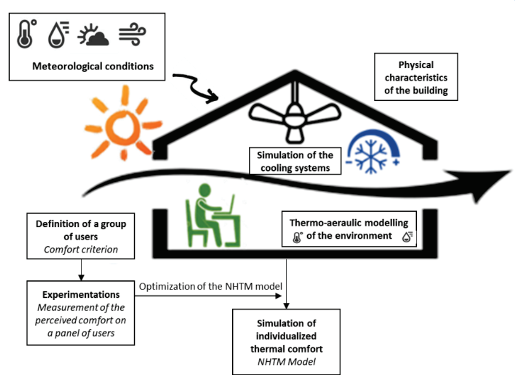
PROJECT SCOPE AND METHODOLOGY

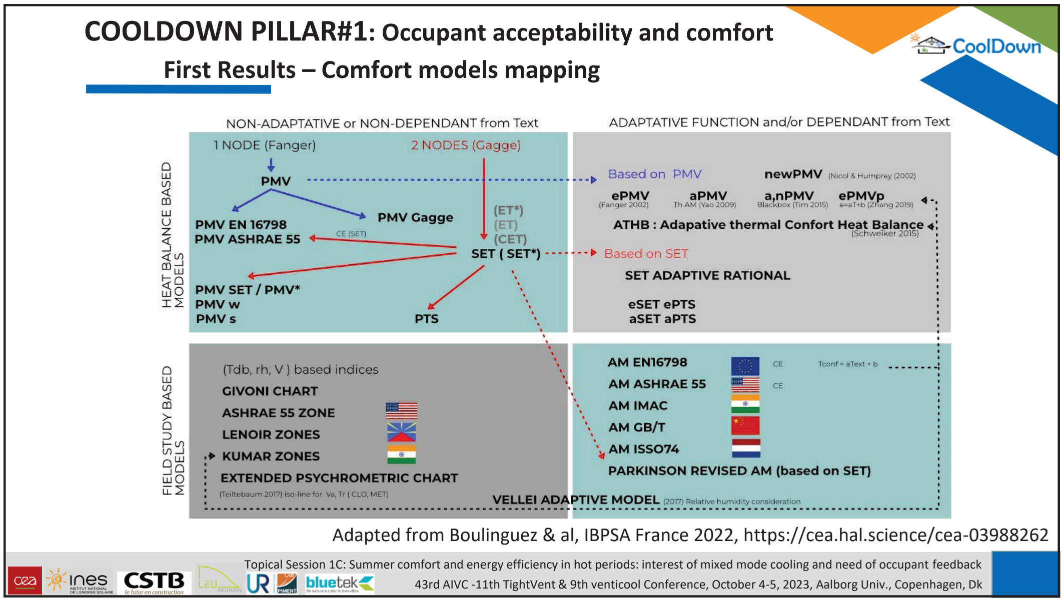


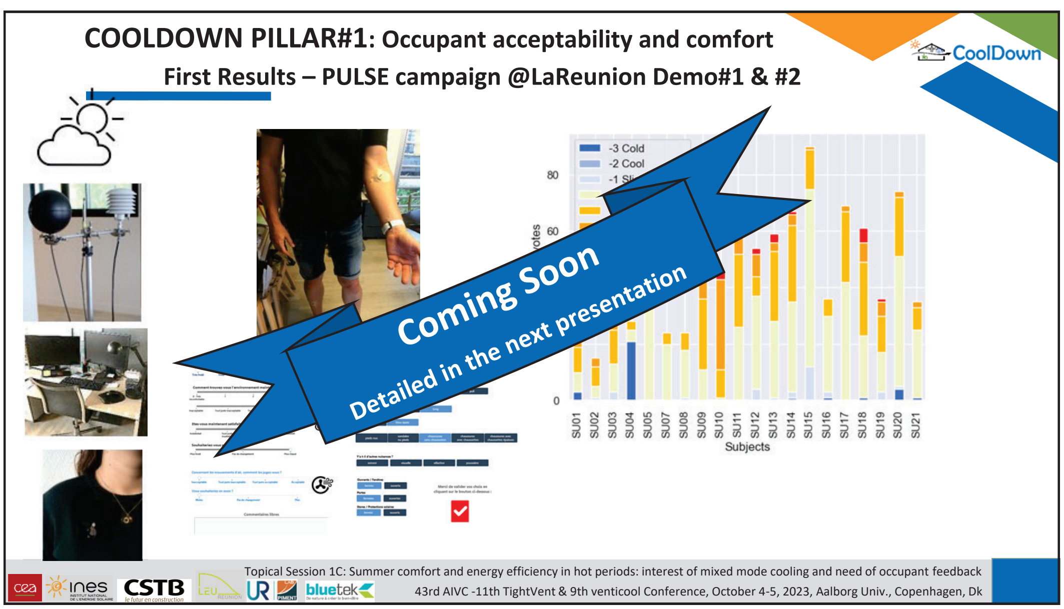
COOLDOWN PILLAR#1: Occupant acceptability and comfort

Methodology

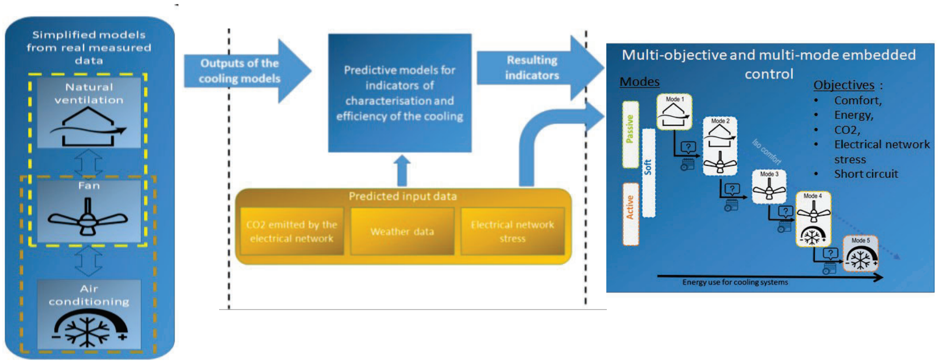
- Get feedback of occupants acceptability regarding the passive, soft and active cooling solutions through surveys and monitoring
- Improve thermal comfort models thanks to collected data
- Value this knowledge to defined indicators & control strategies




COOLDOWN PILLAR#1: Occupant acceptability and comfort
First Results – Comfort models mapping
CoolDown
NON-ADAPTATIVE or NON-DEPENDANT from Text
ADAPTATIVE FUNCTION and/or DEPENDANT from Text
HEAT BALANCE BASED MODELS
1 NODE (Fanger)
2 NODES (Gagge)
PMV
PMV EN 16798
PMV ASHRAE 55
PMV Gagge
CE (SET)
(ET*)
(ET)
(CET)
SET (SET*)
PMV SET / PMV*
PMV w
PMV s
PTS
Based on PMV
newPMV
ePMV
aPMV
a,nPMV
ePMVp
ATHB : Adapative thermal Confort Heat Balance
Based on SET
SET ADAPTIVE RATIONAL
eSET ePTS
aSET aPTS
FIELD STUDY BASED MODELS
(Tdb, rh, V) based indices
GIVONI CHART
ASHRAE 55 ZONE
LENOIR ZONES
KUMAR ZONES
EXTENDED PSYCHROMETRIC CHART
AM EN16798
AM ASHRAE 55
AM IMAC
AM GB/T
AM ISSO74
PARKINSON REVISED AM (based on SET)
VELLEI ADAPTIVE MODEL
Adapted from Boulinguez & al, IBPSA France 2022, https://cea.hal.science/cea-03988262
Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback
43rd AIVC -11th TightVent & 9th venticool Conference, October 4-5, 2023, Aalborg Univ., Copenhagen, Dk


COOLDOWN PILLAR#1: Occupant acceptability and comfort
First Results – PULSE campaign @LaReunion Demo#1 & #2
CoolDown
Coming Soon
Detailed in the next presentation
-3 Cold
-2 Cool
Subjects
Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback
43rd AIVC -11th TightVent & 9th venticool Conference, October 4-5, 2023, Aalborg Univ., Copenhagen, Dk

COOLDOWN PILLAR#2:
Optimal solutions design and control strategies through coupling models



Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback
43rd AIVC -11th TightVent & 9th venticool Conference, October 4-5, 2023, Aalborg Univ., Copenhagen, Dk

COOLDOWN PILLAR#2:
Optimal solutions design and control strategies through coupling models

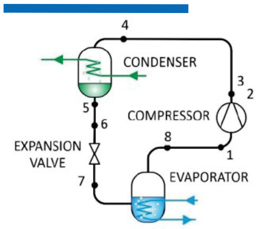


Table 5. Selected data from manufacturer for validation process

N°	Input/Output chilled temperature (°C)	Input/Output cooling temperature (°C)	Refrigeration Capacity (kW)	COP	Consumed power (kW)
D	12/7	35/40	154	3.84	40.1
E	13/8	35/40	159	3.955	40.2
F	15/10	35/40	170	4.218	40.3
G	12/7	40/45	144	3.193	45.1
H	13/8	40/45	150	3.319	45.2
I	15/10	40/45	160	3.532	45.3

$$\begin{cases} \dot{Q}_{evap} = \dot{m}_{ref}.(h_8 - h_1) \\ \dot{Q}_{evap} = UA_{evap}.\dfrac{(T_{LTTF,in} - \bar{\bar{T}}_{evap}) - (T_{LTTF,out} - \bar{\bar{T}}_{evap})}{\ln \dfrac{T_{LTTF,in} - \bar{\bar{T}}_{evap}}{T_{LTTF,out} - \bar{\bar{T}}_{evap}}} \\ \dot{Q}_{evap} = \dot{m}_{LTTF}.Cp_{LTTF}(T_{LTTF,in} - T_{LTTF,out}) \end{cases} \text{ and } \begin{cases} \dot{Q}_{cond} = \dot{m}_{ref}.(h_3 - h_6) \\ \dot{Q}_{cond} = UA_{cond}.\dfrac{(\bar{\bar{T}}_{cond} - T_{HTTF,in}) - (\bar{\bar{T}}_{cond} - T_{HTTF,out})}{\ln \dfrac{\bar{\bar{T}}_{cond} - T_{HTTF,in}}{\bar{\bar{T}}_{cond} - T_{HTTF,out}}} \\ \dot{Q}_{cond} = \dot{m}_{HTTF}.Cp_{HTTF}(T_{HTTF,out} - T_{HTTF,in}) \end{cases}$$

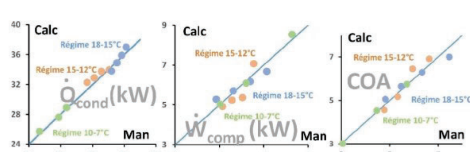


Figure 5: Comparison between model and manufacturer's data

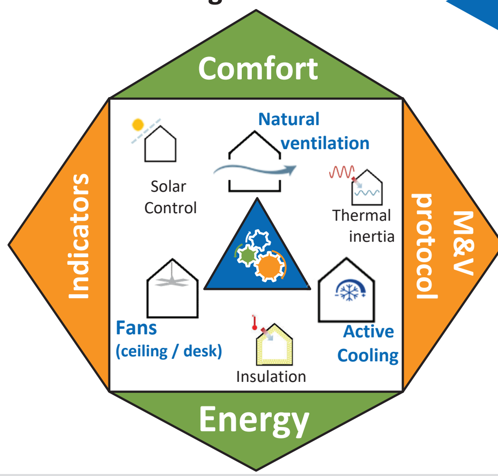
From Boulinguez & al; ICR2023 | 26th International Congress of Refrigeration | August 21st-25th, 2023 | Paris, France

Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback
43rd AIVC -11th TightVent & 9th venticool Conference, October 4-5, 2023, Aalborg Univ., Copenhagen, Dk

COOLDOWN PILLAR#3:
Performance evaluation tools for cooling solutions

CoolDown

Consider both
Comfort & Energy
in
Performance assessment methods
&
Indicators



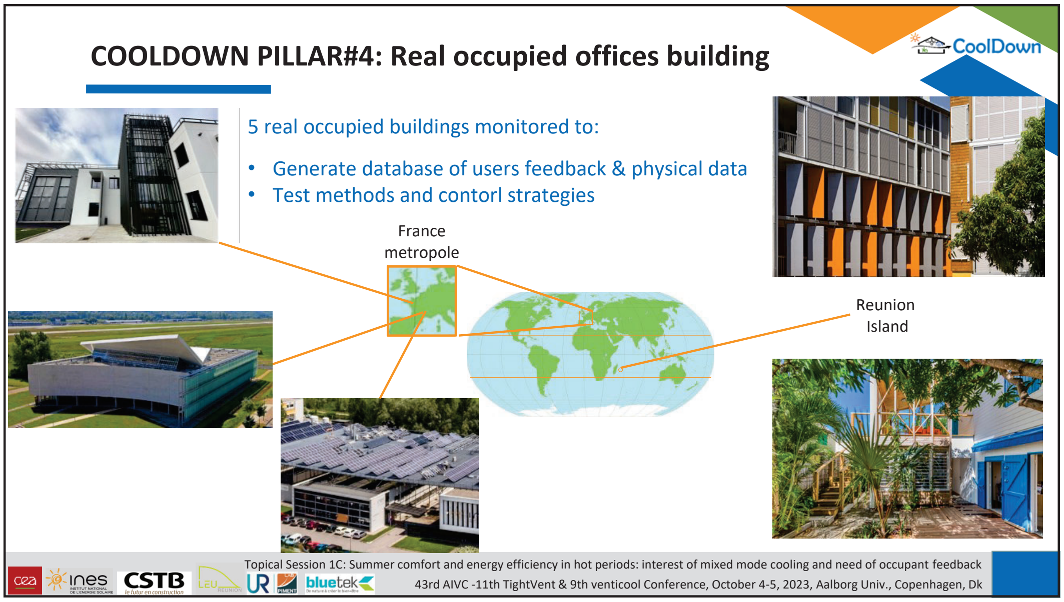
COOLDOWN PILLAR#3:
Performance evaluation tools for cooling solutions

CoolDown

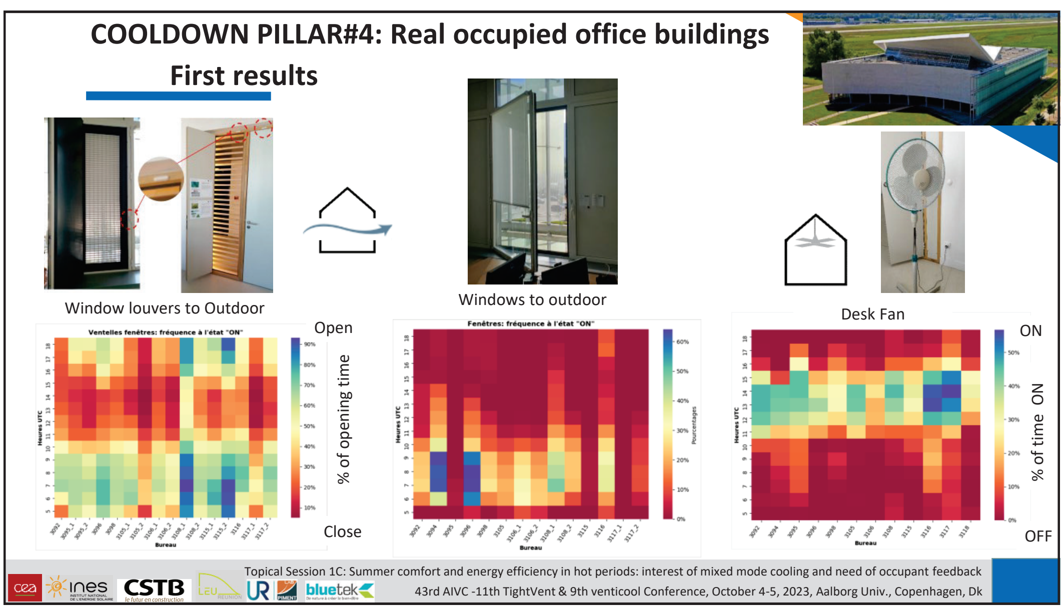
	Indicators	M&V protocol
Natural ventilation	ACH	Tracer Gaz
Fans (ceiling, desks)		
Active cooling		
Solar gain control	Asol (Solar Aperture)	
Insulation	HTC,	CO-heating, Qub, Pstar, SEREINE, …
Thermal inertia		

Task just started – Any input welcome

Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback
43rd AIVC -11th TightVent & 9th venticool Conference, October 4-5, 2023, Aalborg Univ., Copenhagen, Dk


COOLDOWN PILLAR#4: Real occupied offices building
CoolDown
5 real occupied buildings monitored to:
• Generate database of users feedback & physical data
• Test methods and contorl strategies
France metropole
Reunion Island
Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback
43rd AIVC -11th TightVent & 9th venticool Conference, October 4-5, 2023, Aalborg Univ., Copenhagen, Dk

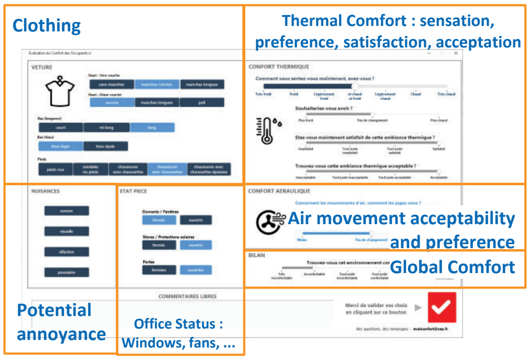
15


COOLDOWN PILLAR#4: Real occupied office buildings
First results
Window louvers to Outdoor
Windows to outdoor
Desk Fan
Open
% of opening time
Close
ON
% of time ON
OFF
Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback
43rd AIVC -11th TightVent & 9th venticool Conference, October 4-5, 2023, Aalborg Univ., Copenhagen, Dk

16

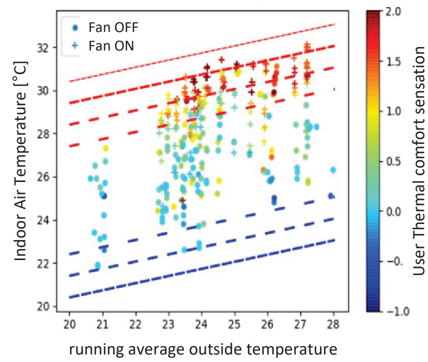
COOLDOWN PILLAR#4: Real occupied office buildings

First results



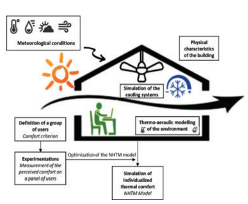
Interface to gather user feedback

User Comfort on Adaptative comfort chart

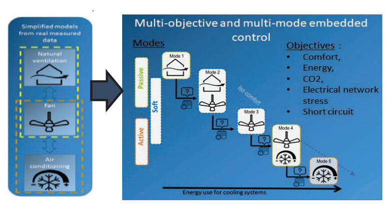


Conclusion and perspective

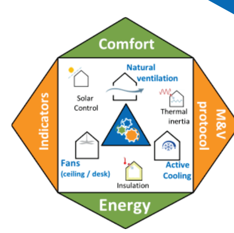
Let's continue the CoolDown adventure : So many challenges to tackle !



Pilar#1 : Occupant acceptability and comfort



Pilar#2 : Optimal solutions design and control strategies through coupling models



Pilar#3 :Performance evaluation tools for cooling solutions

Pilar#4 : 5 real occupied office buildings

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

October 4-5 2023
Copenhagen Denmark

Topical Session 1C: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback

CoolDown

The project *CoolDown* is funded by ANR
French Research Agency
under the number ANR-22-CE22-0014-06

THANK YOU
-
QUESTIONS ?

cea · ines INSTITUT NATIONAL DE L'ENERGIE SOLAIRE · CSTB le futur en construction · bluetek De nature à créer le bien-être · LEU RÉUNION · UR LAB PIMENT · UNIVERSITÉ SAVOIE MONT BLANC · LOCIE

IEA Energy in Buildings and Communities TCP

AIVC2023, Copenhagen

EBC

IEA-EBC Annex 78
Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications

Bjarne W. Olesen & Pawel Wargocki
ICIEE,
DTU.SUSTAIN
Technical University of Denmark

October 4 2023

Technology Collaboration Programme
by iea

1

IEA Energy in Buildings and Communities TCP

Annex 78 Project Period

EBC

~~July 1, 2018 Preparation period~~
~~July 1, 2019 Activity~~ period
July 1, 2023 Reporting period
July 15, 2024 Finished

Technology Collaboration Programme
by iea

2

EBC

ORGANISATION

- Subtask A: Energy benefits using gas phase air cleaning
- Subtask B: How to partly substitute ventilation by air cleaning
- Subtask C: Selection and testing standards for air cleaners
- Subtask D: Performance modelling and long term field validation of gas phase air cleaning technologies

EBC

Ventilation
Information
Paper
n° 42

April 2021

Operating Agent
and Management
Boulevard Poincaré 79
B-1060 Brussels – Belgium
inive@bbri.be - www.inive.org

International Energy Agency's
Energy in Buildings and Communities
Programme

AIVC

Air Infiltration and Ventilation Centre

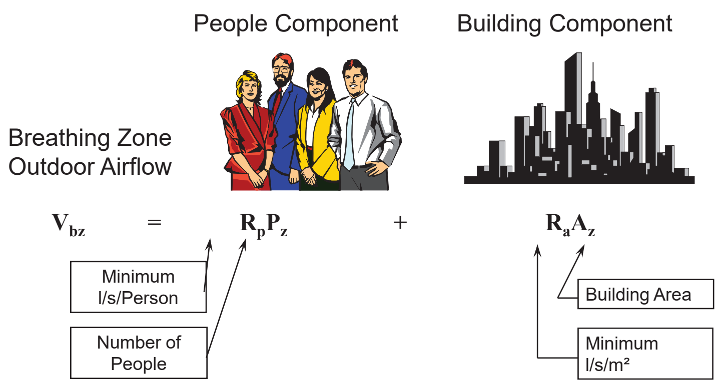
The Concept for Substituting Ventilation by Gas Phase Air Cleaning

Bjarne W. Olesen, DTU, Denmark
Chandra Sekhar, National University of Singapore, Singapore
Pawel Wargocki, DTU, Denmark

IEA Energy in Buildings and Communities TCP

EBC

The concept for calculation of design ventilation rate ISO CEN ASHRAE

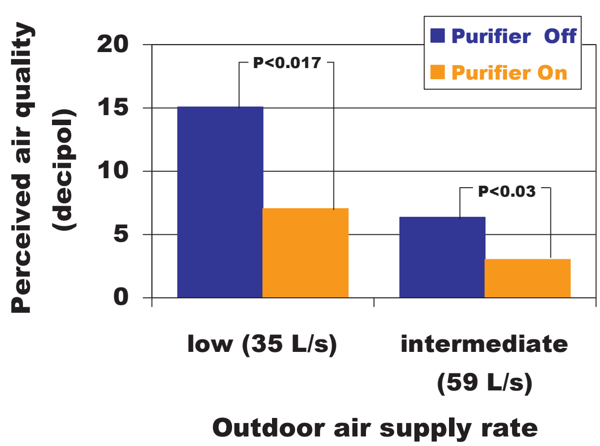


Technology Collaboration Programme
by iea

IEA Energy in Buildings and Communities TCP

EBC

Results: Bldg mat, PCs, filters

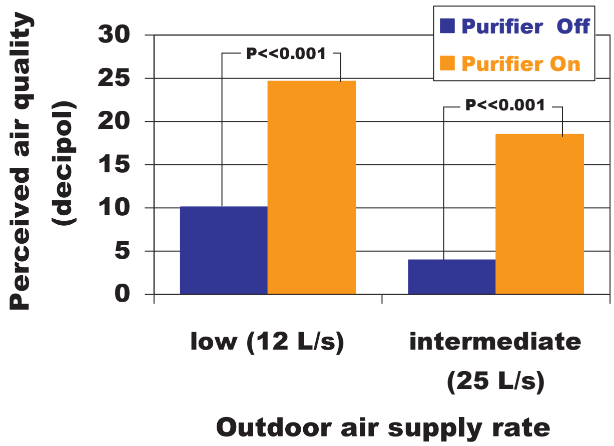


Technology Collaboration Programme
by iea

IEA Energy in Buildings and Communities TCP

EBC

Results: Human bioeffluents

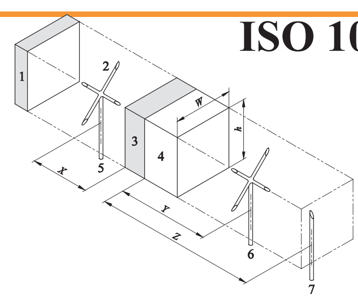


IEA Energy in Buildings and Communities TCP

EBC

TESTING OF GAS PHASE AIR CLEANERS

ISO 10121-2:2014



Key

1 diffusor and Δp device
2 sampling points – should be of "fork" type or similar with multiple inlet points to make a compounded sample over the whole cross section
3 GPACD under test
4 GPACD section of test duct
5 upstream sampling point for T_U, RH_U, p_U and C_U at X mm before the GPACD
6 Downstream sampling point for T_D, RH_D, p_D and C_D at Y mm after the GPACD
7 Q, air flow rate sampling point at Z mm after the GPACD
W internal width of the test duct along the GPACD section, 3+4
h internal height of the test duct along the GPACD section, 3+4

Figure 1 — Normative section of test stand showing ducting, measurement parameters and sampling points

Air Cleaning Efficiency

$$\varepsilon_{clean} = 100(C_U - C_D)/C_D$$

where:

E_{clean} is the air cleaning efficiency
C_U is the gas concentration before air cleaner
C_D is the gas concentration after air cleaner.

ISO/TC 146/SC 6

Date: 2023-09

ISO/FDIS 16000-44:2023 (E)

ISO/TC 146/SC 6/WG 25

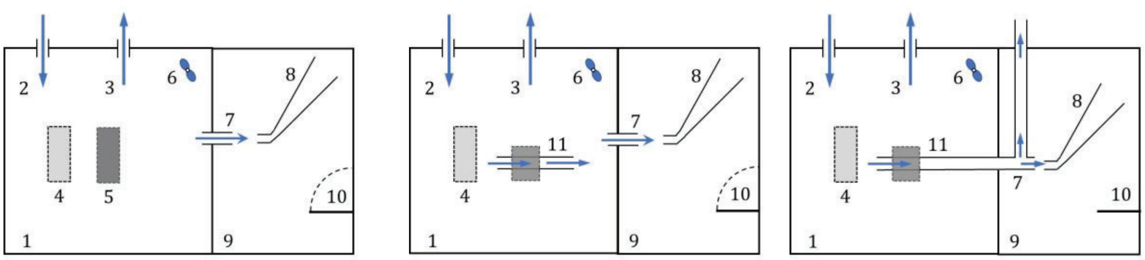
Secretariat: DIN

Indoor air — Part 44: Test method for measuring perceived indoor air quality for use in testing the performance of gas-phase air cleaners.

Air intérieur — Partie 44: Méthode d'essai pour mesurer la qualité perçue de l'airintérieur en vue de tester les performances des épurateurs d'air en phase gazeuse

9

Position of Air Cleaner ISO 16000-44



a) A test room for a standalone air cleaner

b) A test room for a duct air cleaner

c) A test room for a duct air cleaner (single-pass condition)

1	test chamber	7	tube or duct
2	clean and temperature/humidity conditioned air supply inlet	8	sniffing device, complying with relevant specifications and requirements of ISO 16000-28
3	exhaust outlet	9	front/anterior space in which human panel enter
4	emission source	10	Doors where panel enters
5	An air cleaner	11	in duct air cleaner
6	mixing fan		

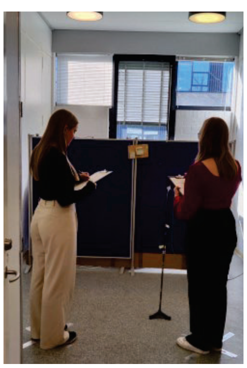
1

10

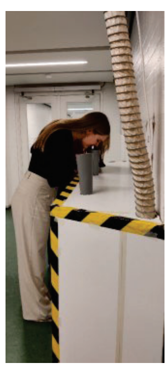
Testing of gas-phase air cleaners for improving perceived indoor air quality (PWI 23743) ISOTC142WG8

Sensory evaluations

Type of exposure



Whole-body exposure



Facial exposure

Scale

Clearly acceptable

Just acceptable

Just unacceptable

Clearly unacceptable

No odour

Slight odour

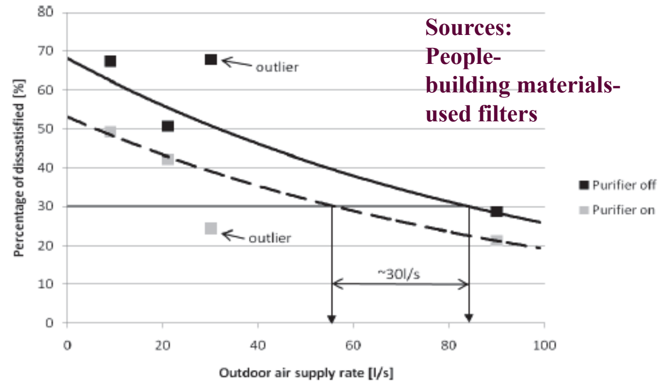
Moderate odour

Strong odour

Very strong odour

Overpowering odour

Effect of air cleaning on perceived Air Quality



13

Deliverables

- A: A method for predicting the energy performance of gas-phase air cleaning technologies and the possible reduction of energy use for ventilation.
    - Lead by Dragos-Ion Bogatu (DTU) and Sasan Sadrizadeh (KTH)
- B: A validated procedure for supplementing (partly substituting) required ventilation rates with gas-phase air cleaning.
    - Lead by Bjarne W. Olesen and Pawel Wargocki
- C: A test method for air cleaning technologies that besides chemical measurements include perceived air quality as a measure of performance.
    - Lead by Pawel Wargocki, Lei Fang and Bjarne Olesen (DTU)
- D: A report on the long-term performance of gas-phase air cleaning technology
    - Lead by Karel Kabele
- E: Models for predicting the performance of gas-phase air cleaning
    - Lead by Jianshun Zhang
- F: A report on Gas Phase Air Cleaning Technologies. Publish with AIVC
    - Lead by Alireza (Fang Lei, Jinhan Mo)

14

Air cleaner as an alternative to increased ventilation rates in buildings:

A simulation study for an office

Alireza Afshari

AALBORG UNIVERSITY
DENMARK

REHVA

Air cleaner as an alternative to increased ventilation rates in buildings: A simulation study for an office

Alireza Afshari
Alessandro Maccarini
Göran Hultmark
Department of the Built Environment (BUILD)
Aalborg University Copenhagen
Denmark

AALBORG UNIVERSITY
DENMARK

Abstract

This study analyses the feasibility of utilizing advanced air cleaner technology for air purification in:

- a system-based filter (recirculating ventilation system),
- a room-based filter (local recirculation in each room),
- a beam-based filter (recirculation in an active chilled beam).

The results show that choosing the appropriate air cleaner can significantly impact energy performance and improvement of indoor air quality.

AALBORG UNIVERSITY
DENMARK

Background

Air pollution poses significant risks to human health, as it comprises a combination of gaseous and particulate contaminants.

This exposure has been linked to adverse effects on the immune [1], respiratory, and cardiovascular systems [2-4], as well as an increased risk of lung cancer [5] and premature mortality [3].

Short-term symptoms of exposure to poor indoor air quality include headaches, eye, nose, and throat irritation, fatigue [6], and asthma [7], which can lead to decreased productivity and increased workplace absenteeism [8].

AALBORG UNIVERSITY
DENMARK

Building model

The building model was chosen to be representative of a typical office room located on the middle floor of a high-rise building. The room has a heated area of 16 m^2 and a volume of 48 m^3.

All the surfaces are considered adiabatic (thermally isolated), except for the south-oriented façade (wall), where ambient boundary conditions are applied.

This facade also includes a window of 6 m^2. The facade has two parts, an opaque element, and a glass element, with U-values of 0.3 W/m^2K and 1.5 W/m^2K, respectively.

Shading devices are installed outside the window, which can block 50% of incoming radiation when direct solar radiation on the south facade is higher than 150 W/m^2. Shadings from nearby obstacles are not considered.

AALBORG UNIVERSITY
DENMARK

Building model

Hourly resolution profiles for occupancy, appliances, and lighting were used to represent user behaviour and internal heat gains.

The profiles were generated based on different user behaviours for weekdays and weekends.

The peak heat gain was assumed during working hours on weekdays and was set 20 W/m^2.

The natural infiltration rate was assumed to be constant and the air change per hour was set to 0.2 ACH.

AALBORG UNIVERSITY
DENMARK

Building model

The filter was modelled to reduce the concentration of pollutants by 80%.

CO_2 was used for the evaluation of indoor air quality.

During working hours, an indoor production of 9.1E-6 kg/s of CO_2 was assumed, while an outdoor concentration of 400 ppm was used as a reference concentration.

An ideal space heating and cooling system was modelled in order to keep the indoor air temperature within the range of 20-24°C equal for all systems simulated.

AALBORG UNIVERSITY
DENMARK

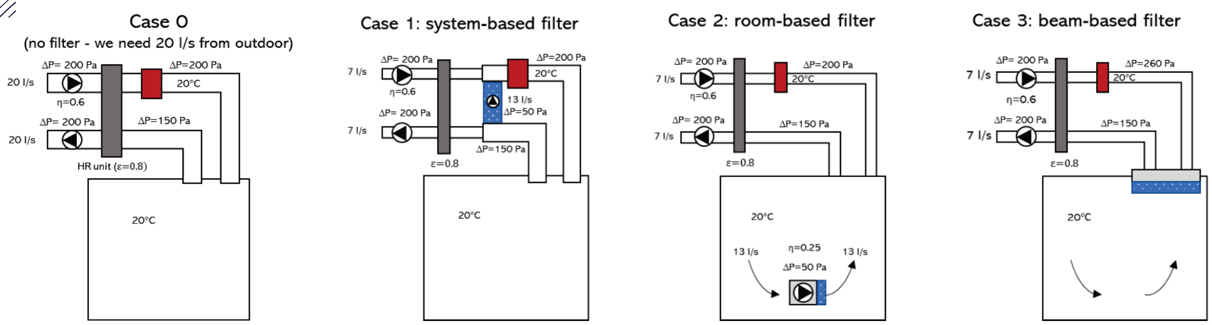
System models

Four different HVAC system configurations were implemented, namely:

- Reference case,
- System-based filter,
- Room-based filter,
- Beam-based filter.

AALBORG UNIVERSITY
DENMARK

Reducing the energy use of ventilation systems by including filters



Reference case (no filter)

Filter integrated into the main ventilation system

Filter integrated in a ventilator unit

Filter integrated in a chilled beam unit

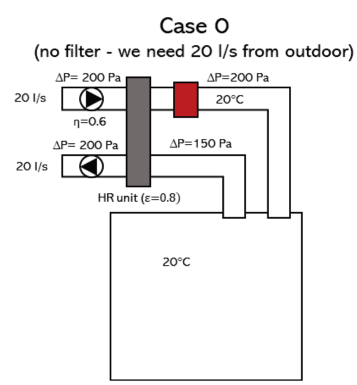
AALBORG UNIVERSITY
DENMARK

The reference case:

Represents a typical office ventilation system consisting of a heat recovery unit, a heating coil, and supply and return fans. The heat recovery unit was modelled as a rotary heat exchanger where the speed of rotations (effectiveness) was regulated according to the actual needs in terms of heat transfer between supply and return air streams.

The maximum effectiveness was set to 0.8. An outdoor air flow rate of 20 L/s is delivered to the office room by the supply fan.

The office room receives an outdoor air flow rate of 20 L/s from the supply fan, which has an efficiency of 0.6. The ducts were set to have pressure drops of 150 Pa, whereas the heat recovery unit was set to have a pressure drop of 200 Pa. The heating coil, which maintains the supply air temperature at 20°C, was assumed to have a pressure drop of 50 Pa.



AALBORG UNIVERSITY
DENMARK

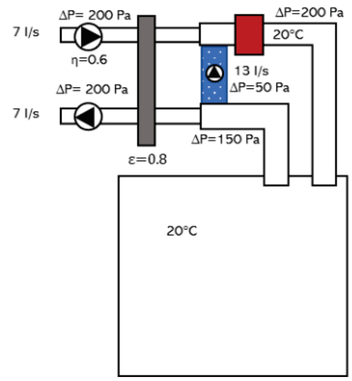
System-based filter

introduces a filter at the system level. This allows for lower outdoor air flow rates by filtering return air from the room.

For this case, an outdoor air flow of 7 l/s was assumed, with a 50 Pa pressure drop set for the filter.

It's worth noting that this approach allows for smaller ducts to be installed in correspondence to the heat recovery unit. The filter was modelled accordingly.

Case 1: system-based filter



AALBORG UNIVERSITY
DENMARK

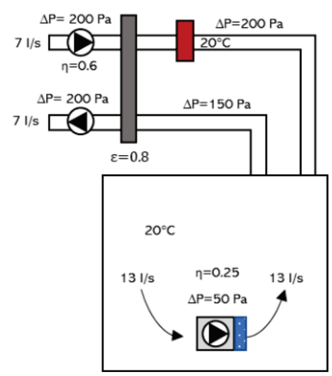
Room-based filter:

introduces a filter at room level.

In this case, the air is filtered within the room using a small fan.

It's worth noting that, such fans are generally less efficient, with a typical value of 0.25 assumed in this study. A pressure drop of 50 Pa was set for the filter.

Case 2: room-based filter



AALBORG UNIVERSITY
DENMARK

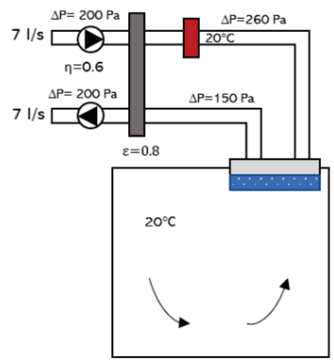
Beam-based filter:

introduces a filter incorporated into a chilled beam unit

In this case, the induced room air is filtered by a device integrated into the beam unit.

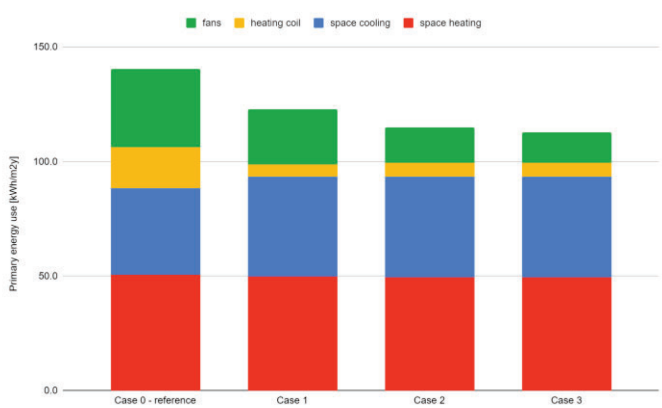
To induce air through the beam unit, the pressure drop in the duct system was increased to 210 Pa.

Case 3: beam-based filter



AALBORG UNIVERSITY
DENMARK

Reducing the energy use of ventilation systems by including filters



Case 3 (beam-based filter) lead to 24% of total primary energy savings compared to the reference case

AALBORG UNIVERSITY
DENMARK

Conclusions

The room-based and beam-based filter systems have similar energy demands for space heating, while the reference case has a slightly higher energy demand due to the lack of air recirculation.

For space cooling, the room-based and beam-based filter systems have the highest energy demand, while the reference case has the lowest energy demand due to a higher supply of outdoor air.

The system using filters has the lowest energy demand for the heating coil, whereas the reference case has the highest demand.

Conclusions

For fans, the beam-based filter has the lowest energy demand due to efficient recirculation of air through induction, while the reference case has the highest due to higher air flow through the air handling unit.

Integrating a filter in the active chilled beam unit results in primary energy savings of approximately 26% compared to the reference case.

KTH ROYAL INSTITUTE
OF TECHNOLOGY

Energy implication of using gas-phase air cleaners in residential & office buildings

Sasan Sadrizadeh
PhD, Professor
KTH & MDU

Nourozi, B., Holmberg, S., Duwig, C., Afshari, A., Wargocki, P., Olesen, B., & Sadrizadeh, S. (2022). Heating energy implications of utilizing gas-phase air cleaners in buildings' centralized air handling units. *Results in Engineering*, *16*, 100619.

1

EBC
Energy in Buildings and Communities Programme

Introduction and background

- **Ventilation** systems are important for maintaining a **healthy and comfortable indoor** environment.
- In cold climates, ventilation systems contribute to **approximately 30% of building heat losses**.
- **Indoor emissions** and **outdoor pollutants** affect **indoor air quality** and need to be controlled.
- **Gas-phase air cleaning** as an extension to the ventilation can help **maintain acceptable indoor air quality**, yet **reduce energy use**.

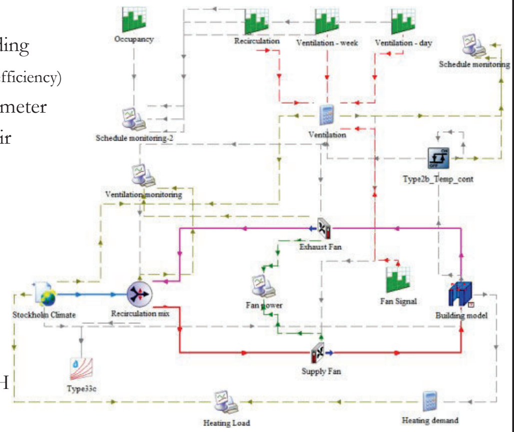
2

Investigated parameters

- **Heating demand** of a ventilated building
- Indoor **TVOC level** (with 60% capturing efficiency)
- Indoor **CO_2 level** as a monitoring parameter
- Possibility of **air recirculation** when air cleaner is integrated.

Simulation case

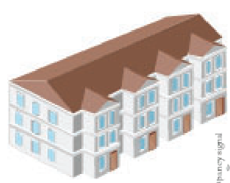
- Newly constructed or renovated buildings
- Older buildings without heat recovery ventilation
- Residential and office cases with various ACH

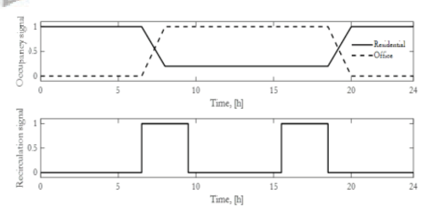


Energy simulation using TRNSYS

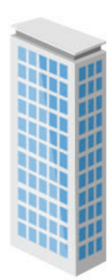
Simulation cases study in <u>Stockholm climate</u> equipped with <u>centralized air handling</u> unit (2000 $m^2_{\text{vent. area}}$)

- **Residential building**
  - 0.45 ACH
  - Occupancy schedule





- **Office building**
  - 2.1 ACH
  - Occupancy schedule
  - Ventilation schedule



Air pollutant	TVOC			CO_2	
Source	Outdoor	Occupants	Interior furnishing	Outdoor	Occupants
Value	μgr.m⁻³	mgr.h⁻¹.person⁻¹	μgr.m⁻³h⁻¹	mgr.m⁻³	gr.h⁻¹.person⁻¹
	110	6.3	120	720	120

Indoor and outdoor emission rates

Location	Reference	TVOC concentration $\mu g.m^{-3}$
Europe	Report EUR 14449 EN. 1992	Comfort range < 300 Multifactorial exposure range < 3000 Discomfort range < 25000 Toxic range > 25000
Finland	Finnish Society of IAQ and Climate. 2000	Individual indoor climate < 200 Good indoor climate < 300 Satisfactory indoor climate < 600
Germany	Federal Environment Agency of Germany	Hygienically safe < 1000 Hygienically noticeable < 3000 Hygienically alarming < 10000 Hygienically unacceptable > 1000
Germany	Seifert B.	300

Guideline values for indoor TVOC concentration

Residential building (0.45 ACH)

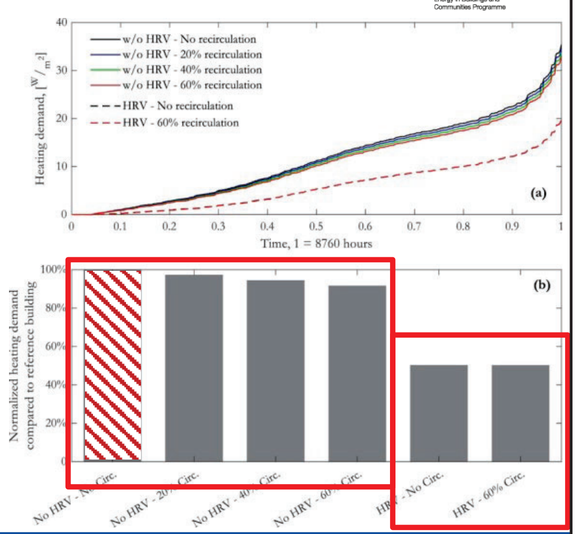
EBC
Energy in Buildings and Communities Programme

Ventilation <u>with</u> heat recovery:

- **The recirculation** effect on **heating demand** is <u>negligible</u>!
- Air cleaner implementation **might not be** that effective!

Ventilation <u>without</u> heat recovery:

- **The recirculation** effect on **heating demand** is <u>small</u>!
- Air cleaner implementation **might reduce** building heating demand!



HRV: Heat Recovery Ventilation

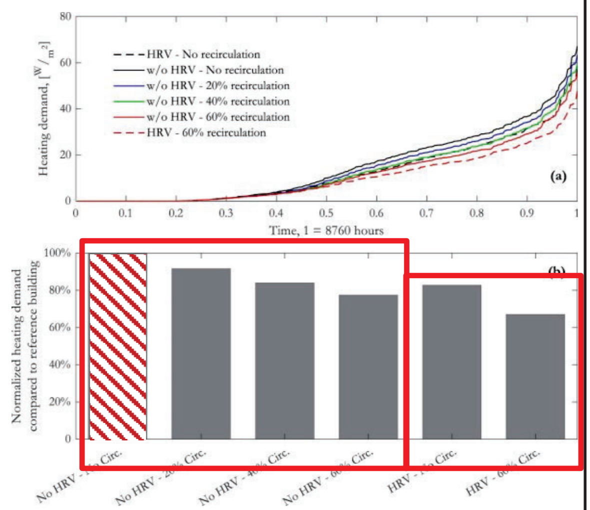
Office building (2.1 ACH)

EBC
Energy in Buildings and Communities Programme

Ventilation with heat recovery:

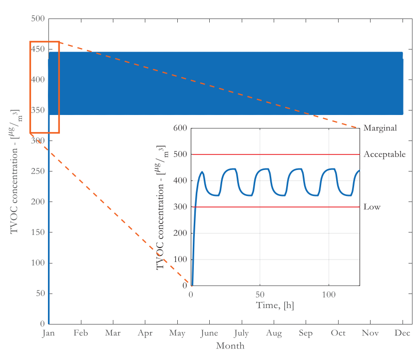
- **The recirculation** effect on **heating demand** is **notable** compared to the residential buildings!
- This is the case for both **with and without** heat recovery!
- Air cleaner implementation **is effective**!

Thus ACH is an important parameter that needs to be considered.

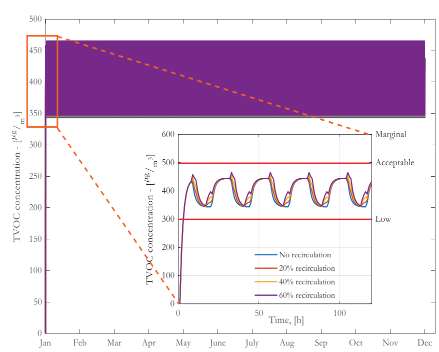


Residential building: Impact of **air recirculation** on TVOC concentration (<500 μg/m³)

EBC
Energy in Buildings and Communities Programme



Without air recirculation

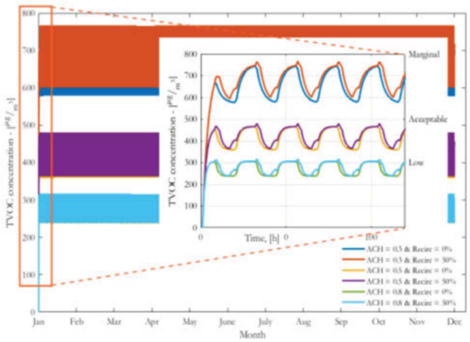


With air recirculation (and air cleaner)

TVOC concentration is within the acceptable range

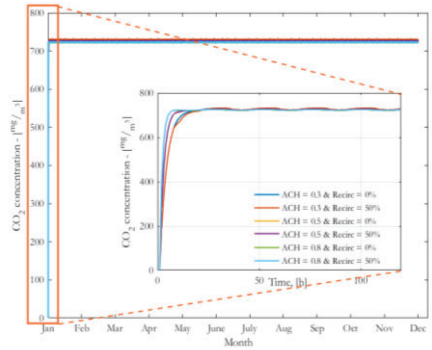
Recirculation does not result in increased TVOC level

Residential building: Impact of air recirculation and ACH on TVOC & CO_2 concentration



TVOC concentration with 0 and 50% air recirculation

- High ACH (>0.5) maintains TVOC concentration within an acceptable range, regardless of recirculation level
- Thus, adding air cleaner and recirculation is beneficial to reduce building heating demand



Co_2 concentration with 0 and 50% air recirculation

Recirculation % and ACH do not changes CO_2 level since the main CO_2 source is the outdoor air.

Conclusion:

- This study examines the effect of **gas-phase air cleaners** on **building heating demand**.
- The study also explores indoor **concentrations of TVOC and CO_2** when gas-phase air cleaners are used.
- Different parameters were also discussed, such as **ACH**, **air recirculation**, **ventilation**, and **occupancy schedule** on indoor **TVOC** and **CO_2** levels.
- Increasing recirculation rate **reduced heating demand** in the office building more than in residential.
- 60% recirculation rate reduced heating demand by **9%** in **residential** and **24%** in the **office building**.
- Integrating gas-phase air cleaner and increasing recirculation rate during rush hours of mornings and evenings kept TVOC and CO_2 concentrations acceptable.
- Indoor CO_2 concentration value was affected less than TVOC's by increasing the recirculation rate.
- Higher ACH minimizes the impact of recirculation rate on TVOC and CO_2 levels.

Thank you!

1

Dragos-Ioan Bogatu
drabo@dtu.dk
International Centre for Indoor Environment and Energy – ICIEE, DTU SUSTAIN, Technical University of Denmark

Gas phase air cleaning effects on ventilation energy use and indicators for energy performance

2

Outline

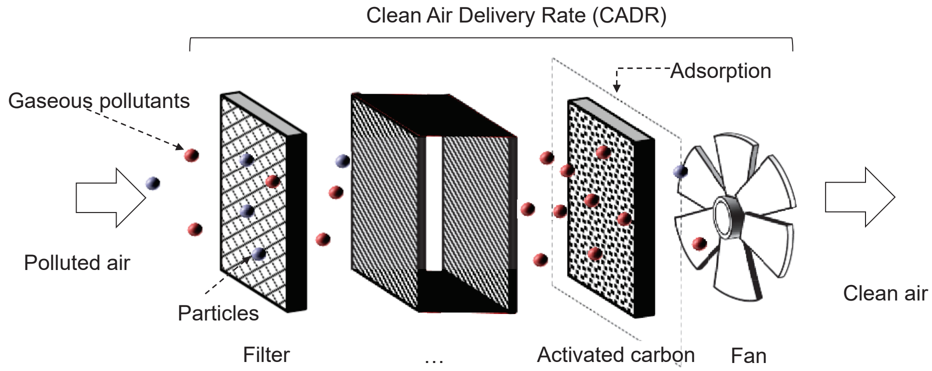
1. Introduction to gas-phase air cleaning
2. Clean Air Delivery Ratio (CADR)
3. Energy use
4. Clean Air Efficiency (CAE)
5. Conclusion

Gas-phase air cleaning (GPAC)

- Equipped with an activated carbon filter
- Removes gaseous pollutants (e.g. benzene, toluene, xylene) & odour
- Cannot remove all pollutants

DTU

Gas-phase air cleaning (GPAC)



DTU

Gas-phase air cleaning (GPAC)

➢**Reduce occupant dissatisfaction** (same outdoor air flow rate)

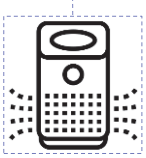
➢**Reduce outdoor air flow rate** (same occupant satisfaction)

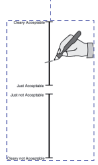
Methods

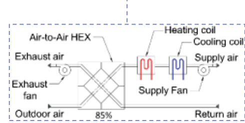
Framework

- Assess the air cleaner's effect on energy use
- Find effect relative to other methods

Stand-alone GPAC → PAQ and CADR (Human subject experiments) → Energy use (building energy simulation) → Clean air efficiency (CAE)





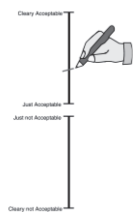


Air purifier icon, monkik, Flaticon, https://www.flaticon.com/free-icons/air-purifier

DTU

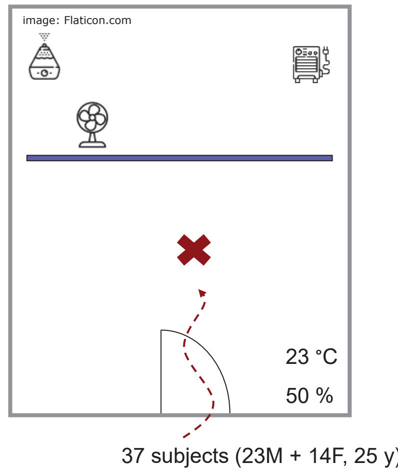
PAQ & CADR

- Human subject experiments



- Estimate difference in q for which the same percentage dissatisfied is achieved

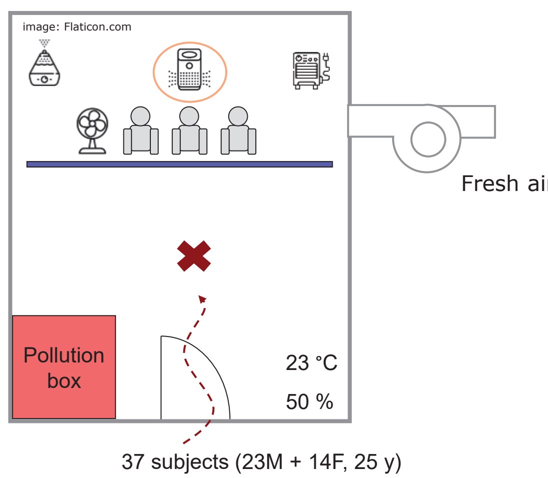
$$CADR = \frac{q - q_{GPAC}}{q} \cdot 100 \ \ [\%]$$



DTU

PAQ & CADR

- Pollution:
  – Building emissions
  – Building emissions & bio-effluents
- Conditions:
  – Without GPAC (REF)
  – With GPAC
- Outdoor air supply:
  – 2.5 / 4.0 / 7.0 / 10 L/s per person



DTU

Building energy simulation

- Determining **energy use**, GPAC **not physically implemented**.
- Implementation by **adjusting air flow rate**:

$$q_{tot} = n \cdot q_p + A_R \cdot q_b$$

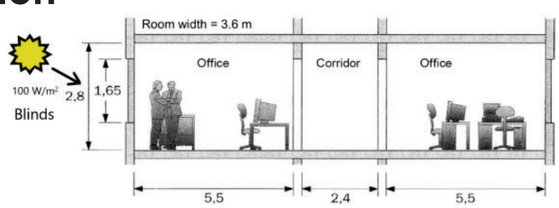
- CADRs:
  - **0%**, **30%**, **50%** of q_{tot}: $q = (1 - CADR) \cdot q_{tot}$
  - **50%** of q_b**:** $q = n \cdot q_p + (1 - CADR) \cdot A_R \cdot q_b$

EN 16798-1:2019, Category II (20% diss.)

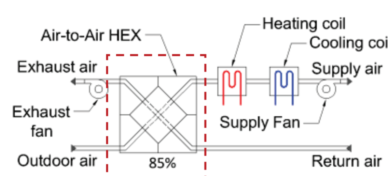
DTU

Building energy simulation

- Copenhagen, DK
- 20 °C < $T_{OP,SP}$ < 26 °C
- Ventilation: CAV
- Scenarios
  - with and without HEX
  - 2x pollution levels (VLP and LP)



Source: Olesen and Dossi, 2004

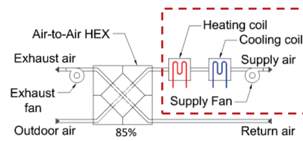


Bogatu et al. "Gas-Phase Air Cleaning Effects on Ventilation Energy Use and the Implications of CO2 Concentration as an IAQ Indicator for Ventilation Control.", Proceedings of Building Simulation 2021, 2021.

Clean Air Efficiency (CAE)

Indicator for comparing the efficiency of the AHU and stand-alone air cleaner

$$CAE = \frac{\text{CADR}}{Energy\ use} \quad [\text{L/s per kWh}]$$



vs.

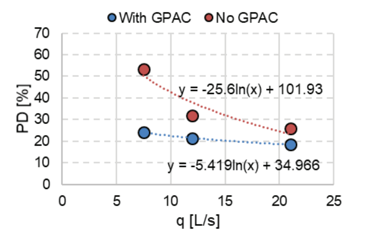
Amount of air, **CADR in L/s**, and energy use for **heating, cooling, and AUX** (transporting air) or **GPAC** [kWh]

image: Flaticon.com

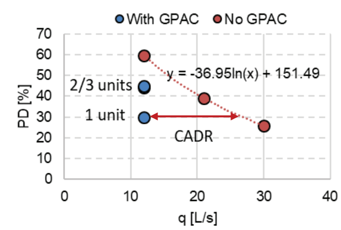
Results

PAQ & CADR

- With GPAC, dissatisfaction rate **reduced** for the same outdoor air flow rate
- With GPAC, outdoor air flow rate can be **reduced** for the same PD
- Increasing n_{GPAC} did not improve PAQ
- CADR:
  a) 50% (12 L/s)
  b) 30% (9 L/s)



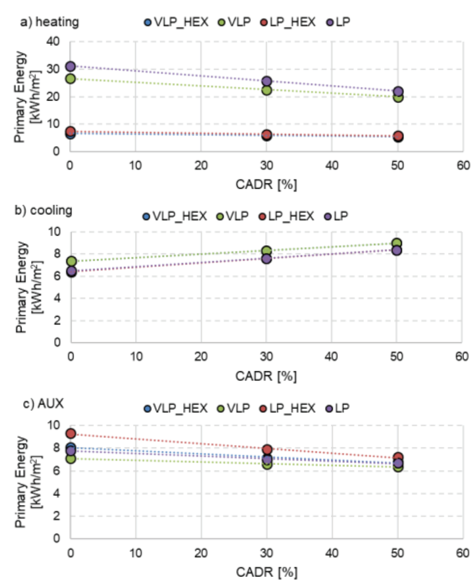
a) building emissions only



b) bio-effluents and building emissions

Energy use

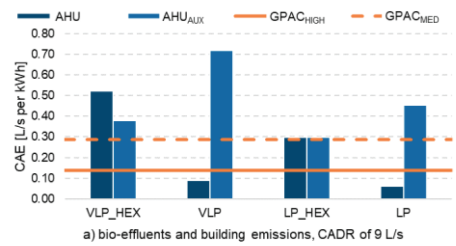
- Linear relationship as a function of CADR
- Heating and AUX decreased and cooling increased as CADR increased
- Heating decreased but AUX increased when the AHU was equipped with a HEX

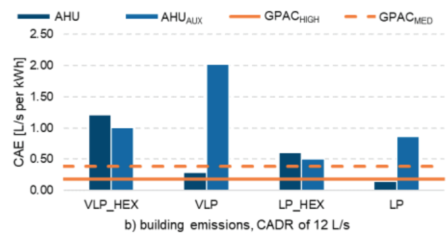


Bogatu et al. "Gas-Phase Air Cleaning Effects on Ventilation Energy Use and the Implications of CO2 Concentration as an IAQ Indicator for Ventilation Control.", Proceedings of Building Simulation 2021, 2021.

Clean Air Efficiency (CAE)

- If the GPAC is compared only to AHU_{AUX}, the GPAC is never efficient
- If a HEX is included the GPAC is not efficient
- Higher savings can be achieved if GPAC can be operated at a setting lower than HIGH (22 W)





Bogatu et al. "Gas-Phase Air Cleaning Effects on Ventilation Energy Use and the Implications of CO2 Concentration as an IAQ Indicator for Ventilation Control.", Proceedings of Building Simulation 2021, 2021.

Conclusions

- CAE can be used to compare different solutions for providing clean air into the space.
- In Copenhagen, DK (high heating load), GPAC was competitive only if the AHU was not equipped with a HEX.
- GPAC more efficient when it removed both bio-effluents and building emissions.
- GPAC can be used to either improve IAQ or reduce air flow rate

Contact: Dragos-Ioan Bogatu
drabo@dtu.dk

This study is part of IEA-EBC Annex 78 supported by Danish government funding EUDP project No.: 64018-0599

Special thanks to:

- Kanta Amada
- Zhengchai Hu
- Pawel Wargocki
- Lei Fang
- Ongun B. Kazanci
- Bjarne W. Olesen

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

INTRODUCTION TO THE PROJECT OF ISO 9972 REVISION

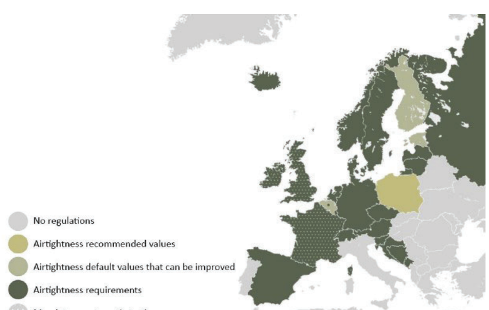
Topical Session, 43rd AIVC Conference, Copenhagen (DK) – 04.10.2023

Valérie Leprince

1

AIRTIGHTNESS REGULATIONS IN EUROPE

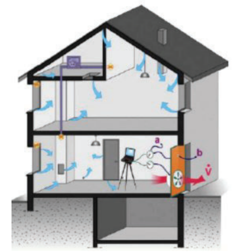
- Increasing number of tests performed in Europe
- Testing → important part in national energy regulations
- Test is used for :
  - **Measuring air leakage** in buildings to fulfill energy performance standards
  - **Comparing relative airtightness** of buildings
  - **Determining reduction** or air permeability after implementation of improvements



Poza-Casado et al. (2020)

2

ISO 9972: FAN PRESURIZATION METHOD



- Describes measurement procedure and calculation methods for determining airtightness
- To obtain comparable and credible results, it needs to be
  - **Reliable** and valid for different kinds of buildings
  - **Reproducible** under challenging environmental conditions
  - **Applicable** in any conditions
  - **Consistent** with other standards
- Recent scientific works + more experience in field testing → **need to improve parts of ISO 9972!**

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN ISO 9972

September 2015

ICS: 91.120.10

Supersedes EN 13829:2000

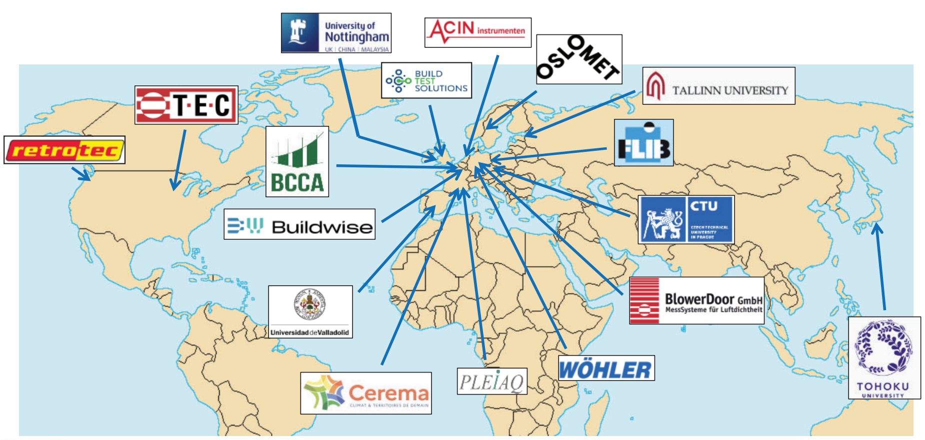
English Version

Thermal performance of buildings — Determination of air permeability of buildings — Fan presurization method
(ISO 9972:2015)

Performance thermique des bâtiments — Détermination de la perméabilité à l'air des bâtiments — Méthode de pressurisation par ventilateur
(ISO 9972:2015)

Wärmetechnisches Verhalten von Gebäuden — Bestimmung der Luftdurchlässigkeit von Gebäuden — Differenzdruckverfahren
(ISO 9972:2015)

WORKING GROUP AFFILIATIONS



REASONS BEHIND A NECESSARY REVISION

Limitations on measurement **reliability**

• Building preparation	Work has not started yet
• Wind speed and temperature measurements	Proposal finished
• Placement of external pressure taps	Work started – more research needed
• Duration of pressure/airflow measurements	Work on proposal has started
• Induced pressure differences	Work has not started yet
• Type of regression	Work on proposal has started

REASONS BEHIND A NECESSARY REVISION

Limitations on measurement **validity**

• Airflow corrections	Proposal finished
• Calculation of building volume and area	Work started – more research needed
• Limits on zero-flow pressure measurements	Work on proposal has started
• Knowledge of uncertainty	
• Errors due to measurement instruments, measurement protocol and analysis	Proposal finished
• Errors arising from physical model assumptions	Work has not started yet

REASONS BEHIND A NECESSARY REVISION

Limitations on measurement **validity**

- Airflow corrections
- Calculation of building volume and area → Bassam Moujalled
- Limits on zero-flow pressure measurements
- Knowledge of uncertainty
  - Errors due to measurement instruments, measurement protocol and analysis
  - Errors arising from physical model assumptions

REASONS BEHIND A NECESSARY REVISION

Limitations on measurement **validity**

- Airflow corrections
- Calculation of building volume and area
- Limits on zero-flow pressure measurements → Benedikt Kölsch
- Knowledge of uncertainty
  - Errors due to measurement instruments, measurement protocol and analysis
  - Errors arising from physical model assumptions

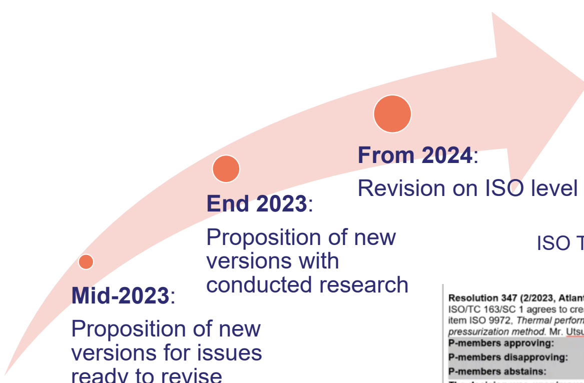
REASONS BEHIND A NECESSARY REVISION

Limitations on measurement **validity**

- Airflow corrections
- Calculation of building volume and area
- Limits on zero-flow pressure measurements
- <u>Knowledge of uncertainty</u>
  - Errors due to measurement instruments, measurement protocol and analysis
  - Errors arising from physical model assumptions

→ Martin Prignon

OUTLOOK



On 2023 September 28th
ISO TC163, SC1 Committee agreed to launch
the revision of ISO 9972!

Resolution 347 (2/2023, Atlanta 2023-09-28)
ISO/TC 163/SC 1 agrees to create an Ad-Hoc group "Air tightness of buildings" to develop the preliminary work item ISO 9972, *Thermal performance of buildings — Determination of air permeability of buildings — Fan pressurization method*. Mr. Utsumi is appointed as the Ad-Hoc group leader.

P-members approving:	**12**
P-members disapproving:	**0**
P-members abstains:	**0**

The decision was *unanimous*

Buildwise

Uncertainties in fan pressurization measurement

Integration of envelope pressure inhomogeneity and autocorrelation aspects

Dr. Ir. Martin Prignon,
Buildwise
martin.prignon@buildwise.be

43rd AIVC conference "Ventilation, IEQ and health in sustainable buildings"

1

- Context
- Novelty 1: Autocorrelation
- Novelty 2: Inhomogeneity
- Analysis of global impact
- Conclusion

Buildwise

2

- Context
- Novelty 1: Autocorrelation
- Novelty 2: Inhomogeneity
- Analysis of global impact
- Conclusion

Buildwise

Uncertainty estimation is crucial for airtightness testing

*"without such an indication, measurement results **cannot be compared**, either among themselves or with reference values given in a specification or **standard**"*

(JCGM, 2008)

Airtightness:
- High importance (standards)
- Often overlooked in research and practice
- Literature shows large gap between estimated and real uncertainties

Objective:
Improve the uncertainty estimation by integrating two aspects in the process

Buildwise

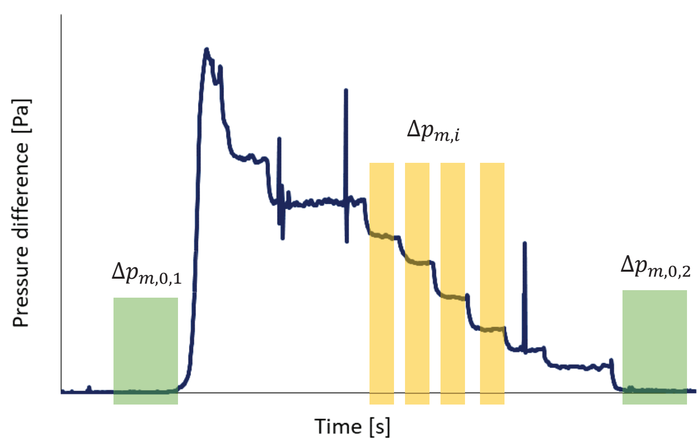
Quick reminder: fan pressurisation test protocol

1. Measurement of $\Delta p_{m,i,k}$; $q_{m,i,k}$; T_i and T_e
2. Determination of Δp_i ; q_i couples
3. Evaluation of the linear model fitting x_i ; y_i couples with $x_i = \ln(\Delta p_i)$ and $y_i = \ln(q_i)$
4. Determination of building characteristics: n ; $\ln(c)$; q_{50} ; n_{50} ; ELA_4 ; etc.

Buildwise

Quick reminder of the five steps to determine Δp_i

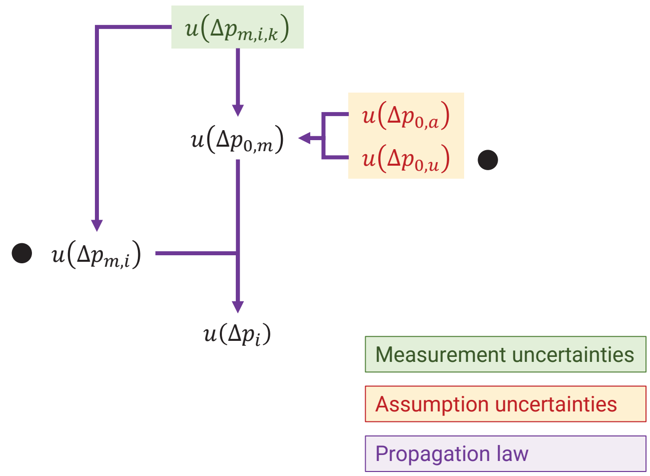
1. Test: measurement of $\Delta p_{m,i,k}$
2. Zero-flow pressure: $\Delta p_{0m} = \frac{\Delta p_{0m,1}+\Delta p_{0m,2}}{2}$
3. At each pressure station: $\Delta p_{m,i} = \frac{1}{N} * \sum_{k=1}^{N} \Delta p_{m,i,k}$
4. $\Delta p_i = \Delta p_{m,i} - \Delta p_{0m}$



Buildwise

Two novelties in the uncertainty estimation process

1. Test: measurement of $\Delta p_{m,i,k}$
2. Zero-flow pressure: $\Delta p_{0m} = \frac{\Delta p_{0m,1} + \Delta p_{0m,2}}{2}$
3. At each pressure station: $\Delta p_{m,i} = \frac{1}{N} * \sum_{k=1}^{N} \Delta p_{m,i,k}$
4. $\Delta p_i = \Delta p_{m,i} - \Delta p_{0m}$



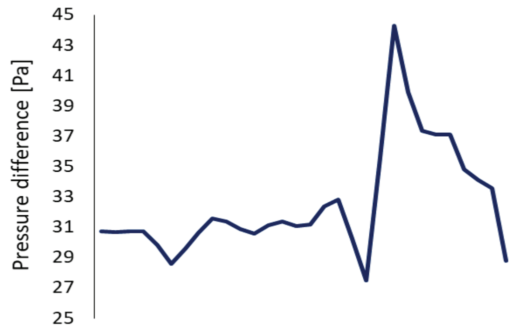
Buildwise

- Context
- **Novelty 1: Autocorrelation**
- Novelty 2: Inhomogeneity
- Analysis of global impact
- Conclusion

Buildwise

Pressure difference measurements seem autocorrelated

Autocorrelation is when a measurement made at a time t depends on a series of measurements made before this one.

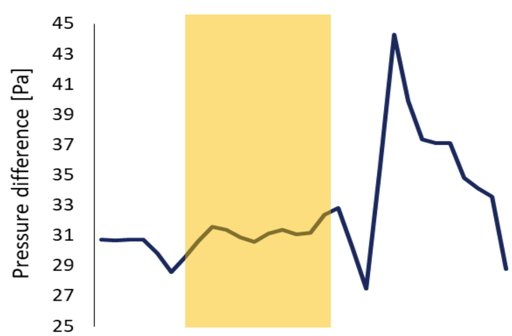


Autocorrelation has an impact on uncertainty calculation

$$\Delta p_{i,m} = \frac{1}{N} * \sum_{k=1}^{N} \Delta p_{i,m,k}$$

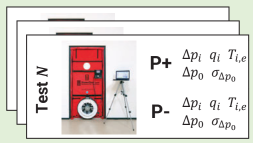
$$u(\Delta p_{i,m}) = \frac{u(\Delta p_{i,m,k})}{\gamma}$$

$\gamma = 1$ Fully correlated (today)
$\gamma = N$ Fully uncorrelated (here $N = 30$)
$\gamma = N_{eff}$ Autocorrelated (suggestion)



Repeatability study to determine the level of autocorrelation (N_{eff}) in pressure measurements

Repeatability study



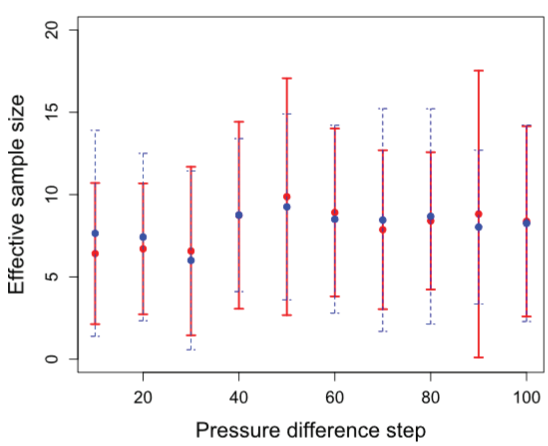
Total: 30 tests
Case: Appartement in Brussels
Prignon et al., 2020

Calculation of N_{eff}

- For each test
- For each mode (P+ and P-)
- At each pressure station (Δp_i)

Buildwise

Results show consequent autocorrelation of the data



--- Depressurisation
— Pressurisation

- No clear difference between
  - P+ and P-
  - Different Δp_i
- $\mu(N_{eff}) = 8.1$ and $\sigma(N_{eff}) = 3.0$

Buildwise

- Context
- Novelty 1: Autocorrelation
- Novelty 2: Inhomogeneity
- Analysis of global impact
- Conclusion

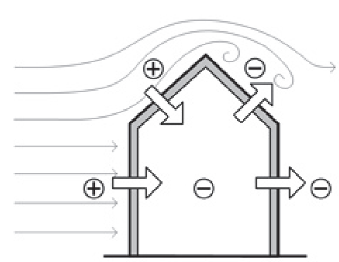
Buildwise

13

Inhomogeneity of pressure difference along the building envelope induces some uncertainty

Distribution of airflows among leaks depends on Δp distribution.
➔ Inhomogeneity represents a source of uncertainty

In this study inhomogeneity is assumed coming only from wind pressure (low-rise building)



Buildwise

14

Inhomogeneity is included as an assumption uncertainty for the zero-flow pressure

Temperature inhomogeneity for climatic chambers,

$$u(T) = \frac{\Delta T_{max}}{\sqrt{3}}$$

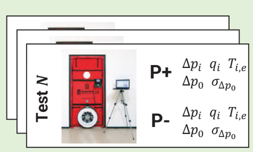
For wind-derived inhomogeneity,

$$u(\Delta p_{0,u}) = \frac{|c_{p,max} - c_{p,min}| * v_w^2 * \rho}{2 * \sqrt{3}}$$

Buildwise

Repeatability study to quantify uncertainty assumption related to inhomogeneity

Repeatability study



Total: 30 tests
Case: Appartement in Brussels
Prignon et al., 2020

Calculation of $u(\Delta p_{0,u})$ for each test
Comparison with $u(\Delta p_{0,a})$

Uncertainty source	Average [Pa]	95% CI [Pa]
$u(\Delta p_{0,a})$	1.1	[0.0 ; 2.1]
$u(\Delta p_{0,u})$	1.6	[0.0 ; 4.2]

- Same order of magnitude than $u(\Delta p_{0,a})$
- Large impact at low pressure station

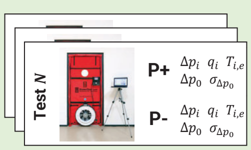
Buildwise

- Context
- Novelty 1: Autocorrelation
- Novelty 2: Inhomogeneity
- **Analysis of global impact**
- Conclusion

Buildwise

Repeatability study to study the impact of two novelties on the whole uncertainty estimation process

Repeatability study



Total: 30 tests
Case: Appartement in Brussels
Prignon et al., 2020

Full post-processing up to the determination of q_{50}

	$u(\Delta p_{m,i,k})$	$u(\Delta p_{0,a})$	$u(\Delta p_{0,u})$	N_{eff}
Case 1	•			
Case 2	•	•		
Case 3	•	•	•	
Case 4	•	•	•	•

Buildwise

Results in brief

- Considering inhomogeneity without autocorrelation leads to an overestimation of calculated uncertainties for n and $\ln(c)$, but a good estimation for q_{50}
- Considering inhomogeneity and autocorrelation reduces uncertainty and improves uncertainty estimation of n and $\ln(c)$

- Context
- Novelty 1: Autocorrelation
- Novelty 2: Inhomogeneity
- Analysis of global impact
- Conclusion

Interesting results, but investigation still important

Conclusion
Relevant additions, but still not enough to explain the observed uncertainty

Further work
- Confirm the trends
- Adapt for high-rise building (stack effect)
- Further quantification of precision errors
- Add biases in the evaluation process

Thank you for your attention

Buildwise

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

Aalborg University **Copenhagen Denmark**

October **4-5 2023**

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

STATISTICAL ANALYSIS OF THE CORRELATIONS BETWEEN BUILDINGS AIR PERMEABILITY INDICATORS

Bassam Moujalled, Bnedikt Kölsch, Adeline Mélois, Valérie Leprince

Cerema & Université Savoie Mont Blanc / LOCIE, France

October 4, 2023

1

CONTEXT OF BUILDING AIR TIGHTNESS DATABASES

Development of building air tightness tests in several European countries thanks to the mandatory requirements

- **Almost all newly built residential buildings are tested in France, Belgium and UK**

Creation of building airtightness databases in these countries

- **Databases with more than 500,000 tests in France and more than 1,000,000 tests in UK**

Comparing building performance across different countries is challenging

- **Various indicators used to measure the air permeability of buildings**

2

OBJECTIVES

Comparison of the air permeability indicator between different countries

- **Identify the indicators and their calculation methods in different countries**

Establish default conversion equations between the main indicators based on the statistical analysis of the French database:

- **Analysis of geometric parameters**
- **Correlations between air permeability indicators**

AIR PERMEABILITY INDICATORS

Air permeability indicators in ISO 9972:

- **Specific air leakage rate $q_{E\Delta P}$ [$m^3.h^{-1}.m^{-2}$]**: airflow rate $q_{\Delta P}$ [$m^3.h^{-1}$] at a specific pressure difference ΔP [Pa] divided by the building envelope area A_E [m^2]
- **Air change rate $n_{\Delta P}$ in [h^{-1}]**: airflow rate $q_{\Delta P}$ [$m^3.h^{-1}$] at a specific pressure difference ΔP [Pa] divided by the building volume V [m^3]
- **Air permeability rate $q_{F\Delta P}$ [$m^3.h^{-1}.m^{-2}$]**: airflow rate $q_{\Delta P}$ [$m^3.h^{-1}$] at a specific pressure difference ΔP [Pa] divided by the net floor area A_F [m^2]

COMPARISON OF AIR PERMEABILITY INDICATORS

The definition of air permeability indicator differs according on the **reference pressure difference** and the **geometric parameter** used in each country

Country	Indicator	Definition	Calculation
France	$Q_{4Pa\text{-}surf}$ [$m^3.h^{-1}.m^{-2}$]	Specific air leakage rate at **4 Pa** divided by heat loss area excluding the basement floor	q_4: air leakage rate at 4 Pa [$m^3.h^{-1}$] **A_{TBAT}: thermal envelope area excluding the basement floor [m^2]**
Germany	n_{L50} [h^{-1}]	Air change rate at **50 Pa**	q_{50}: air leakage rate at 50 Pa [$m^3.h^{-1}$] **V_L: internal air volume [m^3]**
Belgium	V_{50} [$m^3.h^{-1}.m^{-2}$]	Specific air leakage rate at **50 Pa** divided by heat loss area	q_{50}: air leakage rate at 50 Pa [$m^3.h^{-1}$] **A_{test}: thermal envelope area [m^2]**
UK	AP_{50} [$m^3.h^{-1}.m^{-2}$]	Specific air leakage rate at **50 Pa** divided by the internal envelope area	Q_{50}: air leakage rate at 50 Pa [$m^3.h^{-1}$] **A_E: envelope area [m^2]**
Netherlands	q_{v10} [$m^3.s^{-1}$]	Volumetric air flow at **10 Pa**	q_{v10}: volumetric air flow at 10 Pa [$m^3.h^{-1}$]

COMPARISON OF AIR PERMEABILITY INDICATORS

Envelope area calculation

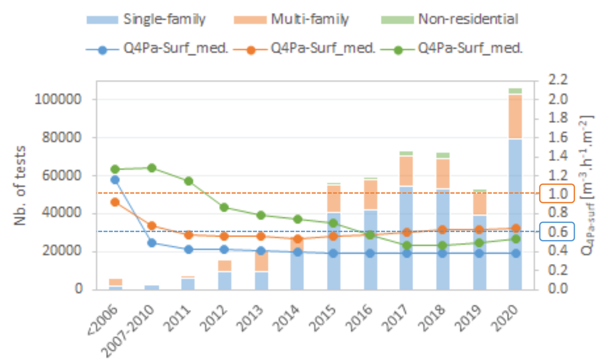
- **ISO 9972:** building envelope area including floor areas and junctions of internal walls (internal dimensions)
- **France:** Thermal loss envelope area A_{TE} in contact with the exterior environment/adjacent unheated spaces/ground, excluding lower floor area (internal dimensions)
- **Belgium:** Thermal loss envelope area A_{TE} in contact with the exterior environment/adjacent unheated spaces/ground (external dimensions)

Building volume calculation

- **ISO 9972:** internal building volume without subtracting the volume of walls, floors, cavities or furniture
- **Germany:** net room volume as a product from the net room area and the middle of the room height (heated or cooled spaces)

DATA IN THE FRENCH DATABASE

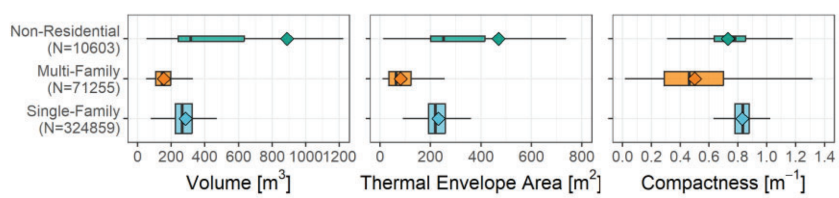
- About 570,000 measurements in the French database
- A set of 406,717 tests is selected for the statistical analysis
  - 324,859 tests in Single-family houses (SF)
  - 71,255 tests in Multi-Family apartments (MF)
  - 10,603 tests in non-residential buildings (NR)
- Air permeability levels :
  - SF : Median $Q_{4Pa\text{-}surf}$ **~0.4 m³.h⁻¹.m⁻²** (n_{50} ~1.7 h^{-1})
  - MF : Median $Q_{4Pa\text{-}surf}$ **~0.6 m³.h⁻¹.m⁻²** (n_{50} ~1.4 h^{-1})
  - NR : median $Q_{4Pa\text{-}surf}$ **~0.5 m³.h⁻¹.m⁻² (n_{50}** ~1.9 h^{-1})

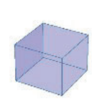
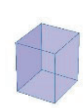
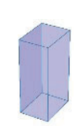


ANALYSIS OF GEOMETRIC PARAMETERS

Geometric parameters

- Thermal loss envelope area except for lower floor A_{TE}
- Internal volume **V**
- **Compactness factor=** A_{TE}/V
  - *The lower this factor, the more compact the building*



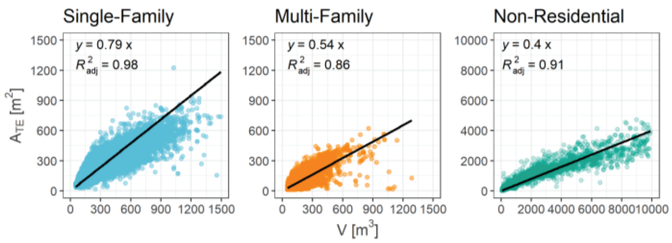
Compactness < 0.8 m⁻¹	Compactness = 0.80 m⁻¹	Compactness = 0.85 m⁻¹	Compactness = 1.00 m⁻¹
Houses with one or more adjacent walls			

ANALYSIS OF GEOMETRIC PARAMETERS

Strong linear correlations are observed between A_{TE} and V

The slopes of the linear regression are 0.79, 0.54 and 0.4 for SF, MF, and NR

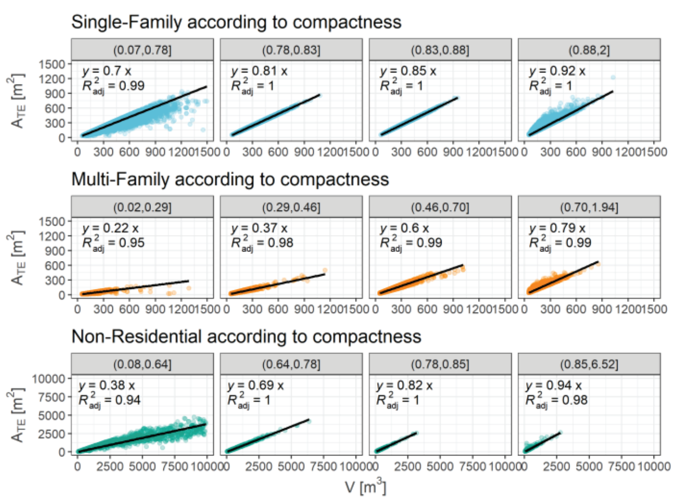
- Average Compactness
- Buildings with lower or higher values of the compactness factor deviate significantly from the regression line



ANALYSIS OF GEOMETRIC PARAMETERS

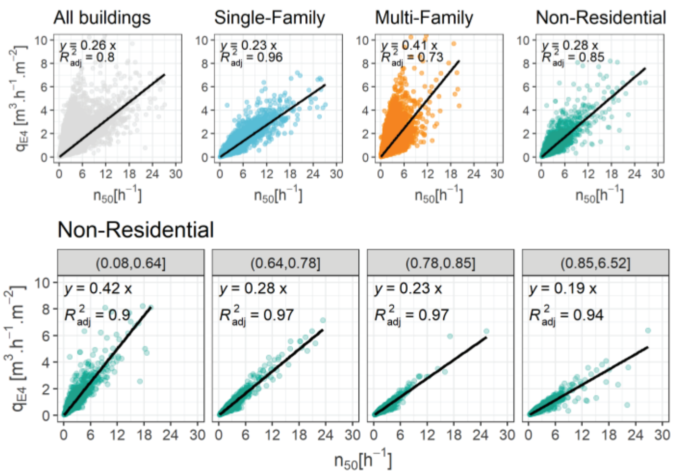
Correlations between the thermal envelope area and the internal volume according to the compactness

- Four classes of compactness corresponding to the quartiles of the compactness factor
- Very strong linear correlations
- Compactness factor appears to be thus a relevant geometric parameter for characterising the relationship between the air permeability indicators



CORRELATIONS BETWEEN AIR PERMEABILITY INDICATORS

- Correlations between five indicators (**specific air leakage rates q_{E4} / q_{E10} / q_{E50} and air change rates n_{10} / n_{50}**) have been calculated
- Correlation between specific leakage rate q_{E4} and air flow rate n_{50} depends on:
  - the building type
  - The building geometry: The more compact the building (i.e., the smaller the compactness factor), the greater the slope of the regression line



CORRELATIONS BETWEEN AIR PERMEABILITY INDICATORS

- Correlations between q_{E4} and n_{50} depending on building type and building compactness

Correlation	Building type	Correlation depending on building type and building compactness			Correlation depending on building type		General correlation	
		Compact.	Reg. coef.	Conf. Int. 95%	Reg. coef.	Conf. Int. 95%	Reg. coef.	Conf. Int. 95%
q_{E4} = Coef * n_{50}	Single-Family houses	(0.07,0.78]	0.264 (r^2=0.965)	[0.264,0.265]	0.228 (r^2=0.964)	[0.228,0.228]	0.26 (r^2=0.801)	[0.26,0.261]
		(0.78,0.83]	0.23 (r^2=0.983)	[0.23,0.231]				
		(0.83,0.88]	0.219 (r^2=0.984)	[0.218,0.219]				
		(0.88,2]	0.2 (r^2=0.977)	[0.2,0.2]				
	Multi-Family apartments	(0.02,0.29]	0.91 (r^2=0.929)	[0.906,0.914]	0.409 (r^2=0.728)	[0.407,0.41]		
		(0.29,0.46]	0.517 (r^2=0.958)	[0.516,0.519]				
		(0.46,0.70]	0.33 (r^2=0.966)	[0.329,0.331]				
		(0.70,1.94]	0.237 (r^2=0.964)	[0.236,0.238]				
	Non-Residential buildings	(0.08,0.64]	0.418 (r^2=0.9)	[0.412,0.423]	0.284 (r^2=0.851)	[0.282,0.287]		
		(0.64,0.78]	0.276 (r^2=0.971)	[0.274,0.278]				
		(0.78,0.85]	0.233 (r^2=0.973)	[0.231,0.234]				
		(0.85,6.52]	0.192 (r^2=0.936)	[0.19,0.194]				

CONCLUSIONS

- Various air permeability indicators used across different countries depending on the specific application and nation's regulation
  - most common indicators:
    - *Specific air leakage rate per envelope area*
    - *Air change rate*
  - Reference pressure differences:
    - *50 Pa in the majority of countries*
    - *Lower values in some countries (e.g. 4 Pa in France, 10 Pa in Netherlands)*
  - Calculation of geometric parameters specific for each country
    - *Building envelope area vs. heat loss area (excluding or not some specific area)*
    - *Internal dimensions vs. external dimensions*
    - *Volume with OR without subtracting the volume of walls, floors, cavities or furniture*

CONCLUSIONS

- The correlations between five indicators (specific air leakage rates q_{E4} / q_{E10} / q_{E50} and air change rates n_{10} / n_{50}) have been calculated according to the building type and compactness
  - Strong linear correlations between indicators (correlation coefficients between 0.80 and 0.99)
  - Correlations between specific leakage rate and air change rate depend on the building type and geometry
    - *The more compact the building (i.e., the smaller the compactness factor), the greater the slope of the regression line*
    - *If the geometry data is missing, a general correlation can be used with a higher estimation error*
- More analysis are needed with other databases to compare the geometry parameters and make cross analysis between countries

B. Moujalled, B. Kölsch, A. Mélois, V. Leprince, Quantitative correlation between buildings air permeability indicators: Statistical analyses of over 400,000 measurements, Energy and Buildings. 298 (2023) 113566. https://doi.org/10.1016/j.enbuild.2023.113566

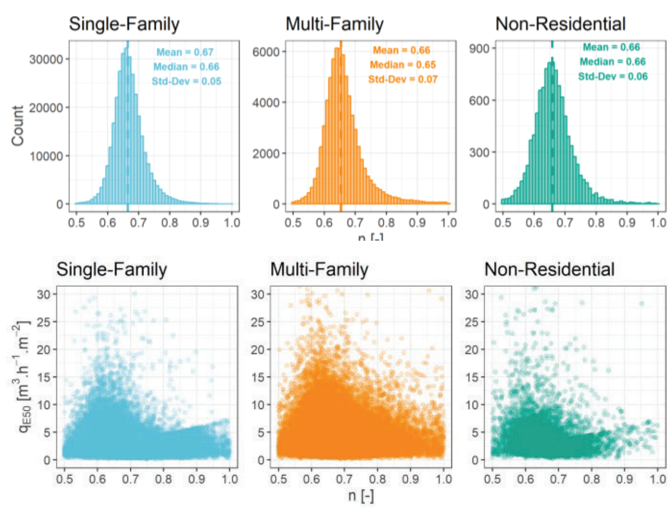
Thank you!

bassam.moujalled@cerema.fr

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

ANALYSIS OF FLOW EXPONENT

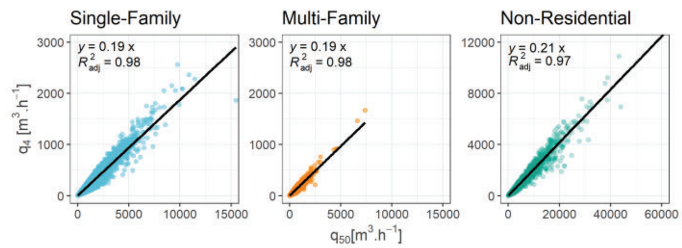
- Median and mean of the pressure exponent around 0.66 and a standard deviation of around 0.06
  - Whatever the type of building or its geometry
- No correlation between leakage rate and exponent n value
  - No tendency of large orifice or specific leaks shape for buildings with a low airtightness level
- No parameter that could influence the pressure exponent has been identified



Cerema
CLIMAT & TERRITOIRES DE DEMAIN

CORRELATIONS BETWEEN AIRFLOW RATES

- Correlations of the airflow rates at 4 Pa and 10 Pa with the flow rate at 50 Pa
  - Very strong linear correlations
  - In case of a one-point airtightness test at 50 Pa, these correlations help to estimate the air leakage at 4 Pa or 10 Pa and thus calculate other air permeability indicators, such as q_{E4}



Building type	q_4 = Coef * q_{50}		q_{10} = Coef * q_{50}	
	Reg. Coef.	Conf. Int. 95%	Reg. Coef.	Conf. Int. 95%
Single-Family houses	0.187 (r^2=0.982)	[0.187,0186]	0.343 (r^2=0.992)	[0.343, 0.343]
Multi-Family apartments	0.193 (r^2=0.979)	[0.193,0.194]	0.350 (r^2=0.991)	[0.350, 0.350]
Non-Residential buildings	0.208 (r^2=0.972)	[0.207,0.208]	0.366 (r^2=0.988)	[0.365,0.367]

RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN

CONCLUSIONS

Statistical analysis of **over 400,000 measurements** from the French database

- The thermal envelope area in the French database excludes the lower floor area !

Compactness factor is a relevant geometric parameter **for characterising the relationship between the air permeability indicators**

- Around 0.8 m^{-1} for a typical single-family house and non-residential buildings
- Lower values for multi-family apartments, especially for apartments on an intermediate level with only one or two facades (0.2 m^{-1})

RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

FLOW ERROR ANALYSIS: ISO 9972 & ZERO-FLOW CONSTRAINTS

A comprehensive study on the influence of steady wind and stack effects

Topical Session, 43rd AIVC Conference, Copenhagen (DK) – 04.10.2023

Benedikt Kölsch, Valérie Leprince, Adeline Mélois, Bassam Moujalled

ISO 9972: FAN PRESURIZATION METHOD

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN ISO 9972

September 2015

ICS: 91.120.10

Supersedes EN 13829:2000

English Version

Thermal performance of buildings — Determination of air permeability of buildings — Fan presurization method
(ISO 9972:2015)

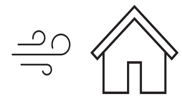
Performance thermique des bâtiments — Détermination de la perméabilité à l'air des bâtiments — Méthode de pressurisation par ventilateur (ISO 9972:2015)

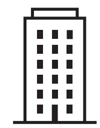
Wärmetechnisches Verhalten von Gebäuden — Bestimmung der Luftdurchlässigkeit von Gebäuden — Differenzdruckverfahren (ISO 9972:2015)

ISO CONSTRAINTS

Zero-Flow Pressure Differences

- Δp_0 = Pressure difference between inside and outside when a building is not artificially pressurized
- ISO 9972 defines constraints to limit the influence of wind + temperatures
- Constraints for valid measurements:
  1. **$|\Delta p_0| < 5$ Pa**
  2. **Lowest Δp_{st} = 10 Pa** or **5 x $|\Delta p_0|$**





ISO CONSTRAINTS EXCLUDE MANY BUILDINGS FROM BEING TESTED!

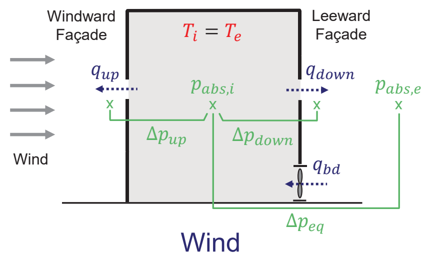
Understanding airflow errors and effectiveness of ISO constraints:

- What is the **error of the measured airflow** induced by Δp_0?
- Which **parameters influence Δp_0** in detail?
- Does **pressure tap position** have an influence on Δp_0 ?
- Are there **alternative constraints** that could be applied when the ones in ISO 9972 are impossible to reach (e.g., for windy or high-rise buildings)?

?

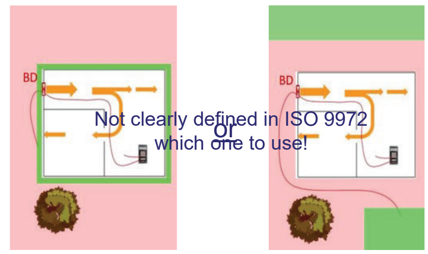
OUR APPROACH

Wind model – pressure tap positions



Next to the building

Further away from the building

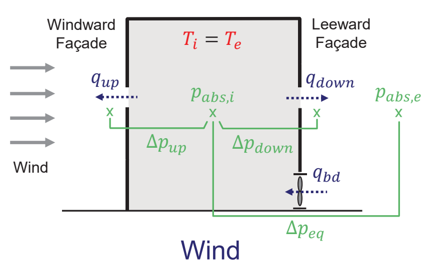


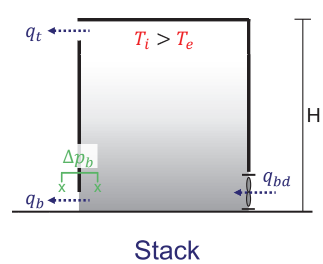
Pressure difference across envelope

Equilibrium internal pressure

OUR APPROACH

Wind and stack effect models





ISO 9972 AIRFLOW ERROR

Calculation procedure and assumptions in ISO 9972:

Correction of the measured pressure station with Δp_0:

$$q_{est} = C_{est}(\Delta p_{st} - \Delta p_0)^n$$

Contrary to the assumption in ISO 9972:

$$(C_{up} + C_{down})(\Delta p_{st} - \Delta p_0)^n \neq C_{up}\,\Delta p_{up}^n + C_{down}\,\Delta p_{down}^n$$

$$C_{real}\,(\Delta p_{st} - \Delta p_0)^n \neq C_{est}\,(\Delta p_{st} - \Delta p_0)^n$$

Airflow error: $\frac{\delta q}{q} = \frac{C_{est} - C_{real}}{C_{real}}$


EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN ISO 9972

September 2015

ICS: 91.120.10 — Supersedes EN 13829:2000

English Version

Thermal performance of buildings — Determination of air permeability of buildings — Fan presurization method
(ISO 9972:2015)

Performance thermique des bâtiments — Détermination de la perméabilité à l'air des bâtiments — Méthode de pressurisation par ventilateur (ISO 9972:2015)

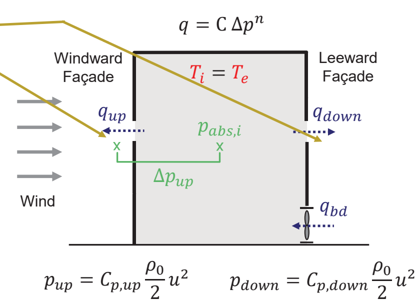
Wärmetechnisches Verhalten von Gebäuden — Bestimmung der Luftdurchlässigkeit von Gebäuden — Differenzdruckverfahren (ISO 9972:2015)

UNDERSTANDING ZERO-FLOW PRESSURE

Upwind measurement position of Δp_0

$$\Delta p_{0,up} = -\frac{p_{up} - p_{down}}{1 + 1/z_w^{1/n}} \qquad z_w = \frac{C_{down}}{C_{up}}$$

- Always **negative**
- Depends on:
  - Upwind pressure
  - Downwind pressure
  - Pressure exponent
  - Leakage distribution



UNDERSTANDING ZERO-FLOW PRESSURE

Upwind measurement position of Δp_0

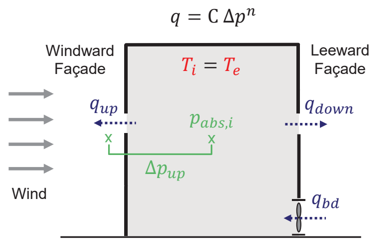
$$\Delta p_{0,up} = -\frac{p_{up} - p_{down}}{1 + 1/z_w^{1/n}} \qquad z_w = \frac{C_{down}}{C_{up}}$$

$$x_w = \frac{p_{up} - p_{down}}{\Delta p_{st}}$$

Airflow error:

$$\frac{\delta q}{q}_{w,up} = \frac{C_{est,w,up} - C_{real,w}}{C_{real,w}}$$

$$= \frac{1 + z_w(1 + x_w)^n}{(1 + z_w)\left(1 + \frac{x_w}{1 + 1/z_w^{1/n}}\right)^n} - 1$$



$$p_{up} = C_{p,up}\frac{\rho_0}{2}u^2 \qquad p_{down} = C_{p,down}\frac{\rho_0}{2}u^2$$

UNDERSTANDING ZERO-FLOW PRESSURE

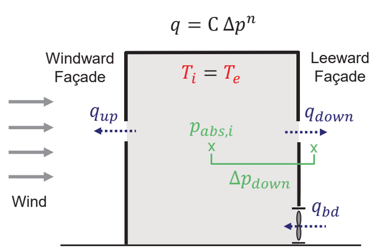
Downwind measurement position of Δp_0

$$\Delta p_{0,down} = \frac{p_{up} - p_{down}}{1 + z_w^{1/n}} \qquad \Delta p_{0,up} = -\frac{p_{up} - p_{down}}{1 + 1/z_w^{1/n}}$$

- Always **positive**

Airflow error:

$$\frac{\delta q}{q}_{w,down} = \frac{z_w + (1 - x_w)^n}{(1 + z_w)\left(1 - \frac{x_w}{1 + z_w^{1/n}}\right)^n} - 1$$

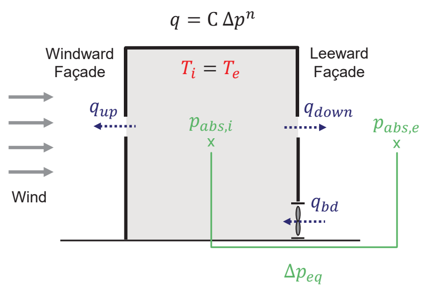


UNDERSTANDING ZERO-FLOW PRESSURE

Equilibrium measurement position of Δp_0

$$\Delta p_{0,w,eq} = \frac{p_{up} + z_w^{1/n} p_{down}}{1 + z_w^{1/n}} \qquad z_w = \frac{C_{down}}{C_{up}}$$

- Can be **positive** or **negative** depending on the **leakage distribution!**



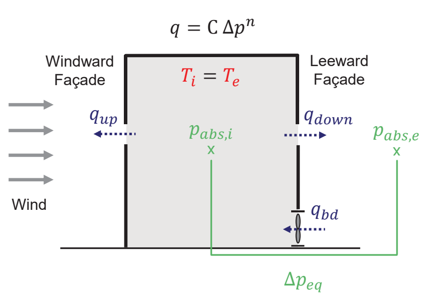
UNDERSTANDING ZERO-FLOW PRESSURE

Equilibrium measurement position of Δp_0

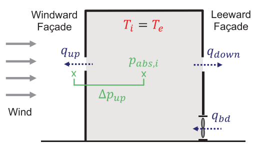
$$\Delta p_{0,w,eq} = \frac{p_{up} + z_w^{1/n} p_{down}}{1 + z_w^{1/n}}$$

Airflow error:

$$\frac{\delta q}{q}_{w,eq} = \frac{(1 - x_{w,up})^n + z_w(1 - x_{w,down})^n}{(1 + z_w)\left(1 - \frac{x_{w,up} + z_w^{1/n} x_{w,down}}{1 + z_w^{1/n}}\right)^n} - 1$$



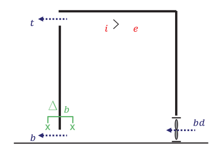
UNDERSTANDING ZERO-FLOW PRESSURE



Wind

$$\frac{\delta q}{q} = \frac{1 + z(1+x)^n}{(1+z)\left(1 + \frac{x}{1+1/z^{1/n}}\right)^n} - 1$$

$$\Delta p_{zf} = -\frac{p_{force}}{1+1/z^{1/n}}$$



Stack

$$p_{force,w,up} = p_{up} - p_{down}$$

$$x_w = \frac{p_{force,w}}{\Delta p_{st}}$$

$$z_w = \frac{C_{down}}{C_{up}}$$

$$p_{force,s} = p_s \approx \frac{\rho_0}{T_0} g\, \Delta T\, H$$

$$x_s = \frac{p_{force,s}}{\Delta p_{st}}$$

$$z_s = \frac{C_t}{C_b}$$

SIMULATION OF VARIOUS BUILDING SCENARIOS

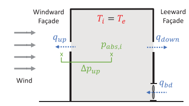
Range of parameters

Input variable	Min. value	Max. value	Distribution characteristics
n	0.5	0.9	Linear distribution in steps of 0.1
$\Delta p_{st,pres/depres}$	± 10 Pa	± 100 Pa	Linear distribution in steps of 10 Pa
u	0 m/s	10 m/s	Linear distribution in steps of 0.1 m/s
z	1/99	99	Logarithmic distribution with 100 values
ΔT	1 K	20 K	Linear distribution in steps of 1 K (always $T_i > T_e$)
H	4 m	100 m	Linear distribution in steps of 1 m
$C_{p,down}$	–	–	$[-0.3, -0.5, -0.7]$
$C_{p,up}$	–	–	$[0.05, 0.25, 0.5]$

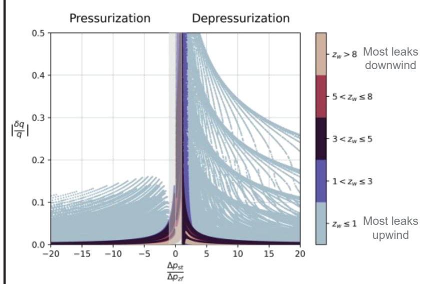
3 million wind and 7 million stack pressure scenarios!

KEY FINDINGS

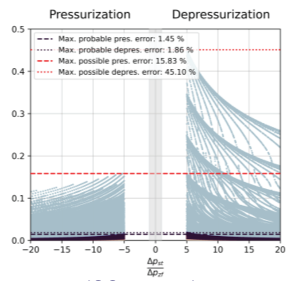
$$z_w = \frac{C_{down}}{C_{up}}$$



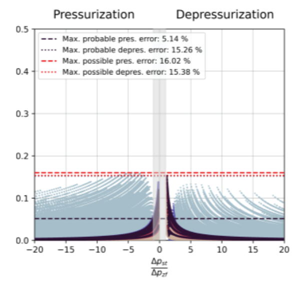
Upwind measurement position of Δp_0



Full dataset



ISO constraints



Alternative

→ Fully pres/depres building with a margin of 10 Pa!

$|\Delta p_0| < 5$ Pa

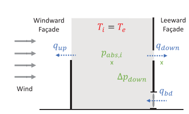
$|\Delta p_{st,low}| > 5 \times |\Delta p_0|$

ISO 9972 & Zero-flow pressure

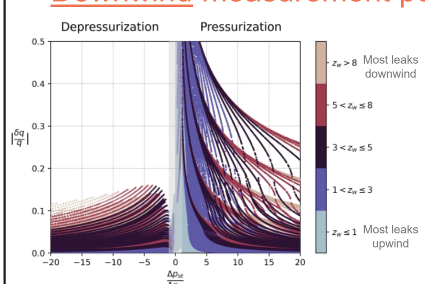
Cerema

KEY FINDINGS

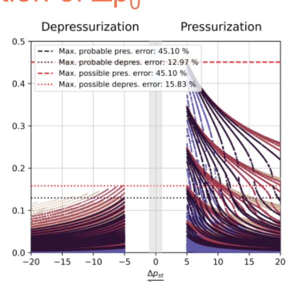
$$z_w = \frac{C_{down}}{C_{up}}$$



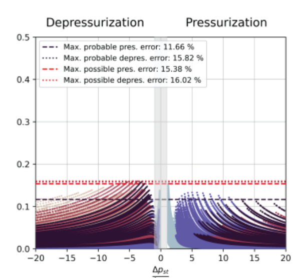
Downwind measurement position of Δp_0



Full dataset



ISO constraints



Alternative

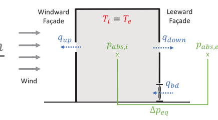
→ Fully pres/depres building with a margin of 10 Pa!

ISO 9972 & Zero-flow pressure

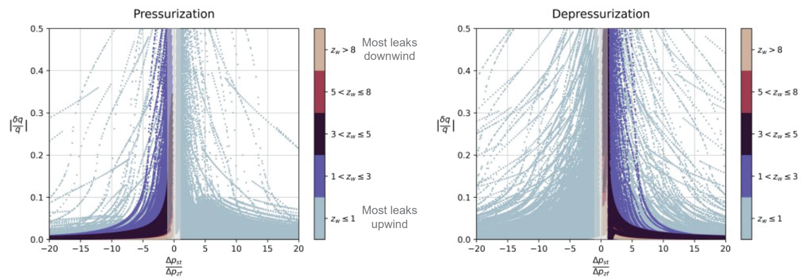
Cerema

KEY FINDINGS

$z_w = \frac{C_{down}}{C_{up}}$

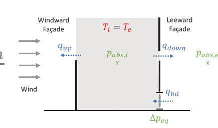


Equilibrium measurement position of Δp_0 – full dataset

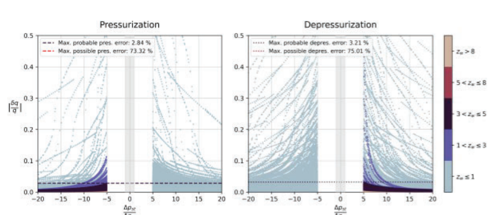


KEY FINDINGS

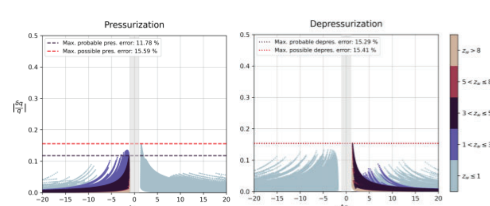
$z_w = \frac{C_{down}}{C_{up}}$



Equilibrium measurement position of Δp_0



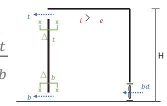
ISO constraints



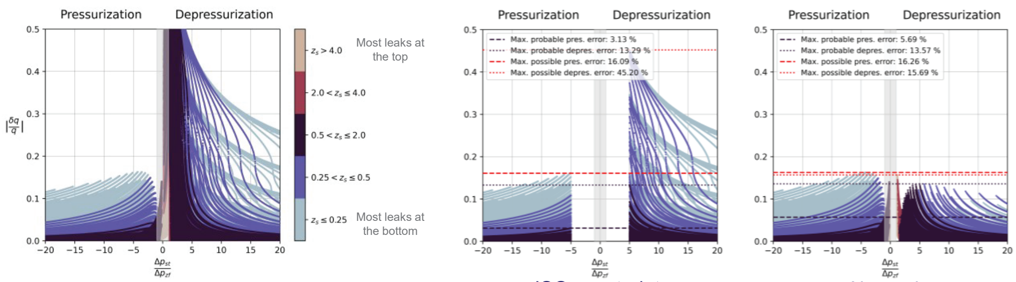
Alternative
→ Fully pres/depres building with a margin of 10 Pa!

KEY FINDINGS

$z_w = \frac{C_t}{C_b}$



Stack measurement position of Δp_0



Full dataset | ISO constraints | Alternative

→ Fully pres/depres building with a margin of 10 Pa!

SUMMARY AND CONCLUSION

- ISO 9972 constraints reduce significant flow errors
- High-rise buildings or buildings in windy locations are often impossible to test

SUMMARY AND CONCLUSION

Alternative: Pressurizing or depressurizing the entire building with a margin of 10 Pa would → same range of error!

Max. probable error:

	Pressurization				Depressurization			
	Downwind	Upwind	Equilibirum	Stack	Downwind	Upwind	Equilibirum	Stack
ISO constraint	45%	1%	3%	3%	13%	2%	3%	13%
New constraint	12%	5%	12%	6%	16%	15%	15%	14%

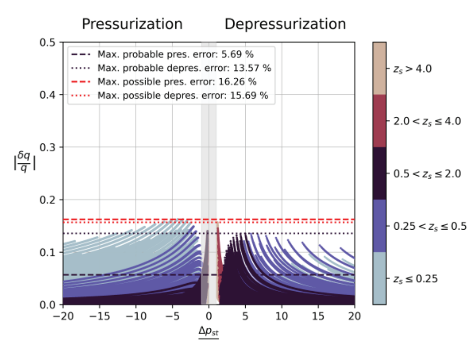
Max. possible error:

	Pressurization				Depressurization			
	Downwind	Upwind	Equilibirum	Stack	Downwind	Upwind	Equilibirum	Stack
ISO constraint	45%	16%	73%	16%	16%	45%	75%	45%
New constraint	15%	16%	16%	16%	16%	15%	15%	16%

QUESTIONS?

Benedikt Kölsch

Benedikt.koelsch@cerema.fr



Which design parameters impact the resilience to overheating in a typical apartment building?

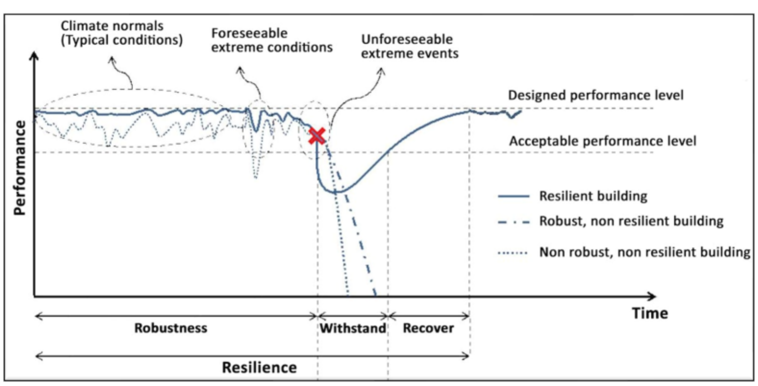
Abantika Sengupta[1,2], *Jef Kerckaert*[1], *Marijke Steeman*[2], *and Hilde Breesch*[1]

1 Department of Civil Engineering
KU Leuven, Belgium

2 Department of Architecture and Urban Planning
Ghent University, Belgium

Problem Statement

IEA EBC Annex 80 - Resilient Cooling of Buildings



Resilience =
**withstand disruptions +
maintain capacity to adapt
+ learn and transform"**

Resilience against what?

-Extreme Overheating events : Heatwaves

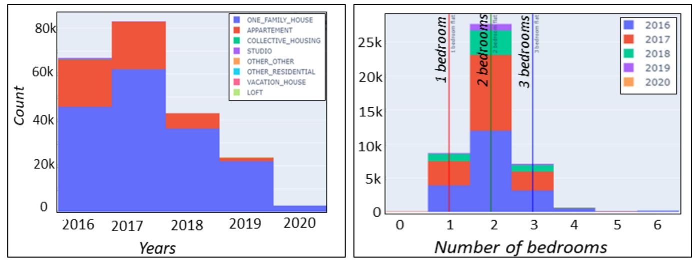
Research objective

To evaluate:
impact of building design parameters
+
implementation of solar shading
+
passive cooling strategy (NNV)

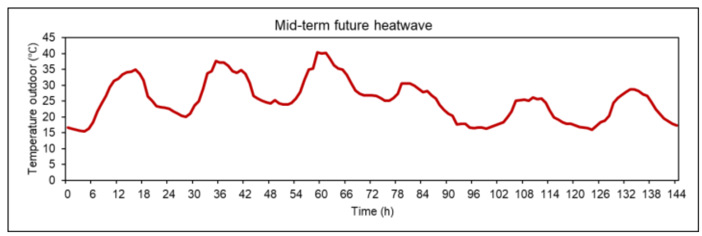
➡ **Thermal resilience to overheating during a heatwave** in a typical Belgian apartment

Annex 80 weather data task force

(a)Typical meteorological year (TMY) 2010s
(b)6 days long heatwave



VEKA data from 2016 to 2020 (new buildings) showing the typology of buildings, number of bedrooms and gross area of each apartment



6 days heatwave (29th June-4th July) mid-term future 2050s

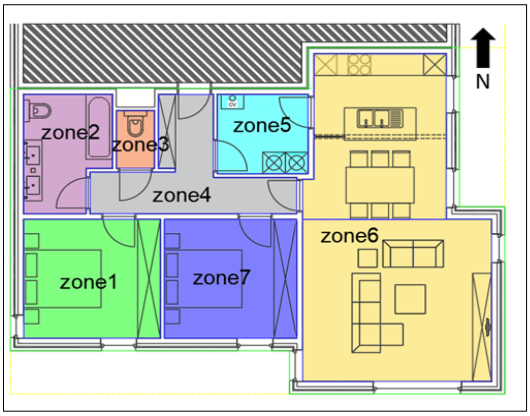
3

Overview

4

Research Methodology

Case study:2-bedroom flat



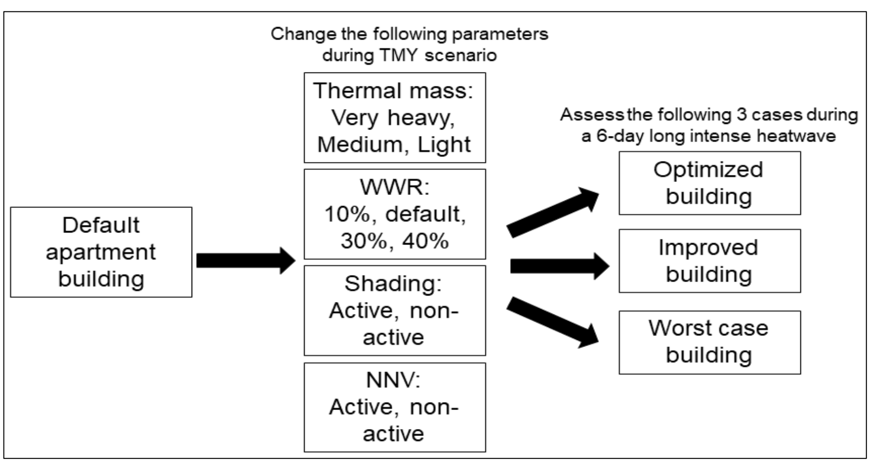
Thermal zone	Area (m²)
Zone 1 (Bedroom 1)	11.9
Zone 2 (Washroom)	2.5
Zone 3 (WC)	5.5
Zone 4 (Corridor)	9.0
Zone 5 (Utility room)	5.3
Zone 6 (Living+ kitchen)	38.9
Zone 7 (Bedroom 2)	11.6

- External wall u-value: 0.24 W/m^{2}K
- Heavy thermal mass
- South oriented
- Double glazed windows (u-value: 1.00 W/m^{2}K, g-value: 0.56)
- WWR 18%
- internal gains (people and equipment) calculated according to EN 16798-1
- **External solar shading : Radiation> 250 W/m^2.**

Natural night ventilation (NNV) is implemented:

- Effective area of = 2.7% of the gross floor area.
- April-September :Between 10 pm to 6 am
- T room >22°C
- T room> T outdoor +2°C
- T outdoor > 12°C
- RH room < 70%
- wind velocity < 10 m/s
- There is no rainfall

5



Key performance indicators

Thermal comfort: % of occupied hours above threshold

Heat stress : % of occupied hours above SET 28-degree threshold

Adapted in ASHRAE 55-2017

- ✓ Equivalent dry bulb temperature of an isothermal environment + 50% RH + clothing standard
- ✓ same heat stress (skin temperature) and thermoregulatory strain (skin wetness) as in the actual test environment.

6

Building energy simulations

Open Studio, EnergyPlus

Base case with TMY contemporary weather data

Worst, **improved** and **optimized** scenario

Implement Heatwave shock on the 6 cases

Scenario No	Thermal mass	WWR	Scenario No	Thermal mass	WWR
			With Natural night ventilation		
A1	Heavy		A19	Heavy	
A2	Medium	10%	A20	Medium	10%
A3	Light		A21	Light	
A4	Heavy		A22	Heavy	
A5	Medium	30%	A23	Medium	30%
A6	Light		A24	Light	
A7	Heavy		A25	Heavy	
A8	Medium	40% 7	A26	Medium	40%
A9 (E1)	Light		A27 (E4)	Light	
With Solar shading					
A10 (E3)	Heavy		A28 (E6)	Heavy	
A11	Medium	10%	A29	Medium	10%
A12	Light		A30	Light	
A13	Heavy		A31 (E5)	Heavy	
A14 (E2)	Medium	30%	A32	Medium	30%
A15	Light		A33	Light	
A16	Heavy		A34	Heavy	
A17	Medium	40%	A35	Medium	40%
A18	Light		A36	Light	

7

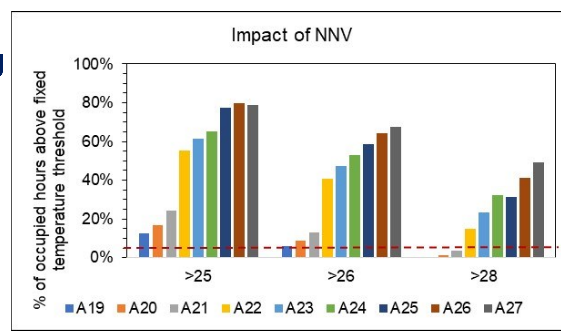
Results

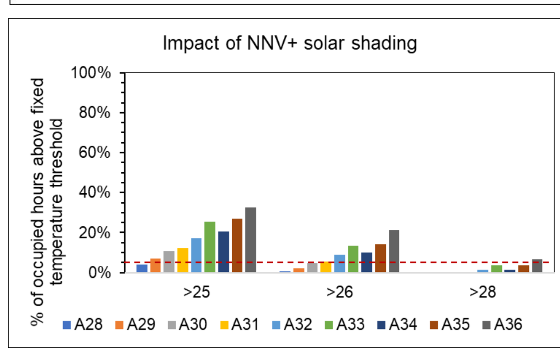
Impact of design and passive cooling

- Thermal Zone 6 (Living-Dining)
  → Critical zone
- Base case scenario: No passive cooling +No solar shading >5% occupied hours above 26℃
- With NNV +Heavy Thermal mass + low WWR
  < 5% occupied hours above 26 ℃
- With NNV + solar shading + up to 30% WWR
  < 5% occupied hours above 26 ℃

Low thermal mass + high WWR
→ **Increases overheating**

Solar shading + Natural night ventilation
→ **Improves thermal resilience**

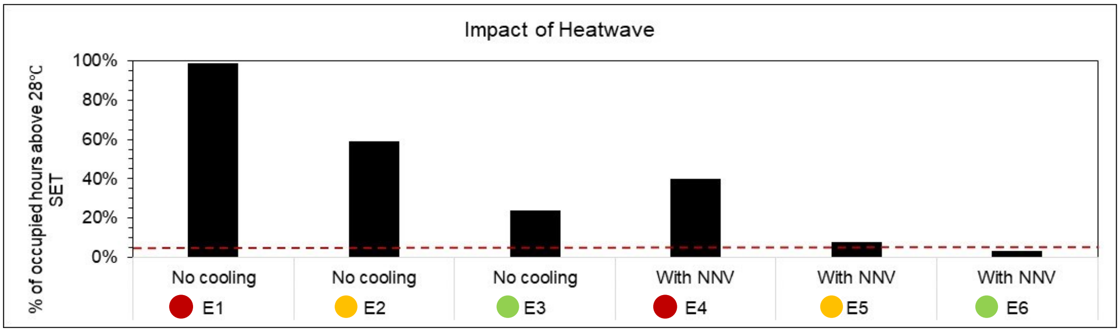




8

Results

Selection of worst, improved and optimized cases

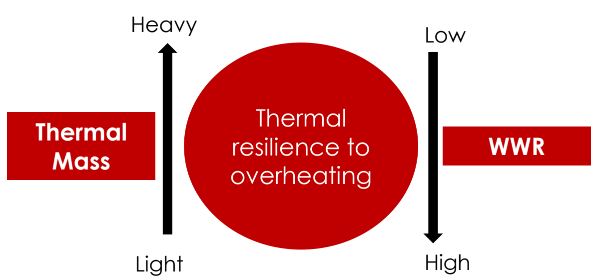


6 days heatwave

Light Thermal mass + 40% WWR + No shading
95% occupied hours > SET 28 degrees

Heavy thermal mass + 10% WWR + Solar shading + NNV
Less than 5% occupied hours > SET 28 degrees

Conclusions



- Higher glazing ratio, high WWR, no shading and with lighter thermal mass ❯ Low thermal resilience
- **WWR** has higher impact than thermal mass
- For buildings with higher WWR and lighter thermal mass, thermal resilience can be improved ❯ **Implement solar shading and passive cooling strategies such as NNV** **WWR**
- During heatwave , NNV is not the most thermal resilience solution as the diurnal variations of temperature are limited

MeSSO

MECHANICAL ENERGY SYSTEM SIMULATION OPTIMISATION

Renewable ventilative cooling? Insights from an Irish perspective

Adam O' Donovan[1,2],
Theofanis Psomas[3], Paul D O'Sullivan[1,2]

[1]MeSSO Research Group, Department of Process, Energy and Transport Engineering, MTU, Cork, Ireland
[3] MaREI Centre for Energy, Climate, and Marine, Ireland.
[2]University of Chalmers, Gothenburg, Sweden

43rd AIVC | 11th TightVent & 9th Venticool Conference | Copenhagen, Denmark, October 4-5, 2023

www.mtu.ie

1

Background and context

Motivation for the paper

Personal background

*Bachelor of Engineering (Honours) in **Sustainable Energy** Engineering*

***Passive Cooling** in Non-Residential Nearly Zero Energy Buildings: A Thermal Comfort Analysis Based on Measurement, Modelling and Simulation – PhD thesis*

42nd AIVC- 10th TightVent & 8th Venticool Conference, 2022

"Is Ventilative Cooling a renewable energy solution and how does it fit into the sustainability agenda?" – Pollet et al. 2022 , 42nd AIVC Conference "Ventilation Challenges in a Changing World" Rotterdam, Netherlands

"Ventilative cooling is, contrary to common renewable energy sources like photo-voltaic etc., **a direct renewable energy source."** – Ventilative Cooling Track Summary, 2022

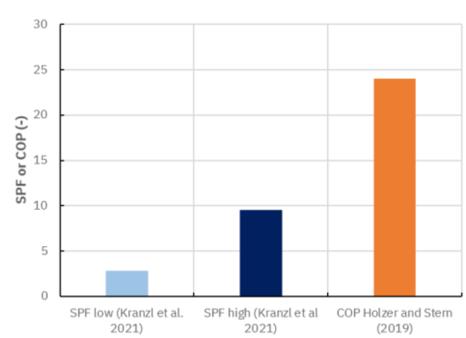


Figure 1: Comparison of SPF values required for renewable status and example from literature

Succeeding Together

www.mtu.ie

2

Background and context
Motivation for the paper

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Personal background

*Bachelor of Engineering (Honours) in **Sustainable Energy** Engineering*

***Passive Cooling** in Non-Residential Nearly Zero Energy Buildings: A Thermal Comfort Analysis Based on Measurement, Modelling and Simulation – PhD thesis*

42nd AIVC- 10th TightVent & 8th Venticool Conference, 2022

"Is Ventilative Cooling a renewable energy solution and how does it fit into the sustainability agenda?" – Pollet et al. 2022 , 42nd AIVC Conference "Ventilation Challenges in a Changing World" Rotterdam, Netherlands

"Ventilative cooling is, contrary to common renewable energy sources like photo-voltaic etc., **a direct renewable energy source."** – Ventilative Cooling Track Summary, 2022

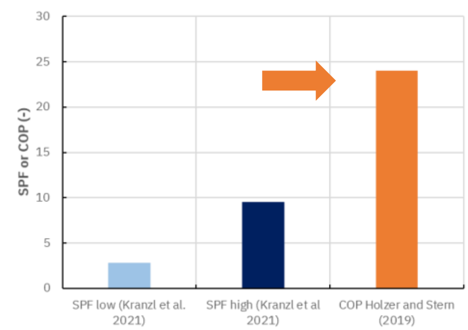


Figure 1: Comparison of SPF values required for renewable status and example from literature

Succeeding Together www.mtu.ie

3

Background and context
Renewable VC – Previous Work and Challenges

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

- Limited work focusing directly in the SPF of VC systems (Yan et al. 2022, Holzer and Stern. 2019)
- The scope of renewables should be outside of reversible heat pumps (Krazl et al. 2021)
- VC as a renewable has to overcome:
  1. Cannot be a passive cooling (building insulation, green roof, vegetal wall, shading, thermal mass) – **not attenuation or demand reduction** (section 2.6.2.1)
  2. Cooling without fans or pumps – this **excludes natural ventilation** (section 2.6.2.2)
  3. Has to exclude ventilation for hygienic purposes cooling is **not intentional** (section 2.6.2.3)

Succeeding Together www.mtu.ie

4

Background and context

Aim and objectives – Renewable NVC and MVC

A: To present an example of renewable NVC and MVC in a residential building at design-stage where **cooling is intentional (actuated by a control system)** and **hygienic ventilation is excluded** in a northern climate in Ireland (**high potential**).

1) Cooling demand assessment (degree hour approach)

2) Simplified design stage of supply from MVC and NVC (cooling potential)

3) Simplified calculation of SPF for MVC and NVC

4) Discussion for residential stock in IE (**cooling demand considered zero** (SEAI, 2022))

Succeeding Together

www.mtu.ie

5

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Materials and Methods

www.mtu.ie

6

Materials and Methods

Residential Case Study and Weather data

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

- Retrofitted detached building, inland location in Ireland.
- Limited overheating from previous work by O' Donovan, Psomas and O'Sullivan et al. 2022 (less than 1% of hours > 28°C in living and sleeping spaces).
- Met Éireann historical data and meteonorm future data

Table 1: Thermo-physical characteristics of case study building used to evaluate renewable NVC and MVC

Variable	Units	Value
Roof U-value	W/m² K	0.13
Wall U-value	W/m² K	0.2-0.23
Floor U-value	W/m² K	0.12-0.13
Window U-value	W/m² K	1.4
Effective air change rate	h^{-1}	0.522
Floor area	m^2	182.09
Volume	m^3	491.64
Heat loss co-efficient	W/K	292

Table 2: Weather data used for different aspects of the work presented

Location (Name, County)	Elevation (m)	Weather files considered for demand estimates	Weather files used for case study demonstration
Athenry, Galway	40	2022, 2030 (RCP 2.6), 2030 (RCP 4.5), 2030 (RCP 8.5), 2040 (RCP 2.6), 2040 (RCP 4.5), 2040 (RCP 8.5), 2050 (RCP 2.6), 2050 (RCP 4.5), 2050 (RCP 8.5)	2022, 2050 (RCP 8.5)
Belmullet, Mayo	9		
Shannon Airport, Clare	15		
Cork Airport, Cork	155		
Phoenix Park*, Dublin	48		
Valentia, Kerry	24		
Ballyhaise, Cavan	78		
Malin Head, Donegal	20		
Gurteen, Tipperary	75		
Johnstown Castle, Wexford	62		
Finner, Donegal	33		

*Wind speed and wind direction for Dublin Airport used in the absence of available data

Succeeding Together www.mtu.ie

Materials and Methods

Cooling demand and supply calculations (part 1)

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

$$CD_h = \sum_{h=1}^{h=8760} (T_e - T_b)^+ \quad \textbf{(1)}$$

$$E_{tot,c} = \frac{H \cdot CD_h}{1000} \quad \textbf{(2)}$$

$$Q_b = \frac{1}{3} C_d A_{op} \sqrt{gH \frac{T_i - T_e}{T_i}} \quad \textbf{(3)}$$

$$Q_w = F_R A_{op} U_R \quad \textbf{(4)}$$

$$Q_{nv} = \max(Q_b, Q_w) \quad \textbf{(5)}$$

T_b: (14 to 18.33°C)

H: 292W/K

Floor area: 182m²

C_d: 0.422

A_{op} = 0.05*Floor area*0.5

F_r=0.025

T_i = T_c (adaptive)

Succeeding Together www.mtu.ie

Materials and Methods

Cooling supply and SPF calculations (part 2)

$$E_{sup,nv} = \frac{Q_{nv} \cdot \rho_a \cdot C_{p,a} \cdot (T_i - T_e)}{1000} \quad \textbf{(6)}$$

$$Q_{mv} = \frac{ACR_{MV} \cdot V}{3600} \quad \textbf{(7)}$$

$$E_{sup,mv} = \frac{Q_{mv} \cdot \rho_a \cdot C_{p,a} \cdot (T_i - T_e)}{1000} \quad \textbf{(8)}$$

$$SPF_{vc} = \frac{Q_{supply}}{E_{INPUT}} \quad \textbf{(9)}$$

Q_{supply} excludes 0.3l/s/m^2 for hygienic ventilation

$ACR_{mv} = 4h^{-1}$

$p_a = 1.2kg/m^3$

$C_{pa} = 1000J/kgK$

E_{INPUT}

2.4kWh/m^2/a – NV
0.1W/(m^3/h) - MV

Table 3: Examples of typical energy consumed to operate MVC or NVC systems

Reference	System type	Units	Values reported
(Cho et al. 2021)	Hybrid systems	kWh/m^2/a	0.3 – 2.8
(Agency and Programme 2018)	NVC	kWh/m^2/a	~1.2
(Santos, Hopper, and Kolokotroni 2016)	NVC + phase change materials	kWh/m^2/a	~0.77
(Yan et al. 2022)	NVC	kWh/m^2/a	0.7-1.3
(Holzer and Stern 2019)	MVC	W/(m^3/s)	<200
(Holzer and Psomas 2018)	MVC	W/(m^3/h)	0.07 - 0.14

Succeeding Together

www.mtu.ie

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

Results and Discussion

www.mtu.ie

Results and Discussion

Cooling demand in Ireland (current and future) part 1

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

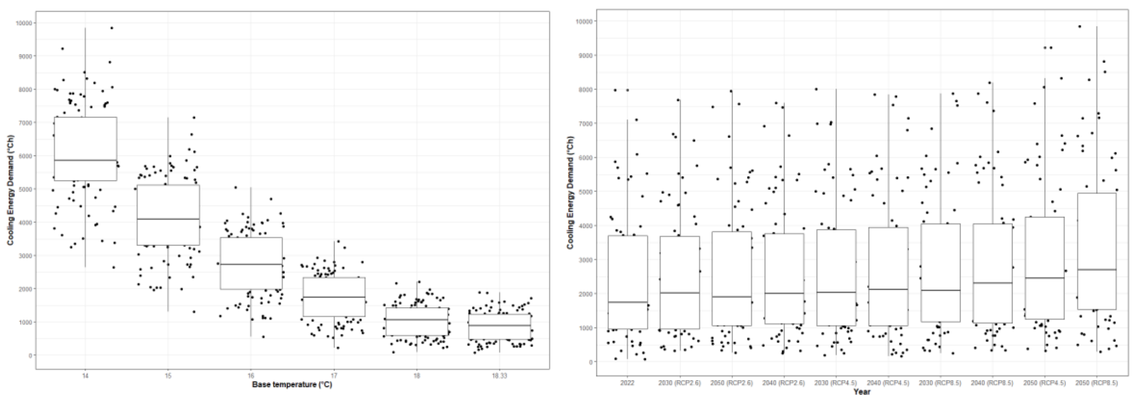


Figure 2: Relationship between cooling degree hours and base temperature and different climate scenarios

Succeeding Together

www.mtu.ie

Results and Discussion

Cooling demand in Ireland (current and future) part 2

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

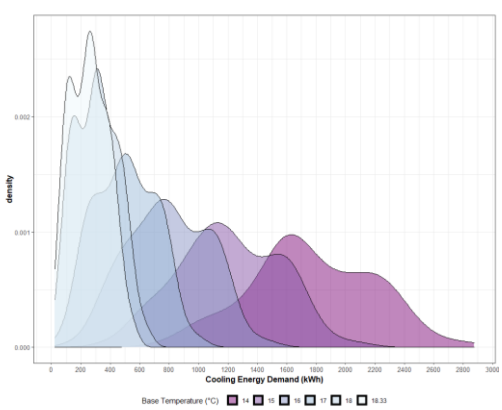


Figure 3: Density plot of estimated cooling energy demand (in kWh) for the selected case study building with respect to different base temperatures

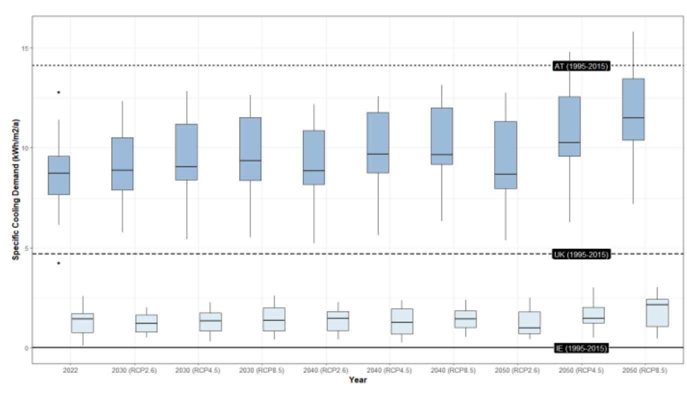


Figure 4: Boxplots of specific cooling demand with respect to climate scenario and different assumptions for base temperature. (Dashed lines indicate different specific cooling demands indicated in the work of (Jakubcionis and Carlsson 2018), for Ireland (IE), United Kingdom (UK), and Austria (AT)).

Succeeding Together

www.mtu.ie

Results and Discussion

Demand vs Supply

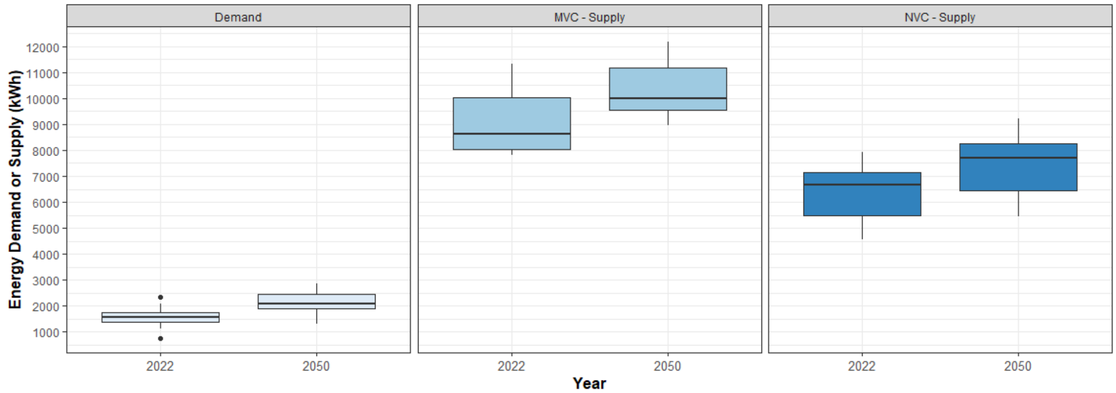


Figure 5: Boxplots of energy demand and supply for cooling with respect to year. (Facet grid represents demand, or supply type for MVC and NVC systems. Note: 2050 refers to RCP 8.5 scenario).

Succeeding Together

www.mtu.ie

Results and Discussion

Seasonal Performance Factor

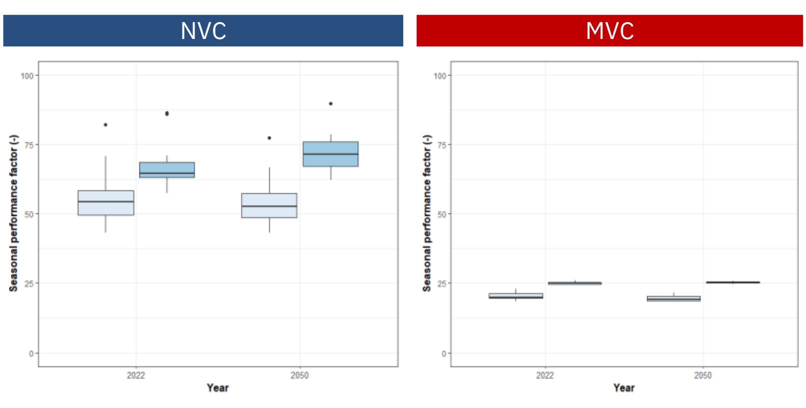


Figure 6: Boxplots of seasonal performance factor with respect to year (Left: SPF values for NVC, Right: SPF values for MVC, colour indicates SPF for day or night-time)

- SPF of **2.6–9.5** is typically required (Kranzl et al. 2021)
- MVC and NVC are **23 and 63** respectively on average
- Capability of generating between **25.1kWh/m²/a to 50.6kWh/m²/a** for NVC, and between **42.9kWh/m²/a to 66.9kWh/m²/a** for MVC.

Succeeding Together

www.mtu.ie

Results and Discussion

Seasonal Performance Factor

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

NVC | MVC

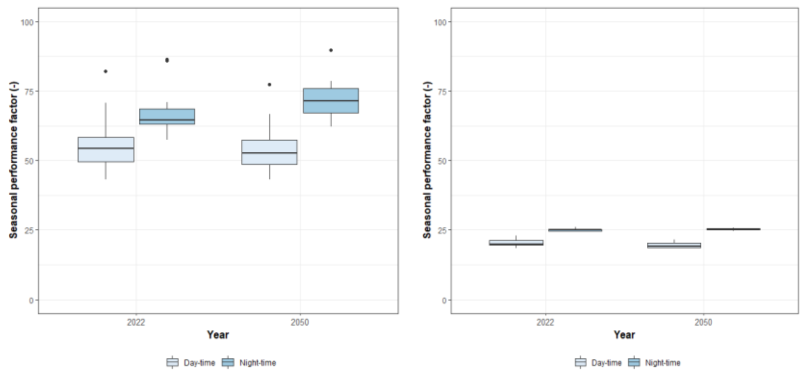


Figure 6: Boxplots of seasonal performance factor with respect to year (Left: SPF values for NVC, Right: SPF values for MVC, colour indicates SPF for day or night-time)

- SPF of **2.6–9.5** is typically required (Kranzl et al. 2021)
- MVC and NVC are **23 and 63** respectively on average
- Capability of generating between **25.1kWh/m²/a to 50.6kWh/m²/a** for NVC, and between **42.9kWh/m²/a to 66.9kWh/m²/a** for MVC.

$*T_e > 14$

Succeeding Together

www.mtu.ie

Results and Discussion

General discussion related to the Irish residential stock

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

- **> 2million homes** in Ireland (CSO,2016), **single-sided NVC** the main cooling strategy
- The average floor area is around 111m², with NVC generating between 25.1kWh/m²/a to 50.6kWh/m²/a in renewable cooling.
- **5.6 – 11.3TWh/a** is currently available from NVC in Ireland
- Supply is likely to be outstripping demand by **>3.5 times**

Succeeding Together

www.mtu.ie

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Conclusion and future work

www.mtu.ie

Conclusion and future work

Renewable cooling in Ireland

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

- **Conclusions**
  - There is a **cooling demand in Ireland**, but the **NVC supply is** currently **meeting this demand**.
  - Current SPF calculations suggest NVC and MVC systems are **currently renewables that are not officially accounted for.**
- **Future work**
  - Calculations of **SPF for MVC and NVC** in real systems and with dynamic simulation.
  - More detail on **cooling base temperatures** for low energy buildings.
  - Exploration on a national scale in more detail using specific HLC.

Succeeding Together

www.mtu.ie

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

MeSSO
MECHANICAL ENERGY SYSTEM SIMULATION OPTIMISATION

Thank You, Any Questions?

adam.odonovan@mtu.ie

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

AIVC

TightVent Europe

venticool
the platform for resilient ventilative cooling

www.mtu.ie

Brunel University London

Urban context and climate change impact on the thermal performance and ventilation of residential buildings

A case-study in Athens

Maria Kolokotroni, May Zune, Thet Paing Tun

Brunel University London

Ilia Christantoni, and Dimitra Tsakanika

DAEM SA, City of Athens IT Company

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 768576

PRELUDE

PRELUDE: Prescient building Operations utilizing Real Time data for ENergy Dynamic Optimization

21 Partners

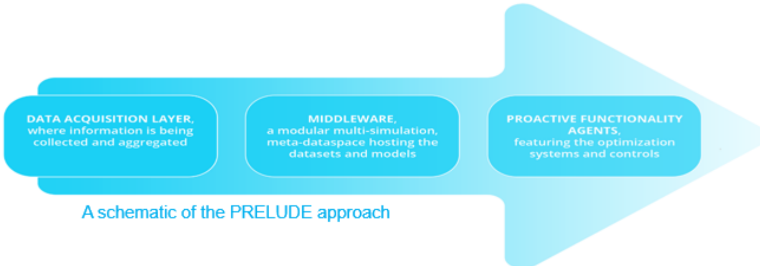
Started in December 2021

To complete in May 2024

https://prelude-project.eu/

8 pilot buildings in Denmark, Poland, Switzerland, Italy and Greece

A testing Living Lab in Austria



A schematic of the PRELUDE approach

The PRELUDE project focusses on assessing the right level of smartness necessary for any given household/building and then providing the optimal tools according to the needs of the user.

The system is designed to be versatile and adapt to the engagement, monitoring, and automation level of the building.

- Passive solutions, such as natural ventilation and cooling, are prioritized through a free-running strategy.
- Predictive maintenance is implemented to reduce costs, emphasizing Renewable Energy Sources.
- Big data and advanced analytic tools are used to facilitate flexible building side demand and ease the integration into district heating and electricity grids.
- Proactive optimization is to be achieved through data predictive control.

PRELUDE pilot buildings


Geneva


Torino


Athens

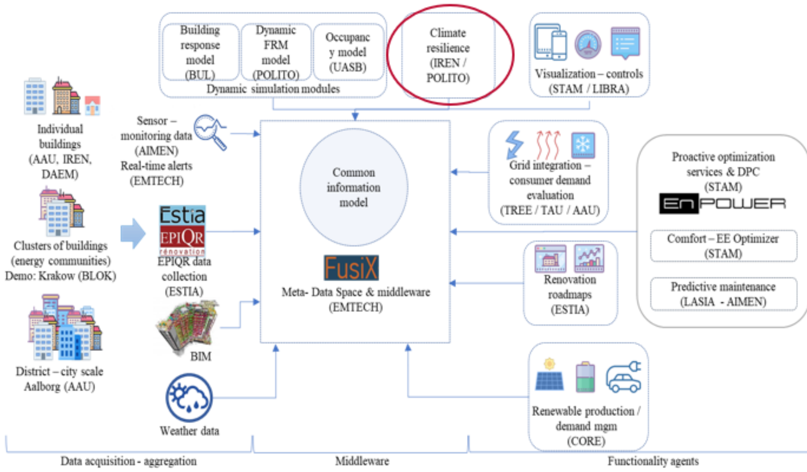

Rye

PRELUDE Pilot Buildings

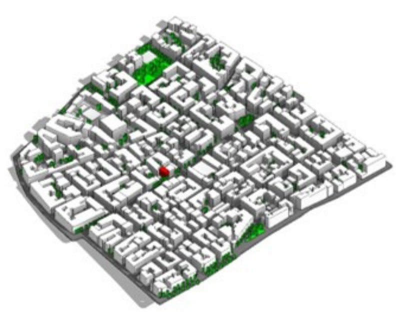

Egernsund


Krakow

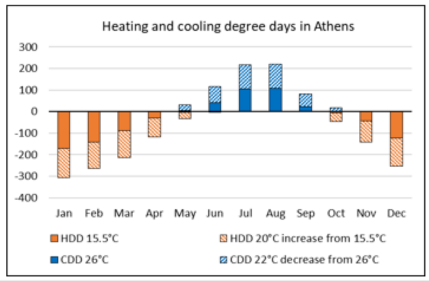
PRELUDE: Prescient building Operations utilizing Real Time data for ENergy Dynamic Optimization



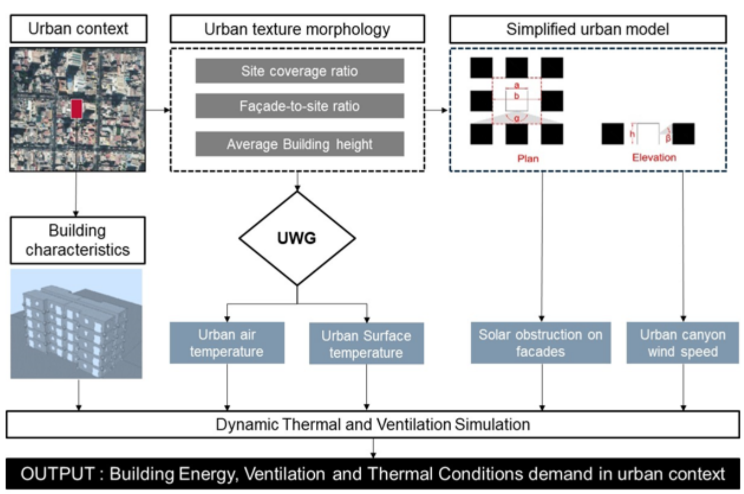
Impact of microclimate on the Athens pilot



Typical weather file – Athens airport



Urban Settings: how to model?



Source: Salvati, A., Palme, M., Chiesa, G., & Kolokotroni, M. (2020). Built form, urban climate and building energy modelling: case-studies in Rome and Antofagasta. Journal of Building Performance Simulation, 13(2), 209–225. https://doi.org/10.1080/19401493.2019.1707876

Urban weather generator calculations

Autodesk *Revit* was used to generate the required building information for the UWG program. After the UWG's .xlsm files and other source files are co-simulated using Matlab, two urban weather files for current and future scenarios were obtained

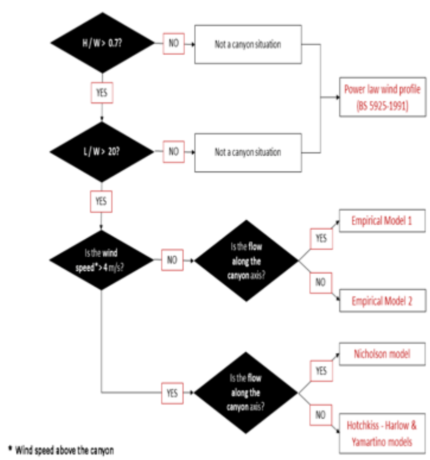
Urban Characteristics	Input data	Vegetation Parameters	Input data
Average Building Height	15.78	Urban Area Veg Coverage	0.0157
Fraction of waste heat into the canyon	1	Urban Area Tree Coverage	0.0245
Building Density	0.473	Veg Start Month	1
Vertical to Horizontal Ratio	1.078	Veg End Month	12
Urban Area Characteristic Length	250	Vegetation Albedo	0.25
Max Dx	62.5	Latent Fraction of Grass	0.5
Road Albedo	0.1	Latent Fraction of Tree	0.5
Pavement Thickness	0.5	Rural Road Vegetation Coverage	0.8
Sensible Anthropogenic Heat (Peak)	20		
Latent Anthropogenic Heat (Peak)	2		

Wind speed and solar obstruction

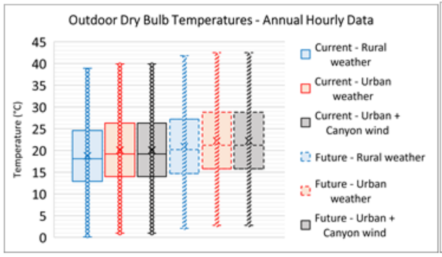
The hourly wind speed was calculated using the algorithms developed from experimental data in Athens (similar canyons). These were carried out under the European project UrbVent almost 20 years ago.

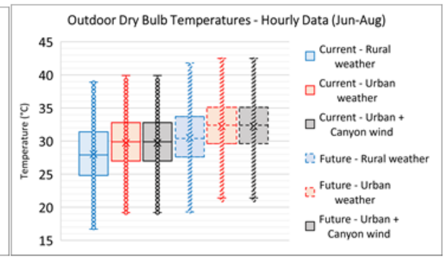
Hourly wind speed values of canyon wind were calculated for the undisturbed wind and wind direction values found in the rural weather files. The urban canyon wind speed values were then replaced with the urban weather files generated from the UWG program.

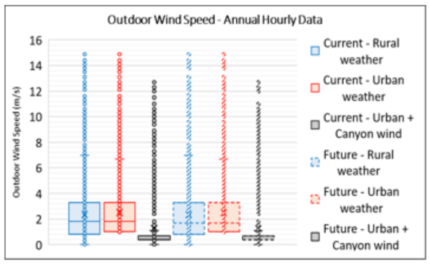
Overshadowing was calculated from the EnergyPlus program

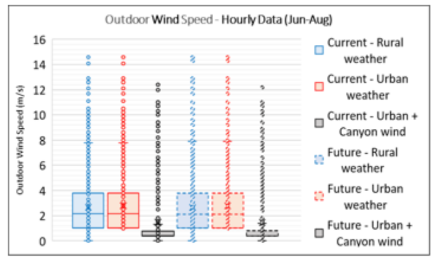


Weather data comparison



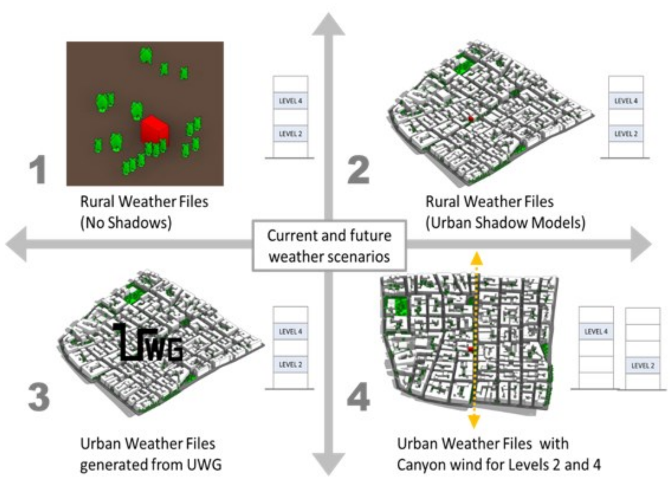




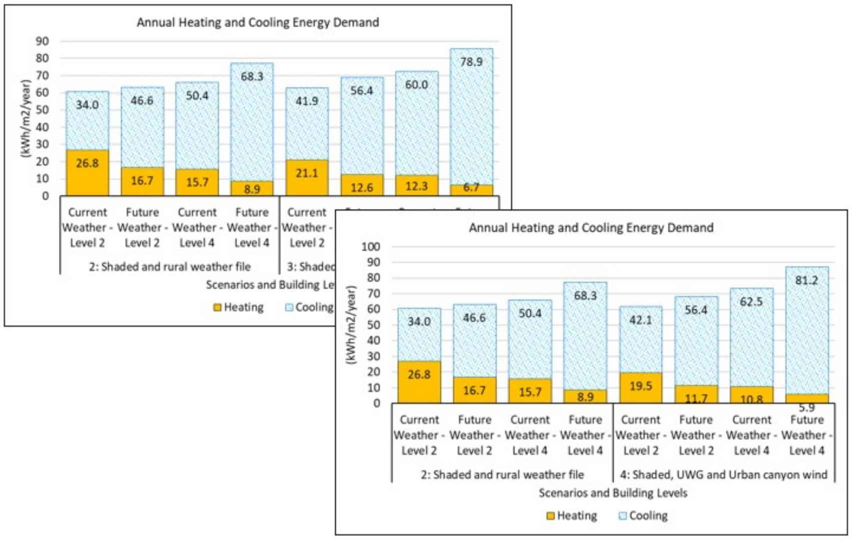


Future weather is RCP8.5 scenario for the year 2050

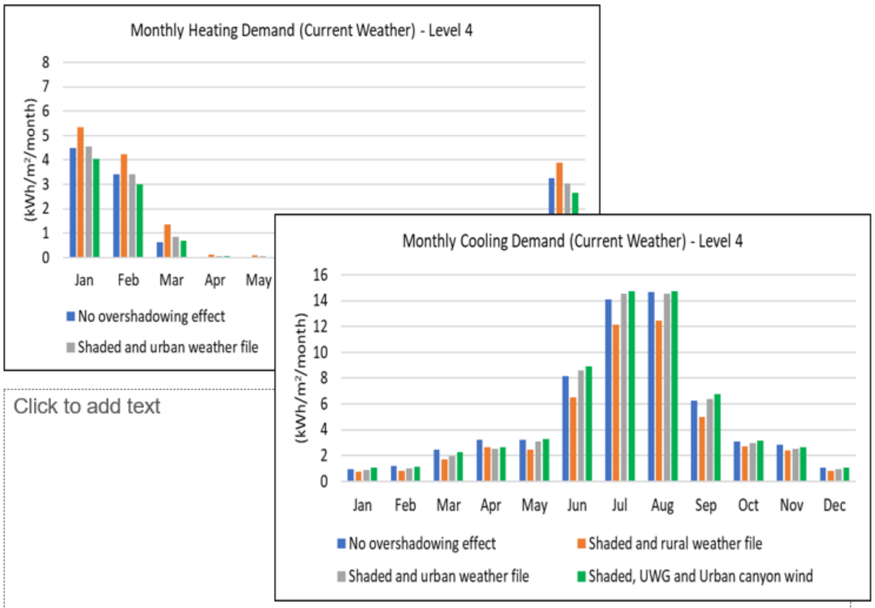
Simulations using EnergyPlus



Energy use simulation results

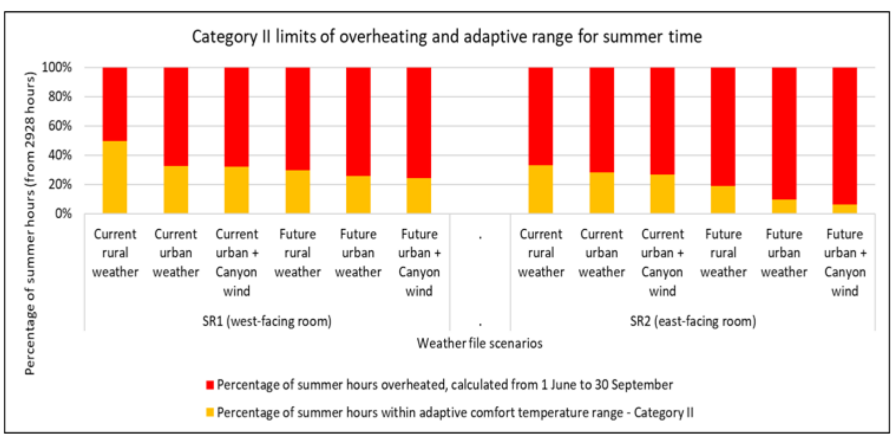


Weather file	Heating	Change ratio	Cooling	Change ratio	Total	Change ratio
Overshadowing included in simulations						
Building Level 4	kWh/m2/year		kWh/m2/year		kWh/m2/year	
Current Weather	15.7		50.4		66.1	
Current Urban Weather (UWG)	12.3	0.78	60	1.19	73.1	1.11
Current UWG, Urban canyon Wind	10.8	0.69	62.5	1.24	74.0	1.12
Future Weather	8.9	0.57	68.3	1.36	77.8	1.18
Future Urban Weather (UWG)	6.7	0.43	78.9	1.57	86.0	1.30
Future UWG, Urban canyon Wind	5.9	0.38	81.2	1.61	87.5	1.32
Building Level 2						
Current Weather	26.8		34		60.8	
Current Urban Weather (UWG)	21.1	0.79	41.9	1.23	63.8	1.05
Current UWG, Urban canyon Wind	19.5	0.73	42.1	1.24	62.3	1.03
Future Weather	16.7	0.62	46.6	1.37	63.9	1.05
Future Urban Weather (UWG)	12.6	0.47	56.4	1.66	69.5	1.14
Future UWG, Urban canyon Wind	11.7	0.44	56.4	1.66	68.5	1.13



Click to add text

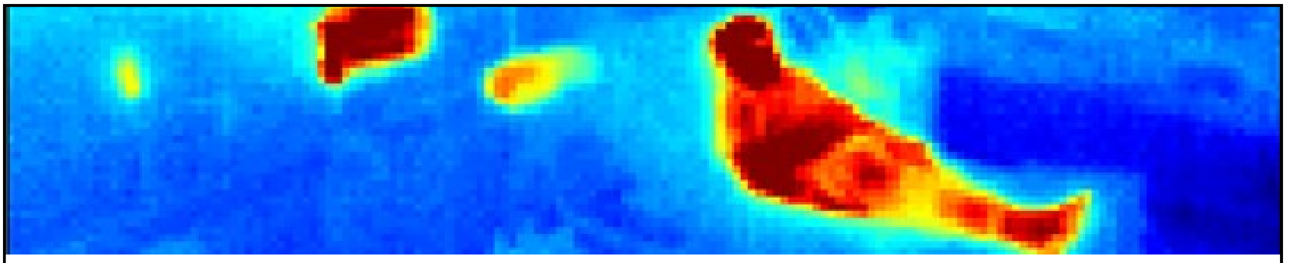
Overheating assessment



Conclusions

- The confounding effects of urban density, urban textures and exposure to the wind, building design and human activities alter weather characteristics over and around urban areas.
- Weather files were generated from the UWG program and urban canyon wind calculation, and were used to compare how different weather impacts building performance. The overshadowing effects from the surrounding buildings were considered as it is relevant to an urban setting.
- The case study building is located in Athens within an urban canyon with data obtained from the PRELUDE H2020 project.
- Simulations showed (typical weather file compared with fully modified urban weather file)
  - an increase of the cooling demand by 24%. In the future (2050) we will have a 66% increase in cooling demand
  - total energy demand (heating and cooling) increased only 3% for lower floors and 12% for higher floors due to the reduction of heating demand. In the future we will have an increase 32% for higher floors and 13% for lower floors.
  - If the building is free floating an adaptive thermal comfort analysis indicated that only 25% of the summertime will be comfortable in the future in comparison to 50% prediction by current typical weather.
- Therefore, the use of a suitable weather file to include urban external conditions in thermal simulations is essential for more accurate predictions of energy demand and internal avoidance of overheating in free-running buildings.

Thank you



Thermography-based assessment of mean radiant temperature and occupancy in healthcare facilities

Pilot study at Hannover Medical School

Paul Seiwert

EBC | Institute for Energy Efficient Buildings and Indoor Climate
E.ON Energy Research Center
RWTH AACHEN UNIVERSITY

1

Why are occupancy and mean radiant temperature important information for building control?

Convalescence time and overall medical outcomes in hospitals and other healthcare facilities are **influenced by indoor environmental conditions** [1]

Demand controlled ventilation (DCV) as energy efficient way for providing high IEQ [2]

DCV requires detailed information on **occupancy and indoor environmental parameters**

Pictograms: [5]

2

Pilot study on sustainable hospitals - overview

Partners: Chalmers University of Technology
Hannover Medical School
Furbish AB
RWTH Aachen University

Observation period: Mid November – Mid December 2020

Observation space: 5 patients rooms and 1 physicians room in ward for cardiovascular heart diseases at Hannover Medical School

Study design:

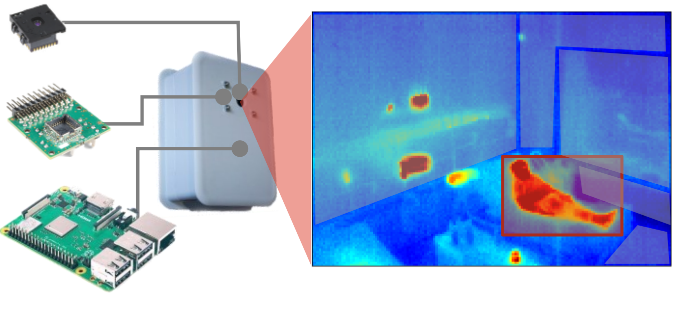
- Experimental observation of indoor environment
  - 1 IEQ measurement system (1) per room
  - 2 thermography sensor systems (2) per room
- Patient survey
- Patient diary

Ward building at Hannover Medical School

Exemplary patient room with measurement equipment

E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

Hardware and objectives of thermography based measurement



Mean radiant temperature calculation

Calculation of MRT based on wall, (ceiling) and floor surface temperature and according view factors

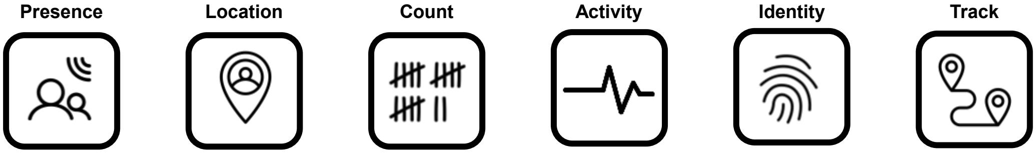
Occupancy detection

Machine learning algorithms for detection of occupants based on temperature difference from background

Images: [6]

E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

Requirements and properties of image based sensors for occupancy detection



Spatial–temporal properties of occupancy measurement [2]

- Several different occupancy technologies available
  - e.g. PIR-, CO_2-, Image-, Electromagnetic sensors
  - Selection can be based on different spatial-temporal properties for detection
- Image based sensors so far have limited applications for occupancy detection
  - Machine learning → computation intensive
  - Capable of covering all properties of occupant detection
  - Privacy considerations are important factor for implementation and acceptance

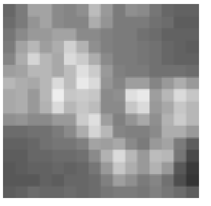


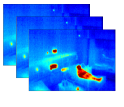
Image of low resolution thermography sensor for occupancy detection [3]

Pictograms: [5]

Data pipeline and training process for machine-learning model

Data basis:

Frames from 10 sensors (2 per room) at 10 second intervals



Preprocessing:

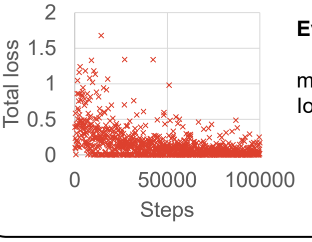
- Normalization
- Redundancy test
- Validity test

Data pipeline:

- Annotation of occupants in frames with bounding boxes
- 1000 frames (800 training / 200 evaluation)

Network training and evaluation:

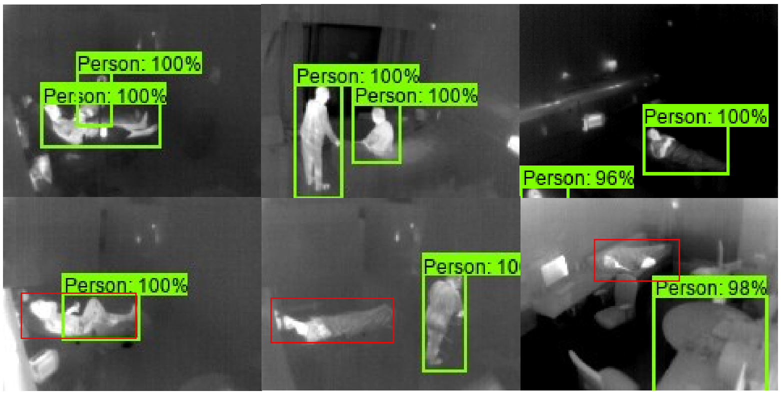
Network: Faster R-CNN Inception ResNet V2 640x640 (transfer learning: pre-trained on visual domain images)



Evaluation metrics:

mAP – mean average precision
IoU – intersection over union

Results of occupancy detection



Exemplary frames with boundary boxes for identified occupants (green) and missing ground truth values (red)

Metric	Value
mAP (overall)	0.47
mAP@IoU=0.5	0.80
mAP@IoU=0.75	0.48

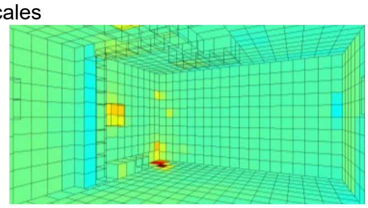
- False Negatives occur frequently when body is partially obstructed (e.g. by blanket)
- Overfitting due to low variation in training data and sensor installation positions
- Further classes (body posture/activity) may reduce variation within classes

Summary and outlook

- Acquired data enable machine learning based detection of occupants in hospital rooms
- Presence and count may be evaluated with the proposed methodology
- Light-weight model can be executed on low capacity systems e.g. Raspberry Pi for real time applications
- Accuracy is within typical accuracy of neural networks for object detection

- For further details on mean radiant temperature assessment, please refer to conference paper

- **Outlook**
  - Acquisition of further training data with higher variation in perspectives and scales
  - Introduction of additional classes for activity and body posture evaluation
  - Network training exclusively with IR domain data
  - Integration into 3D-mapping of thermal boundary conditions (see [3])
    - →Location / tracking assessment



Paul Seiwert, M. Sc.
Research Associate, Team Occupant Behaviour and Comfort

T +49 241 80-49777
F +49 241 80-49769
pseiwert@eonerc.rwth-aachen.de

RWTH Aachen University
E.ON Energy Research Center • Institute for Energy Efficient Buildings and Indoor Climate

Mathieustraße 10
52074 Aachen • Germany
www.eonerc.rwth-aachen.de/ebc

References:

[1] Shajahan, Amreen; Culp, Charles H.; Williamson, Brandon (2019): Effects of indoor environmental parameters related to building heating, ventilation, and air conditioning systems on patients' medical outcomes: A review of scientific research on hospital buildings. In: Indoor Air 29 (2), S. 161–176. DOI: 10.1111/ina.12531.

[2] Labeodan, Timilehin; Zeiler, Wim; Boxem, Gert; Zhao, Yang (2015): Occupancy measurement in commercial office buildings for demand- driven control applications—A survey and detection system evaluation. In: Energy and Buildings 93, S. 303–314. DOI: 10.1016/j.enbuild.2015.02.028.

[3] Berger, M.; Armitage, A. (2010): Room occupancy measurement using low-resolution infrared cameras. In: IET Irish Signals and Systems Conference (ISSC 2010). IET Irish Signals and Systems Conference (ISSC 2010). Cork, Ireland, 23-24 June 2010: IET, S. 249–254.

[4] Seiwert, Paul; Schmitt, Lukas; Wesseling, Mark Thomas; Müller, Dirk (2018): Detection of Vertical Air Temperature Distribution by Long- Wave Infrared Thermography. In: Finnish Society of Indoor Air Quality and Climate (Hg.): Proceedings: Roomvent&Ventilation 2018. Excellent Indoor Climate and High Performing Ventilation. Unter Mitarbeit von Risto Kosonen, Mervi Ahola und Jarkko Narvanne. Roomvent&Ventilation. Espoo, Finland, 02.06-05.06.2018. Helsinki, Finland: SIY Indoor Air Information Oy.

[5] Pictograms from Noun project(CC BY 3.0):
ventilation by IconMark; clock by Yoyo; Man in Hospital by Gan Khoon Lay; Human by Cuputo; Temperature by Vectors Market; Map by Vectorstall; Count by Adrien Coquet; activity by asnirun al wowo; I dentity by Vectorstall; Pin by Vectorstall

[6] Images from Flir Inc. and Raspberry Pi Foundation

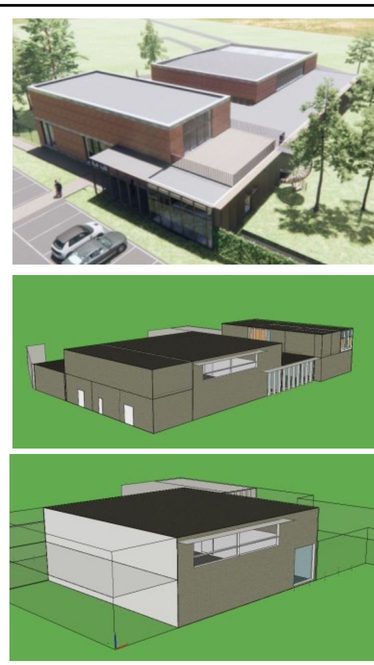
EBC | Institute for Energy Efficient Buildings and Indoor Climate | E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

Analyzing natural ventilation and cooling potential in a communal space building in Belgium under future climate conditions.

Shiva Khosravi
Joost Declercq
Delphine Ramon

1

Analyzing natural ventilation and cooling potential in a communal space building in Belgium under future climate conditions.



2

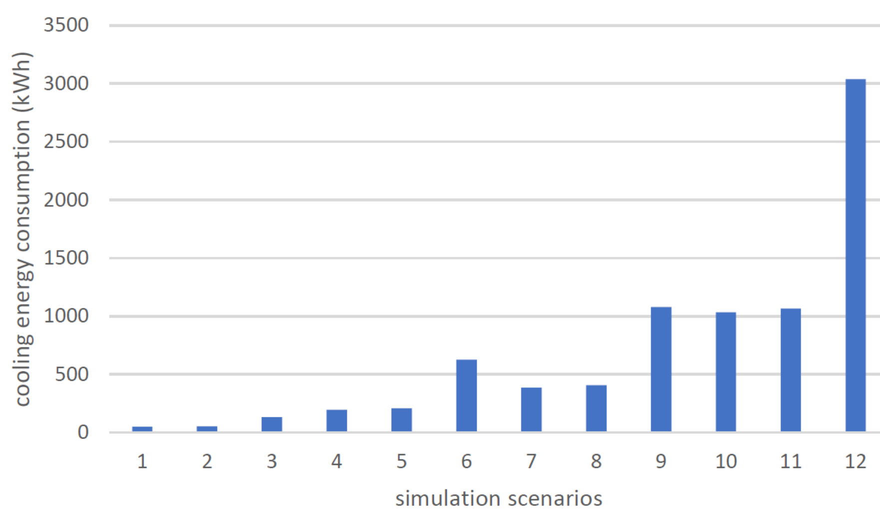
3

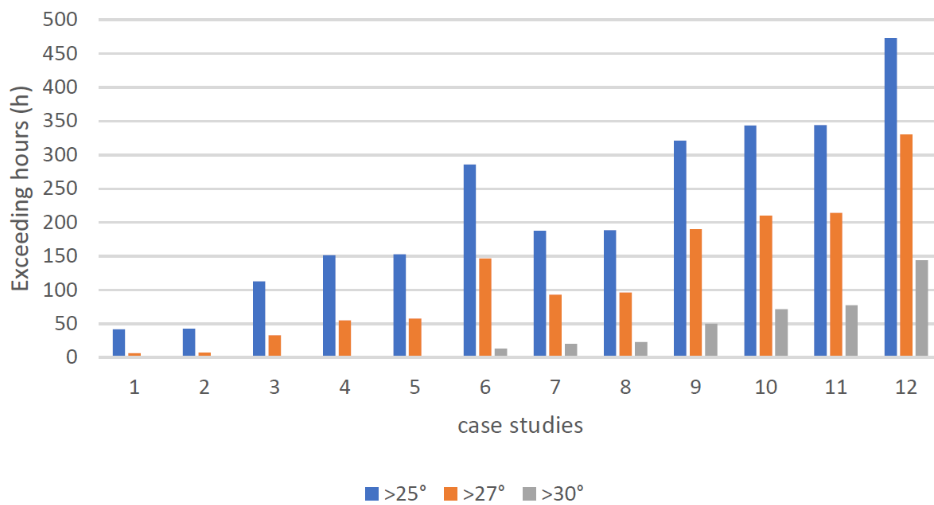
Method

scenarios	Type of weather data	Passive cooling strategy	Thermal mass
Scenario 1	TMY current	Natural ventilation	high
Scenario 2	TMY current	Natural ventilation	low
Scenario 3	TMY current	No passive cooling	high
Scenario 4	TMY future	Natural ventilation	high
Scenario 5	TMY future	Natural ventilation	low
Scenario 6	TMY future	No passive cooling	high
Scenario 7	EWY Current	Natural ventilation	high
Scenario 8	EWY Current	Natural ventilation	low
Scenario 9	EWY Current	No passive cooling	high
Scenario 10	EWY future	Natural ventilation	high
Scenario 11	EWY future	Natural ventilation	low
Scenario 12	EWY future	No passive cooling	high

4

Results





Results

Conclusion

- Results clearly indicate that natural ventilation combined with thermal mass can have a significant influence.
- In anticipated future climate scenarios, the inclusion of mechanical cooling becomes essential to achieve summer comfort under all circumstances. However, the potential energy savings achieved by combining mechanical cooling with natural ventilation are projected to be even higher compared to the present climate.

Follow us

A study of indoor environment and window use in French dwellings monitored during a summer with heatwaves

Mathilde Hostein[1,2], Bassam Moujalled[1,3], Marjorie Musy[1,3] and Mohamed El Mankibi[2]

[1] Cerema, BPE Research Team, 46 rue Saint Théobald, 38081 L'Isle d'Abeau, France

[2] Univ. Lyon, ENTPE, Ecole Centrale de Lyon, CNRS, LTDS, UMR 5513, 3 Rue Maurice Audin, 69518 Vaulx-en-Velin, France

[3] Univ. Savoie Mont Blanc, CNRS, LOCIE, UMR 5271, 60 rue du lac Léman, Savoie Technolac, 73376 Le Bourget-du-Lac, France

mathilde.hostein@cerema.fr

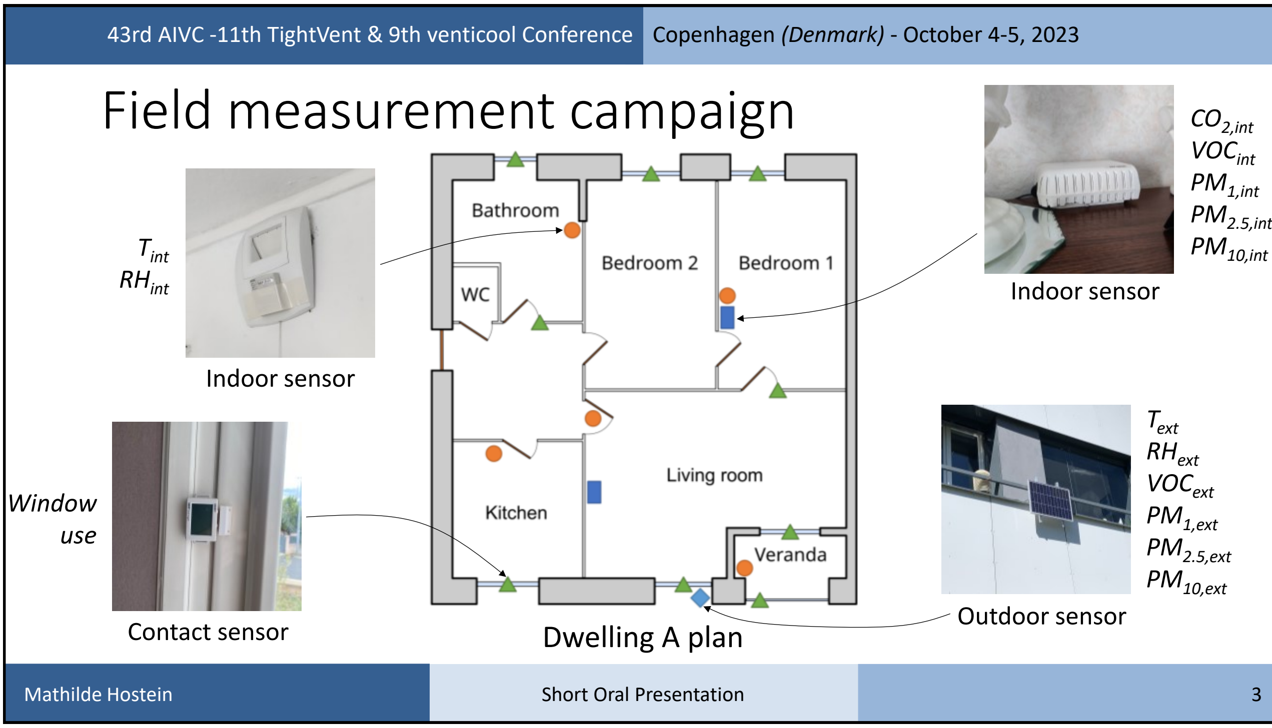
1

Field measurement campaign

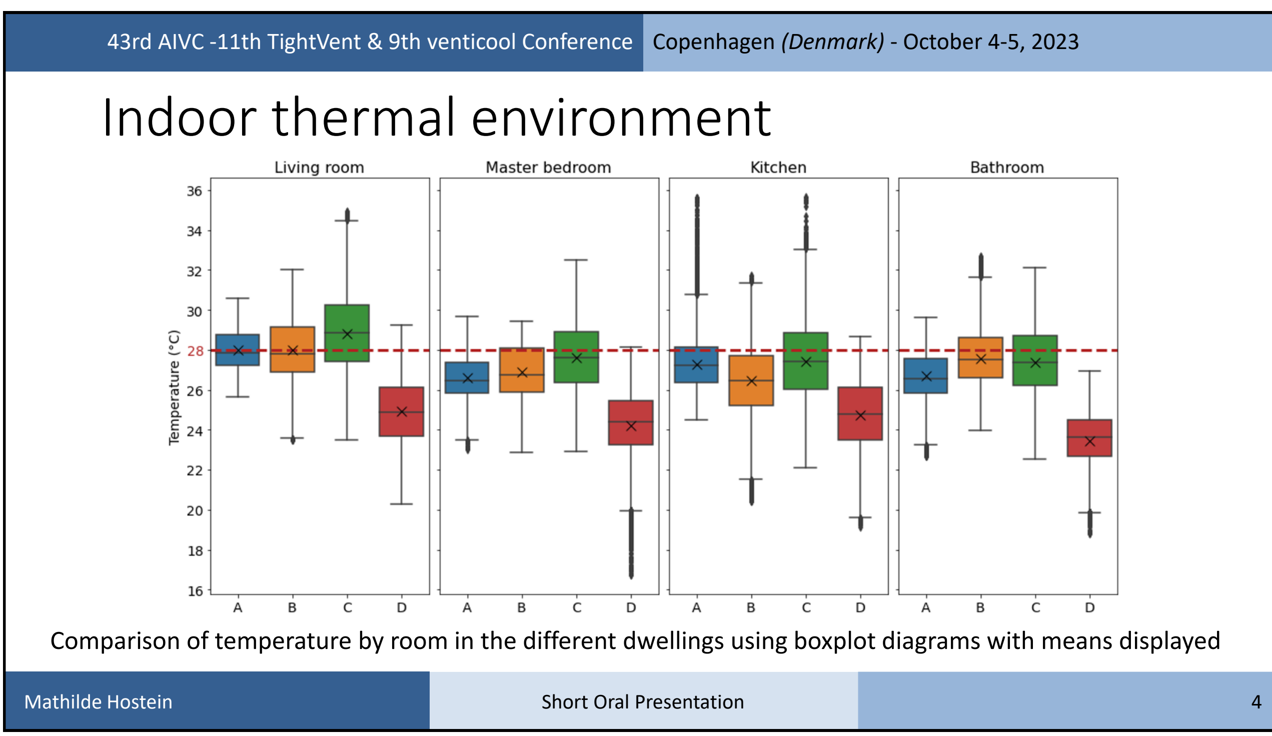
- CREATIV research project
  - Thermal comfort
  - Indoor air quality
  - Heatwave

- Lyon & Clermont-Ferrand
- 4 dwellings monitored
- June to September 2022
- Surveys :
  - Logbook
  - Thermal comfort surveys
  - General questionnaire
- Measurements

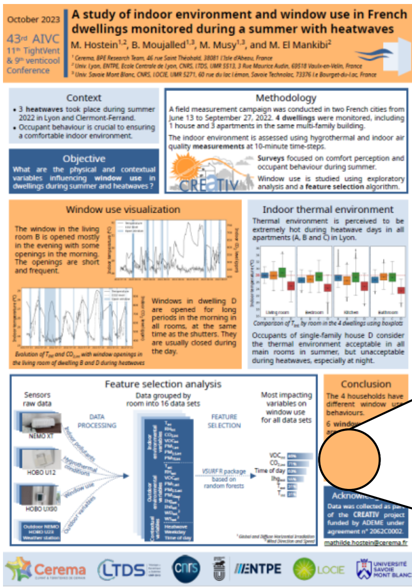
2


43rd AIVC -11th TightVent & 9th venticool Conference
Copenhagen (Denmark) - October 4-5, 2023
Field measurement campaign
T_{int}
RH_{int}
Indoor sensor
Window use
Contact sensor
Bathroom
WC
Bedroom 2
Bedroom 1
Living room
Kitchen
Veranda
Dwelling A plan
$CO_{2,int}$
VOC_{int}
$PM_{1,int}$
$PM_{2.5,int}$
$PM_{10,int}$
Indoor sensor
T_{ext}
RH_{ext}
VOC_{ext}
$PM_{1,ext}$
$PM_{2.5,ext}$
$PM_{10,ext}$
Outdoor sensor
Mathilde Hostein
Short Oral Presentation
3

3


43rd AIVC -11th TightVent & 9th venticool Conference
Copenhagen (Denmark) - October 4-5, 2023
Indoor thermal environment
Living room
Master bedroom
Kitchen
Bathroom
Temperature (°C)
36
34
32
30
28
26
24
22
20
18
16
A
B
C
D
Comparison of temperature by room in the different dwellings using boxplot diagrams with means displayed
Mathilde Hostein
Short Oral Presentation
4

4



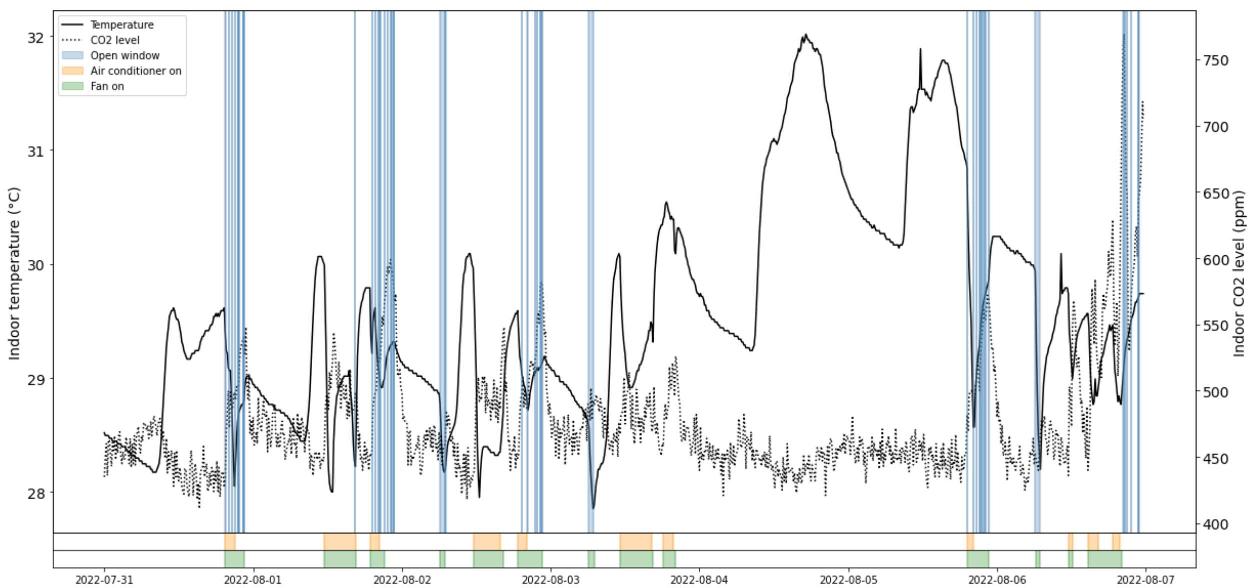
More during the poster session…

Window use drivers

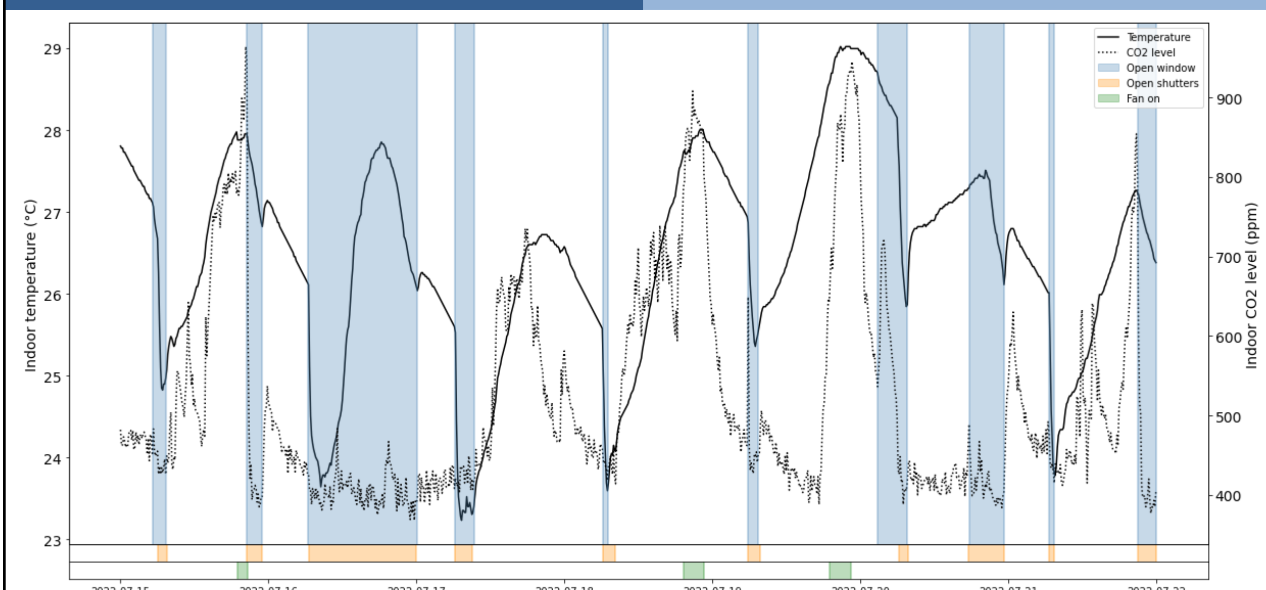
- T_{int} et T_{ext}
- $CO_{2,int}$ et VOC_{int}
- Ihg_{ext}
- Time of day

Thank you !

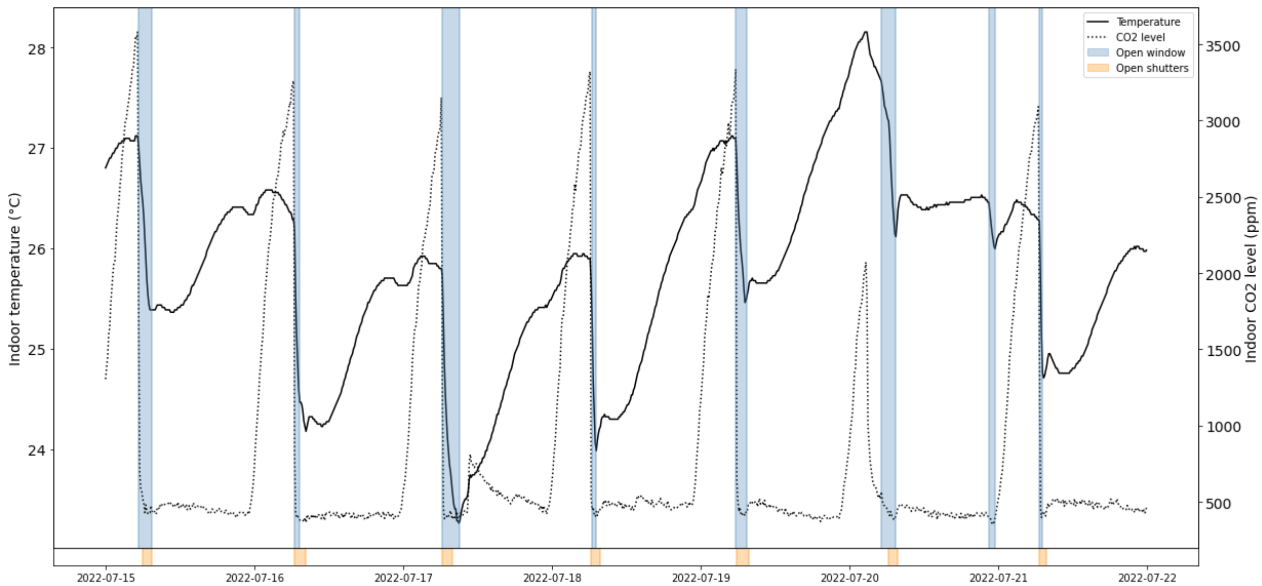
Evolution of the inddor environment with adaptation actions in the living room of dwelling B during the 3rd heatwave



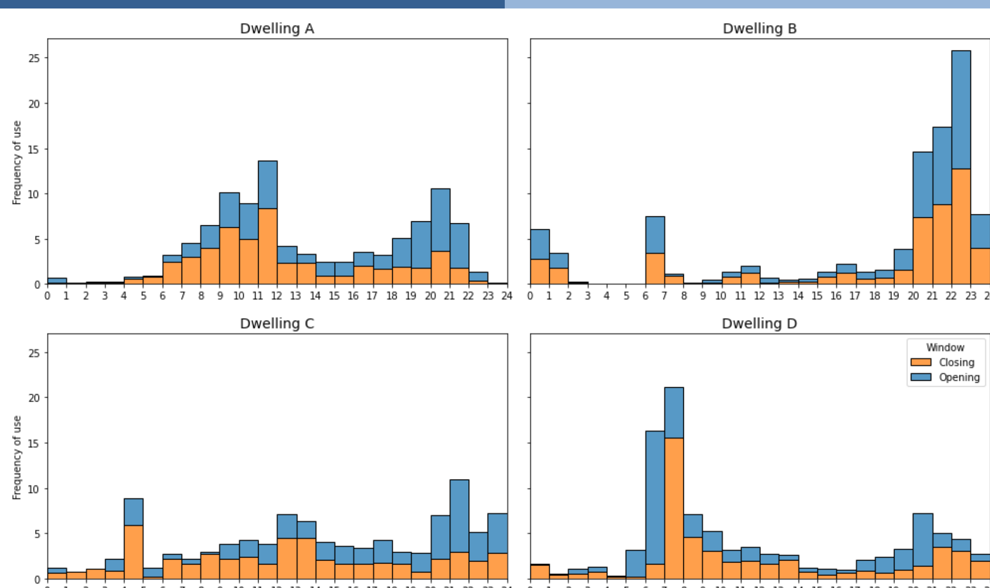
Evolution of the inddor environment with adaptation actions in the living room of dwelling D during the 2nd heatwave

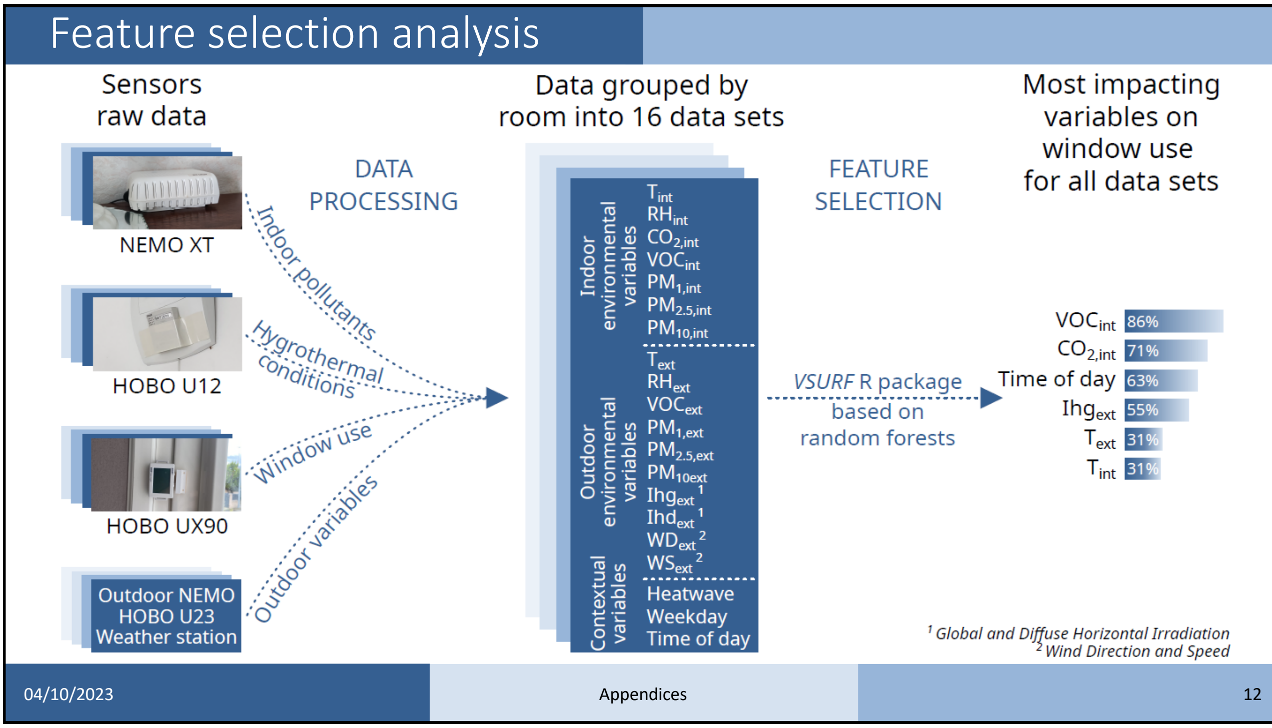


Evolution of the inddor environment with adaptation actions in the bedroom of dwelling D during the 2nd heatwave

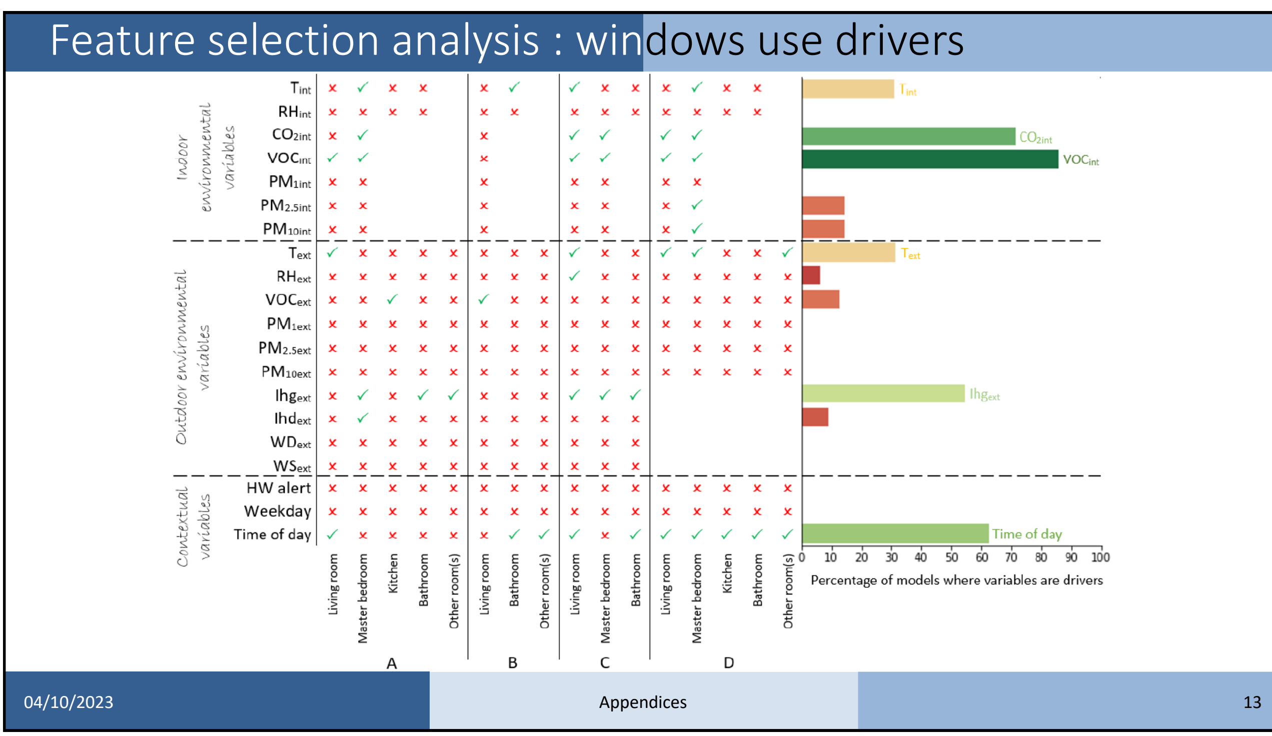


Windows openings and closings accoring to the time of day




Feature selection analysis
Sensors raw data
NEMO XT
HOBO U12
HOBO UX90
Outdoor NEMO
HOBO U23
Weather station
DATA PROCESSING
Indoor pollutants
Hygrothermal conditions
Window use
Outdoor variables
Data grouped by room into 16 data sets
Indoor environmental variables
T int
RH int
CO2,int
VOC int
PM1,int
PM2.5,int
PM10,int
Outdoor environmental variables
T ext
RH ext
VOC ext
PM1,ext
PM2.5,ext
PM10ext
Ihg ext 1
Ihd ext 1
WD ext 2
WS ext 2
Contextual variables
Heatwave
Weekday
Time of day
FEATURE SELECTION
VSURF R package based on random forests
Most impacting variables on window use for all data sets
VOC int 86%
CO2,int 71%
Time of day 63%
Ihg ext 55%
T ext 31%
T int 31%
1 Global and Diffuse Horizontal Irradiation
2 Wind Direction and Speed
04/10/2023
Appendices
12

12


Feature selection analysis : windows use drivers
Indoor environmental variables
T int
RH int
CO2int
VOCint
PM1int
PM2.5int
PM10int
Outdoor environmental variables
T ext
RH ext
VOC ext
PM1ext
PM2.5ext
PM10ext
Ihg ext
Ihd ext
WD ext
WS ext
Contextual variables
HW alert
Weekday
Time of day
Living room
Master bedroom
Kitchen
Bathroom
Other room(s)
A
B
C
D
0 10 20 30 40 50 60 70 80 90 100
Percentage of models where variables are drivers
04/10/2023
Appendices
13

13

Importance of thermal stack effect in ventilative cooling concepts for residential buildings

AIVC 2023

04/10/2023

HOME OF OXYGEN

DUCO

1

Research question

Evolutions in residential building sector (e.g. in the Netherlands)

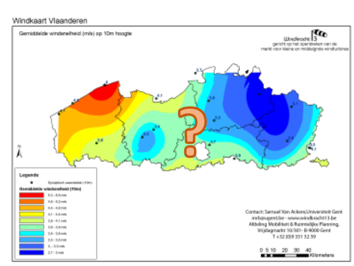
- factory-built (modular) dwellings
- light-weight (sustainable, recyclable) construction
- thoroughly designed

What ventilative cooling concepts to use in residential buildings with light-weight construction?

- That are effective in improving indoor temperature
- That are robust to external conditions

While also:

- being cost-effective
- being burglary-, insect-, weather-proof
- integrating well with other systems
- …



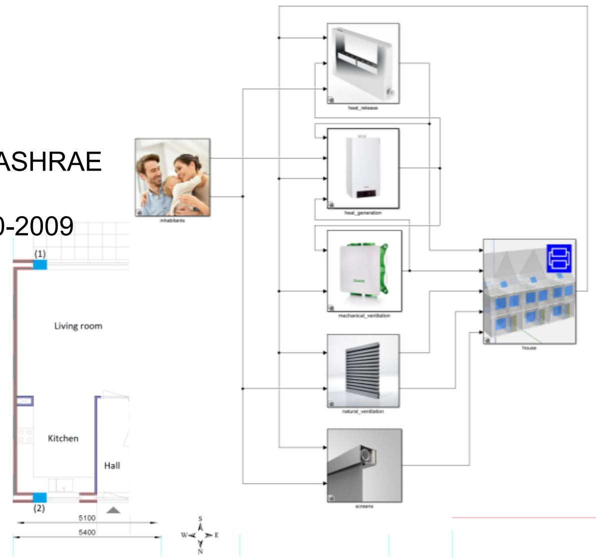
HOME OF OXYGEN

DUCO

2

Model-based simulation setup

- Three-floor terraced house
  - light-weight construction style (CLT)
  - 4 different orientations
  - suburban and urban environment (using ASHRAE correction for wind speed)
- Belgian climate data with extremes from 2000-2009
- Three-person family
- Ventilative cooling:
  - Manual occupant window opening
  - Temperature-controlled
    - single-sided ventilation (1)
    - cross-ventilation (1)(2)
    - thermal stack ventilation (1)(3) (*)

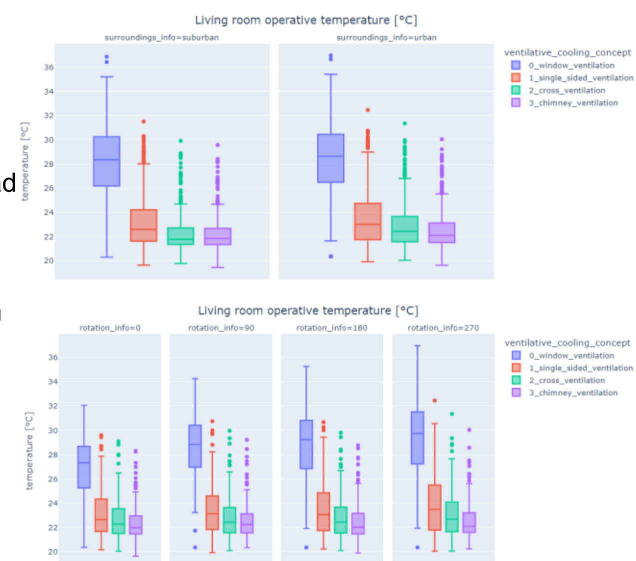


(*) an open staircase is assumed

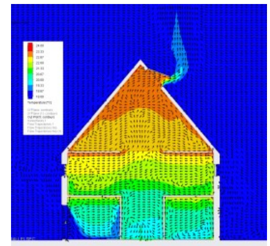
Results

Robustness to external conditions (May-September)

- Cross-ventilation and single-sided ventilation have higher living room temperatures and spread in urban environments
- Thermal stack ventilation has the lowest living room temperatures and spread independent of (sub)urban environment and building orientation

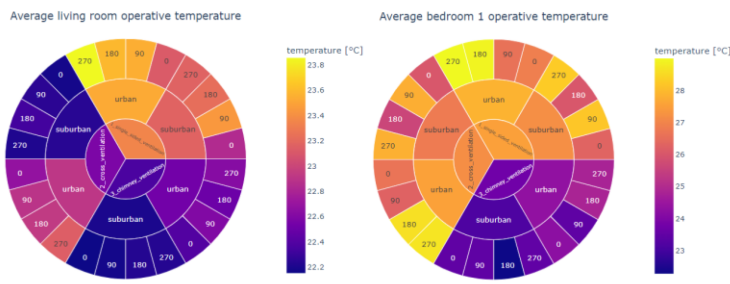


Conclusion



What ventilative cooling concepts to use in residential buildings with light-weight construction?

- Thermal stack based ventilation concept:
  - is generally robust to external conditions such as the surroundings and building orientation
  - also reduces bedroom temperatures significantly during hot periods



Performance 2

Durability of ventilation performance

Performance 2 project - Winter IAQ campaigns in 13 dwellings equipped with Humidity-based DCV systems: analysis of the ventilation performance after 15 years of use

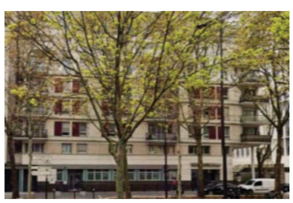
Adeline Mélois, Ambre Marchand Moury, Marc Legree, Juan Rios, Jérémy Depoorter, Nicolas Dufour, Sylvain Rebières, Gaëlle Guyot

RÉPUBLIQUE FRANÇAISE · ADEME · RÉPUBLIQUE FRANÇAISE · Cerema · UNIVERSITÉ SAVOIE MONT BLANC · LOCIE · AERECO · anjos

1

Performance 2 project (2020 – 2024)

Aim: qualify the durability of smart ventilation systems with humidity-based demand-controlled ventilation, and especially their resiliency regarding long-term use by various tenants



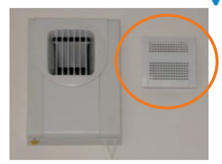
Paris Building
19 instrumented dwellings

Villeurbanne (Lyon) Building
12 instrumented dwellings

monitored since their construction during the 2007-2010 Performance project
→ in situ sensors in the air terminal devices (directly inside the ATD and with circuit board near the ATD)

2

Performance 2 project (2020 – 2024)



- **Continuous monitoring + 2 winter campaigns on-site:**
  - Preliminary inspection of ventilation systems
  - Measurements in dwellings:
    - ventilation performance
    - comfort parameters (T°, RH)
    - indoor air quality (CO2, VOCs, Formaldehyde & PM)
  - Interviews of the tenants
  - Outdoor weather stations
- **Laboratory campaign:**
  - evaluation of the air terminal devices' performance before and after cleaning
  - calibration of the sensors and study of the reliability of the indoor air quality sensors
- **Analysis:**
  - assessment of the performance of the ventilation systems regarding indoor air quality, energy input, and their robustness compared to their use by the tenants

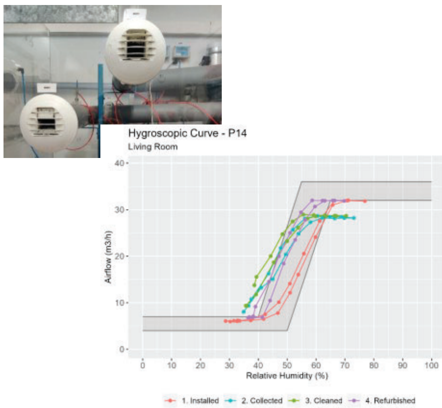
Analysis - Methodology

1) Durability evaluation : comparison Performance 1 / Performance 2

Analysis - Methodology

1) Durability evaluation : comparison Performance 1 / Performance 2

- In laboratory

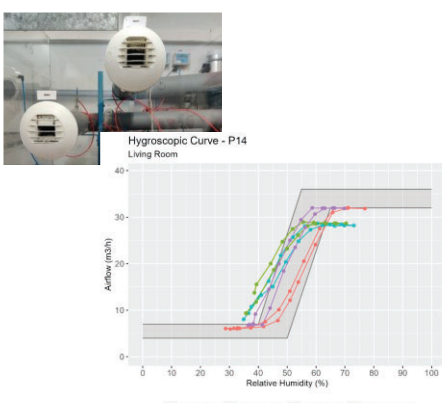


Mélois et al. Durability of humidity-based ventilation components after 13 years of operation in French residential buildings – assessment of components performance in laboratory. Energy and Buildings, 2023.

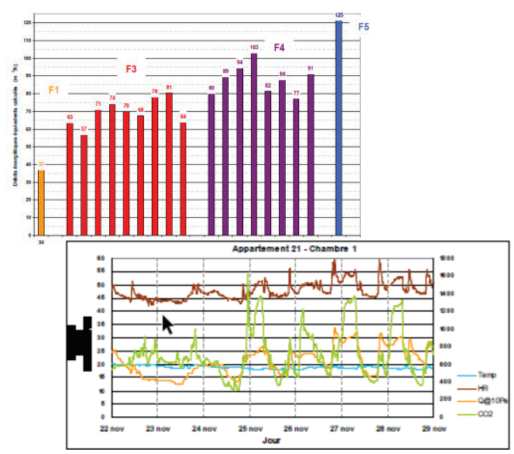
Analysis - Methodology

1) Durability evaluation : comparison Performance 1 / Performance 2

- In laboratory
- On-site



Mélois et al. Durability of humidity-based ventilation components after 13 years of operation in French residential buildings – assessment of components performance in laboratory. Energy and Buildings, 2023.



Analysis- Methodology

2) Performance regarding IAQ: new evaluations

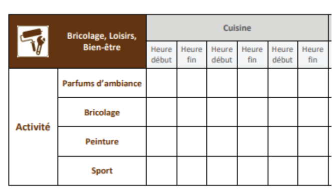
Parameter	Sensors	Limits	Analyses
Formaldehyde	NEMOs	• Average values for 2h	?
Total VOC	Embeded sensor	• Which VOCs? • Unit? • 24h Auto calibration	Only dynamic analyses
Light VOC	NEMOs	• Which VOCs? • Unit? • High uncertainty	Only dynamic analyses
PM2.5	Embeded sensor	• High uncertainty	Descriptive statistics with precaution
	NEMOs	• High uncertainty	Descriptive statistics with precaution
PM10	NEMOs	• Extrapolated from PM25	No possible analysis
PM1	NEMOs	• High uncertainty	Descriptive statistics with precaution

Analysis- Methodology

3) Evolution of ventilation CONDITIONS & NEEDS

- Diagnosis of the whole ventilation system

- Evaluation of the evolution of occupancy
  - Number of occupants
  - Age
  - Home office



Bricolage, Loisirs, Bien-être		Cuisine					
		Heure début	Heure fin	Heure début	Heure fin	Heure début	Heure fin
Activité	Parfums d'ambiance						
	Bricolage						
	Peinture						
	Sport						

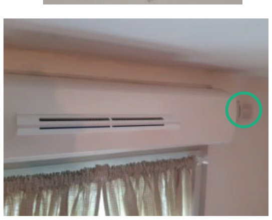
- Evaluation of the airing behaviour
- Evaluation of the internal sources of pollutants

Participating volunteer dwellings

Paris		Year	Villeurbanne	
15	Dwellings volunteer for the project	2019	7	Dwellings volunteer for the project
13	Dwellings included in the monitoring phase	2021	7	Dwellings included in the monitoring phase
7	Dwellings participated to the 1st winter campaign	2021/22	6	Dwellings participated to the 1st winter campaign
4	Dwellings participated to the 2nd winter campaign	2022/23	4	Dwellings participated to the 2nd winter campaign

Analysis- First results

- Relative Humidity/Airflow + Refurbished lab characterization:



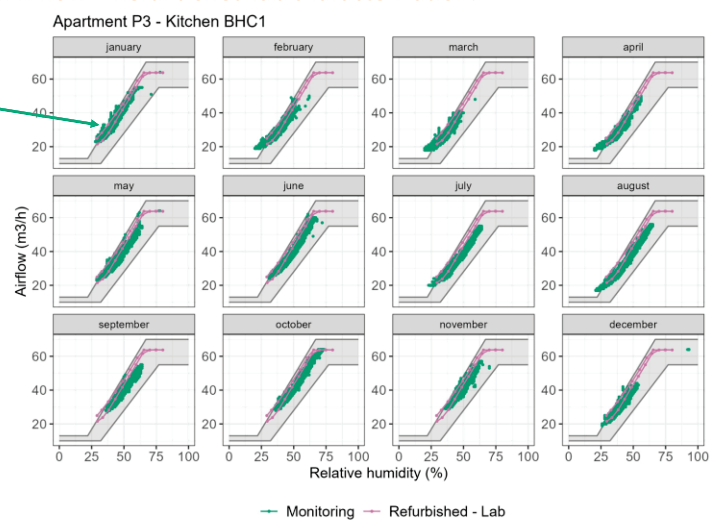
Analysis- First results

- **Relative Humidity/Airflow + Refurbished lab characterization:**

CO_2, RH, T, PM2.5 and VOC +
Shutter Opening and Pressure*

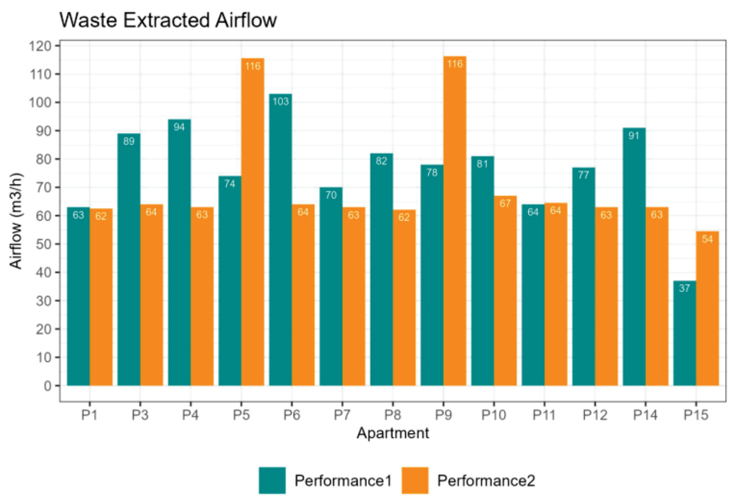
Analysis- First results

- **Relative Humidity/Airflow + Refurbished lab characterization:**



Analysis- First results

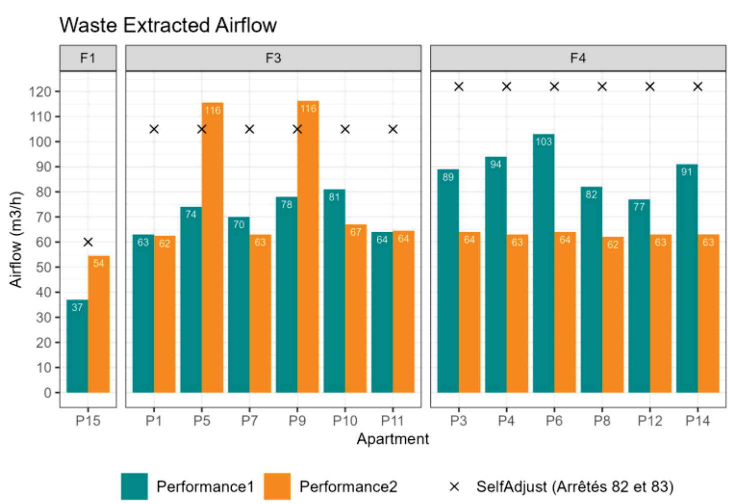
- **Comparison Performance 1 et Performance 2 wasted airflow:**



13

Analysis- First results

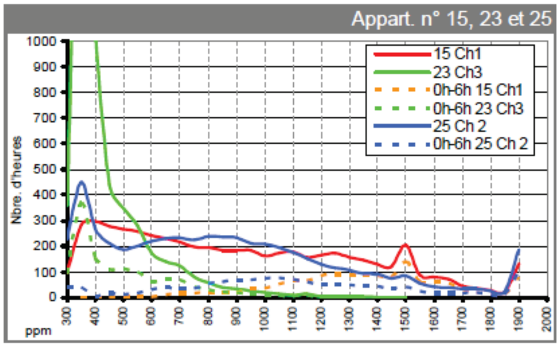
- **Comparison Performance 1 et Performance 2 wasted airflow:**



14

Analysis- First results

- Time per average CO2 concentration:

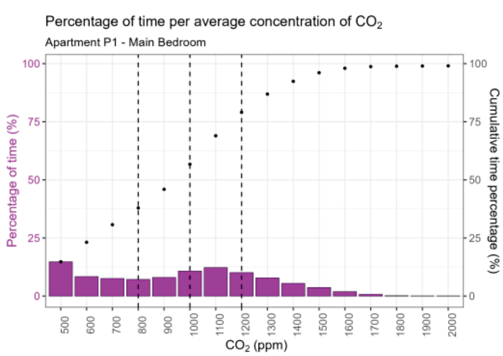


Performance 1 → More spent time at higher average CO2 concentration values when considering only 0h and 6h than for a 24h period

15

Analysis- First results

- Time per average CO2 concentration:

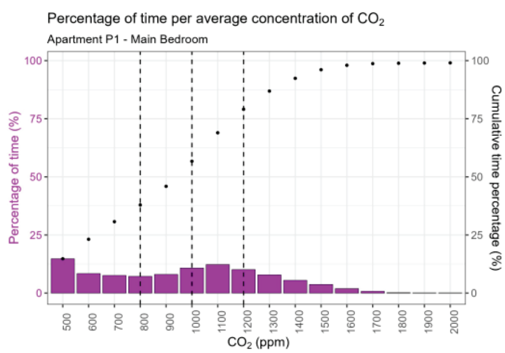


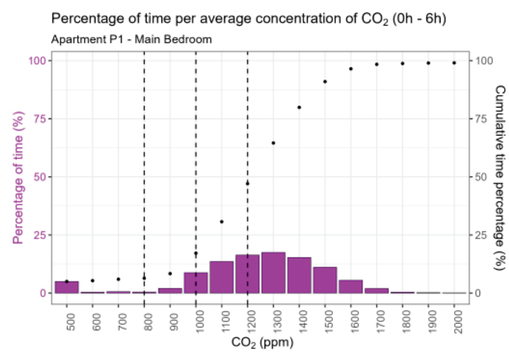
Performance 1 → More spent time at higher average CO2 concentration values when considering only 0h and 6h than for a 24h period

16

Analysis- First results

- Time per average CO2 concentration:





Performance 1 → More spent time at higher average CO2 concentration values when considering only 0h and 6h than for a 24h period
Performance 2 → Same tendancy

Analysis- First results

- Through the detection of humidity (intrinsically human origin), air inlets allow an increase in airflow during increases in CO2 levels ?

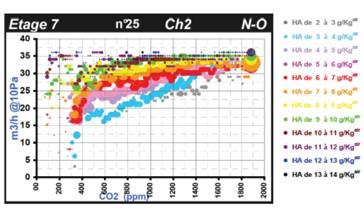


Figure 21 : exemple de l'ouverture moyenne de l'entrée d'air d'un appartement occupé par 4 enfants sur un an

Performance 1 → General tendency of opening of air inlets with the rise in the CO2 level

Analysis- First results

- Through the detection of humidity (intrinsically human origin), air inlets allow an increase in airflow during increases in CO2 levels ?

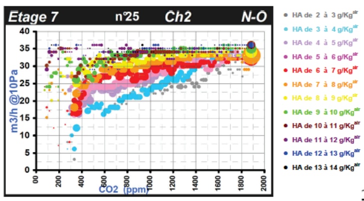
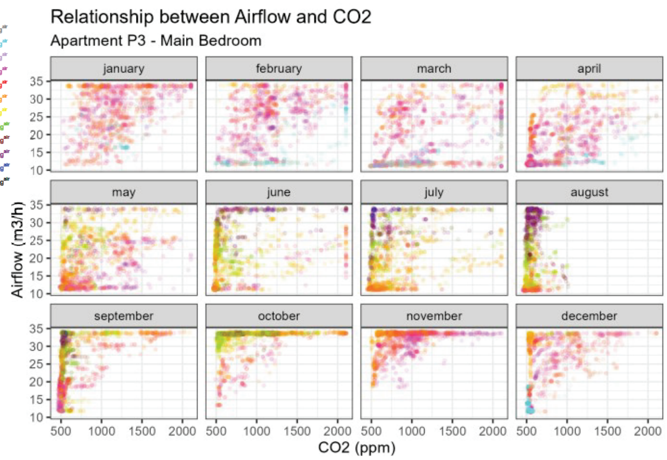


Figure 21 : exemple de l'ouverture moyenne de l'entrée d'air d'un appartement occupé par 4 enfants sur un an

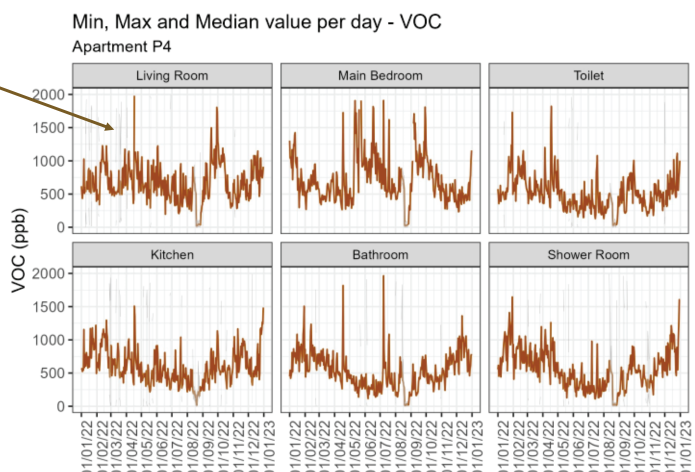


Performance 1 → General tendency of opening of air inlets with the rise in the CO2 level

Performance 2 → To verify…

Analysis- First results

- Study of the VOC temporal dynamic evolution: uncertainties on the absolute values after lab characterization



Analysis- First results

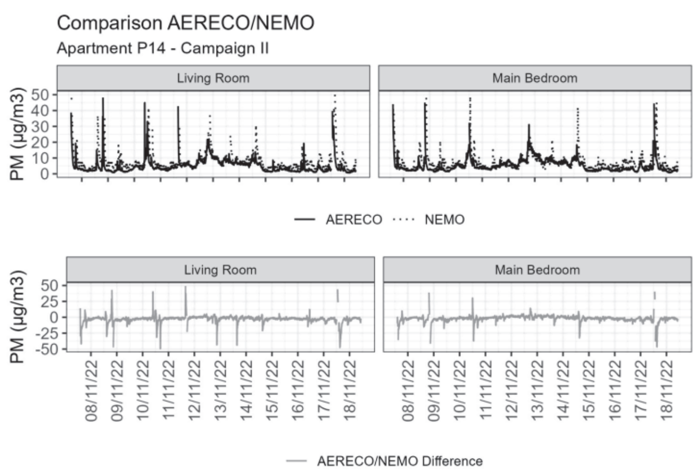
- Comparison AERECO/NEMO sensors: Particle Matter (PM) 2.5

AERECO sensors → Installed in all the rooms - 1 record every minute for 2 years

NEMO sensors → 2 IAQ campaings of 2 weeks each installed in the main chamber and living room - 1 record every 10 minutes

Analysis- First results

- Comparison AERECO/NEMO sensors: Particle Matter (PM) 2.5



Next steps

- **Evaluation of the durability from on-site measurements**
  - Comparison with design documents
  - Comparison with Performance 1 project
- **Evaluation of actual performance of ventilation system regarding IAQ and Energy**
  - Indicators for IAQ performance
  - Evaluation of the humidity based system for others pollutants
- **Evaluation of the impact of the occupants**
  - Data collected with interviews
  - Data extrapolated from measurements
- **End of the project: June 2024**
- **Many data: others studies may be performed after Performance 2 project**

Performance 2

Durability of ventilation performance

Thank you for your attention

performance2@cerema.fr

RÉPUBLIQUE FRANÇAISE ADEME RÉPUBLIQUE FRANÇAISE Cerema UNIVERSITÉ SAVOIE MONT BLANC LOCIE AERECO anjos

Checking and assuring real IAQ and energy performances through demand control and cloud connectivity

RENSON®
Creating healthy spaces
VENTILATION | SUNPROTECTION | OUTDOOR

Ivan Pollet, Kevin Verniers, Steven Delrue
R&D Renson

AIVC Conference, October 4-5, 2023, Copenhagen

1

The Renson story
about the company

RENSON®
Creating healthy spaces

FACTS & FIGURES

- Belgian family business, since 1909
- Headquarters in Waregem (Belgium)
- Core businesses
  - Ventilation
  - Sun shading
  - Outdoor living solutions
- 1200 employees, 10% employed in R&D
- Annual turnover of over 220 Mio €

MISSION

Creating happiness and well-being
by bringing people a healthy and comfortable
in- & outdoor environment

2

Renson Ventilation Strategy (residential)

RENSON
Creating healthy spaces

- ❑ Ventilate **sustainably >** limitation of **material use & energy use**
  - ✓ Minimize **mass** & **number** of **components**
  - ✓ Maximize **repairability** & **recyclability**
  - ✓ Ventilate **where** and **when** needed on a **sufficient** level
  - ✓ Avoid '**overventilation'** except for **ventilative cooling**
  - ✓ Improvement **Total Life Cycle**

- ❑ Enhance **servitization:**
  - ✓ **Unburden: support** & **facilitate practice:** planning/installation/commissioning/service
  - ✓ **Visualize** + **communicate** + **sensibilize** about the invisible **IAQ**

Connectivity highly facilitates

3

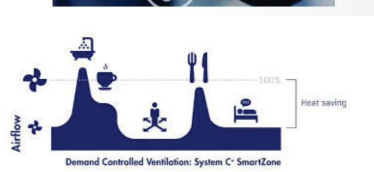
Renson specializations

RENSON
Creating healthy spaces

Control systems: - advanced

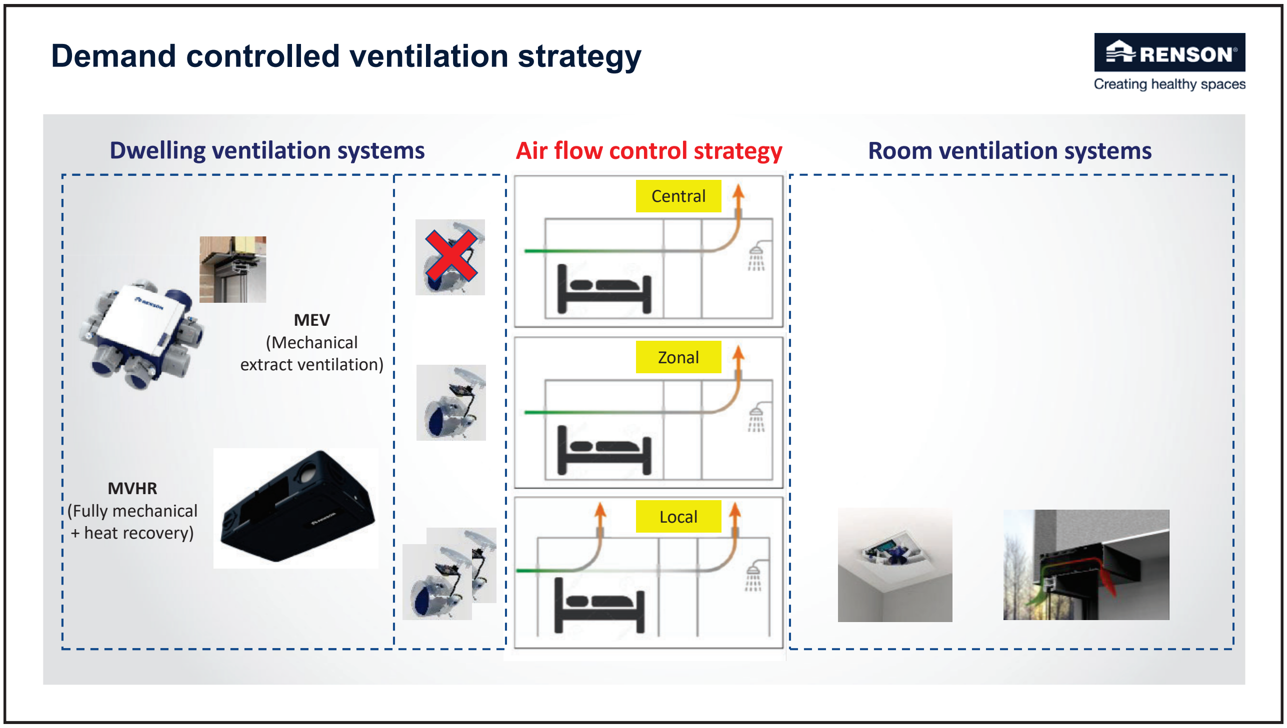
- demand driven: RH, CO_2, VOC, T, I_{sol} …

Smart Living



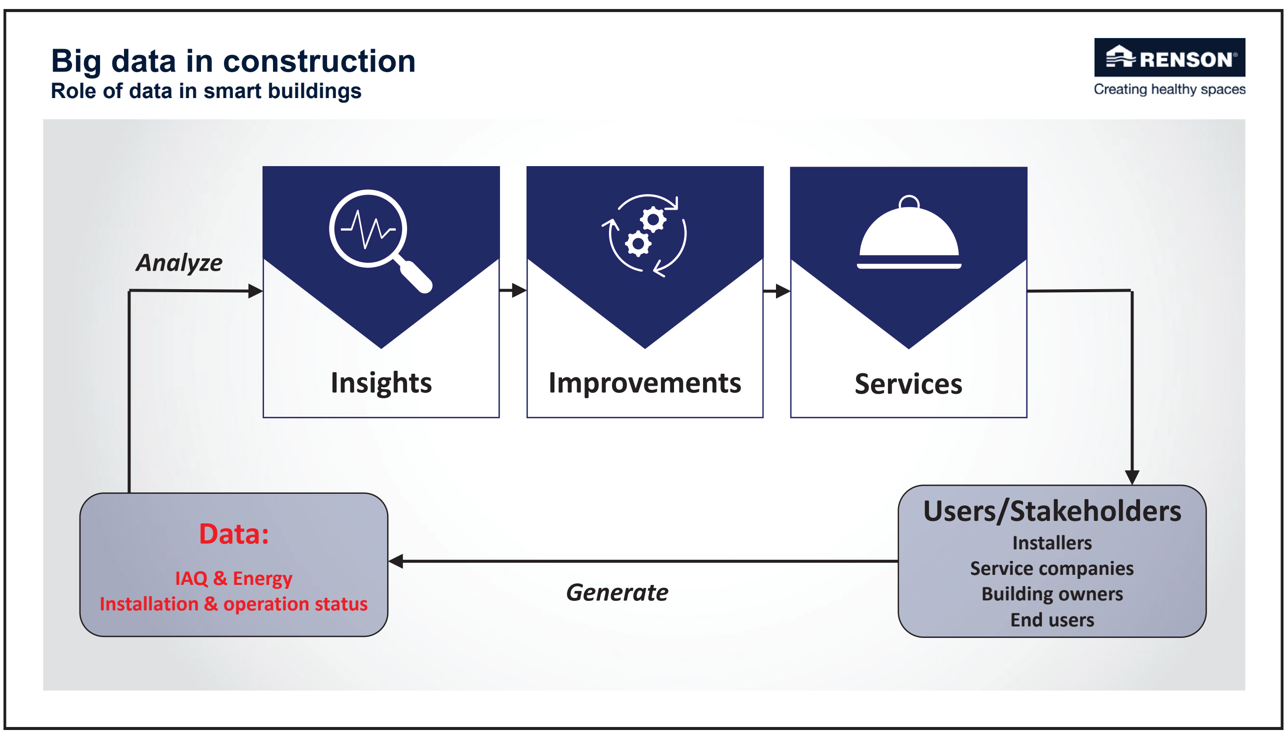
IoT devices: cloud connectivity & Data

4



Demand controlled ventilation strategy
RENSON
Creating healthy spaces
Dwelling ventilation systems
Air flow control strategy
Room ventilation systems
MEV
(Mechanical
extract ventilation)
MVHR
(Fully mechanical
+ heat recovery)
Central
Zonal
Local

5



Big data in construction
Role of data in smart buildings
RENSON
Creating healthy spaces
Analyze
Insights
Improvements
Services
Users/Stakeholders
Installers
Service companies
Building owners
End users
Data:
IAQ & Energy
Installation & operation status
Generate

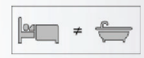
6

Big data in construction > Servitization
Role of data in smart buildings

RENSON® Creating healthy spaces

Current servitization through digital interactions:

- With residents/installers: via resident/set-up app & web portals
  - **Project preparation & planning** > installation, system calibration & commissioning
  - **Push notifications** > via smartphone for filter warnings and error detection
  - **Visual representation** > real time/historic air quality and ventilation levels
  - **Service management and follow-up** > remote inspection of functioning/maintenance
  - **Automatic software updates**
  - …



Wrong valve detection

- With smart home/home automation: via API and/or via switching module

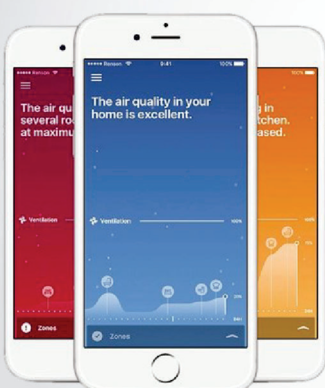
7

Big data in construction > Insights
Inform occupants about air quality and energy consumption

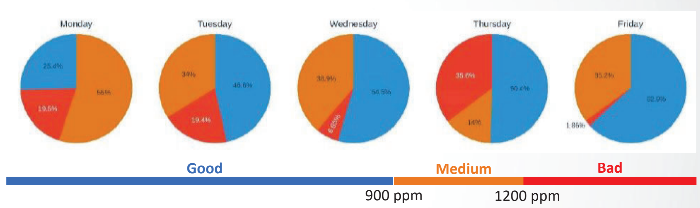
Insights

RENSON® Creating healthy spaces

Mobile & web applications

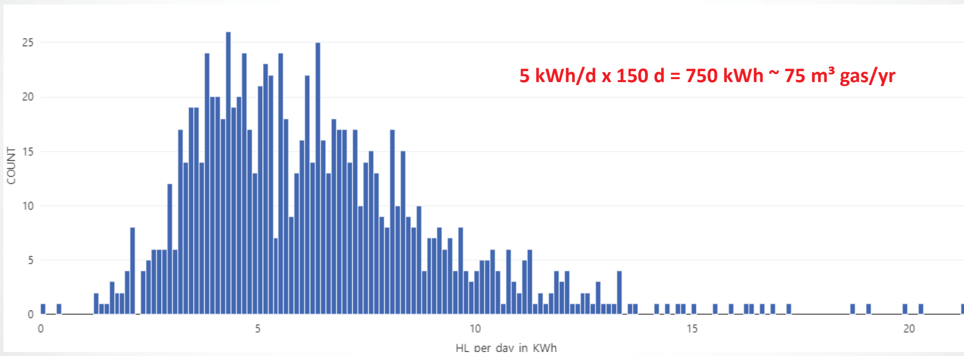


Reporting with statistical summaries



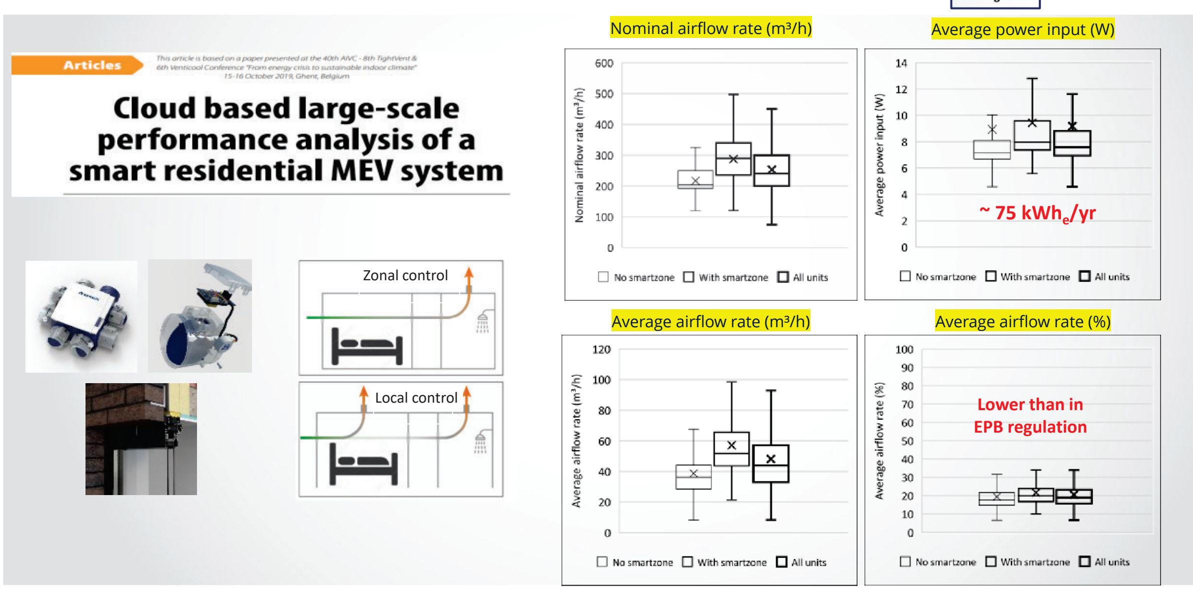
8

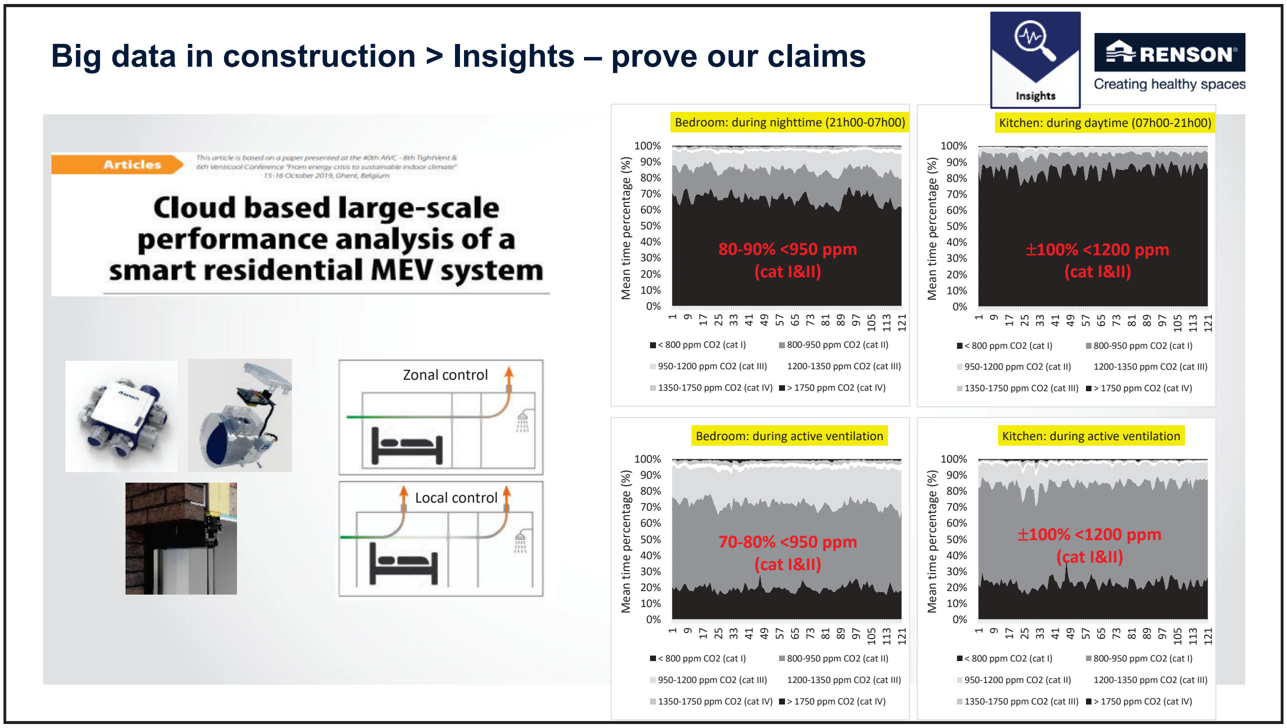
Big data in construction > Insights – ventilation losses



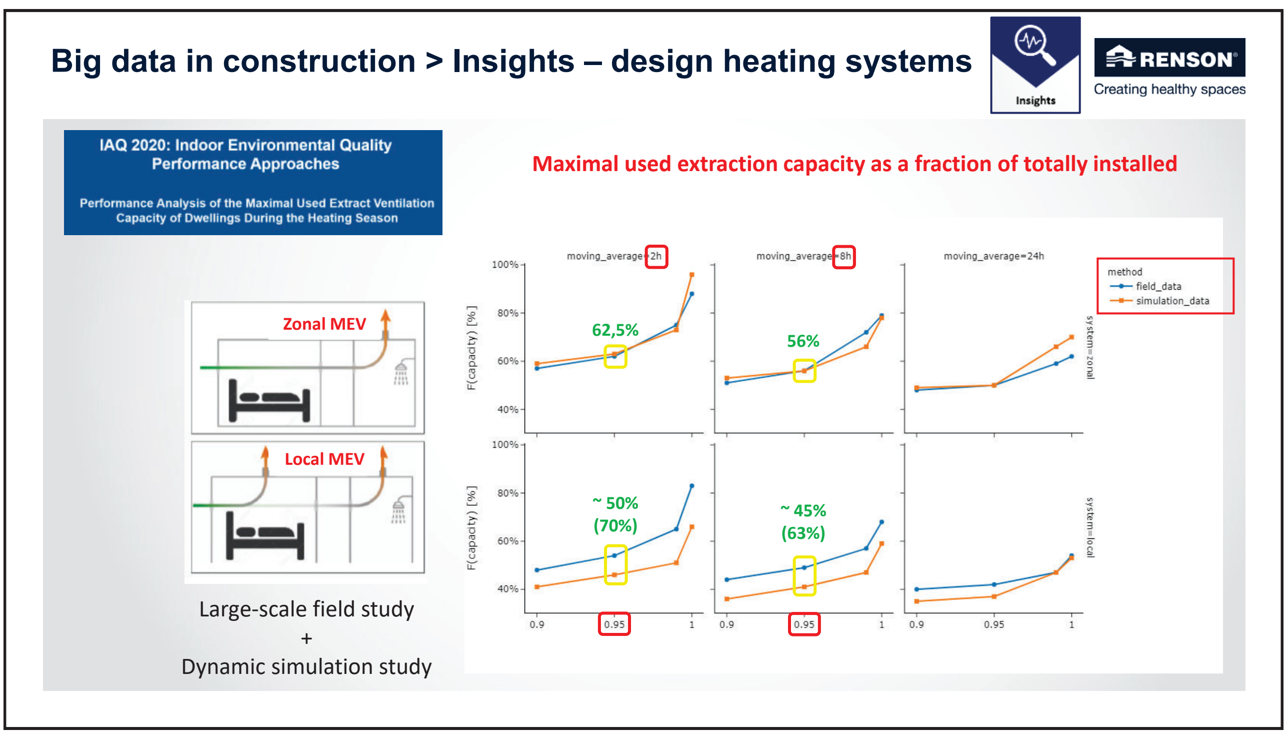
Ventilation heat losses caused by Healthbox 3.0

Big data in construction > Insights – prove our claims




Big data in construction > Insights – prove our claims
Insights
RENSON
Creating healthy spaces
Articles
Cloud based large-scale performance analysis of a smart residential MEV system
Zonal control
Local control
Bedroom: during nighttime (21h00-07h00)
80-90% <950 ppm (cat I&II)
Kitchen: during daytime (07h00-21h00)
±100% <1200 ppm (cat I&II)
Bedroom: during active ventilation
70-80% <950 ppm (cat I&II)
Kitchen: during active ventilation
±100% <1200 ppm (cat I&II)
Mean time percentage (%)
< 800 ppm CO2 (cat I)
800-950 ppm CO2 (cat II)
950-1200 ppm CO2 (cat III)
1200-1350 ppm CO2 (cat III)
1350-1750 ppm CO2 (cat IV)
> 1750 ppm CO2 (cat IV)

11


Big data in construction > Insights – design heating systems
Insights
RENSON
Creating healthy spaces
IAQ 2020: Indoor Environmental Quality Performance Approaches
Performance Analysis of the Maximal Used Extract Ventilation Capacity of Dwellings During the Heating Season
Maximal used extraction capacity as a fraction of totally installed
Zonal MEV
Local MEV
Large-scale field study
+
Dynamic simulation study
moving_average=2h
moving_average=8h
moving_average=24h
method
field_data
simulation_data
F(capacity) [%]
system=zonal
system=local
62,5%
56%
~ 50%
(70%)
~ 45%
(63%)
0.9
0.95
1

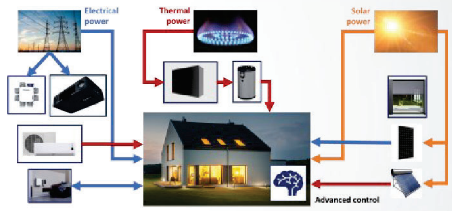
12

Future

RENSON
Creating healthy spaces

Creation of Smart Living concept: HVAC, solar shading, PV, …

- Cloud connection
- Overall & advanced controls
- Increase/guarantee performance
- Facilitate maintenance & repair



Conditions:

- **Sustainable**: minimize environmental impact by ‘collaboration’
- Operate within the **security and privacy rights**
- **Added value** > Cost

Ivan.Pollet@renson.be
T: +32 470 13 33 19

Steven.Delrue@renson.be
T: 32 478 96 17 73

RENSON®
Creating healthy spaces

VENTILATION | SUNPROTECTION | OUTDOOR

universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen

universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen

Data driven models for fault detection
Combining thermal and indoor air quality grey box models

Gabriel Rojas, University of Innsbruck
Romed Jenewein, University of Innsbruck
Klaus Prenninger, Salzburg University of Applied Sciences
Johannes Schnitzer, Forschung Burgenland

AIVC Conference, Copenhagen
Oct. 4th, 2023

AFOM - Automatisierte Fehler & Optimierungsanalyse durch Messwerterfassung

1

Typical faults

System renovation | Maintenance and repair

Design | Construction | Operation

Design
- Over-sizing, under-sizing
- Unbalanced water and air system
- Inefficient air distribution in rooms

Construction
- Damage of building envelope
- High resistance of water and air system caused by construction issues
- Inefficient room heating and cooling, e.g. air outlet, radiator being covered
- Wrong sensor location

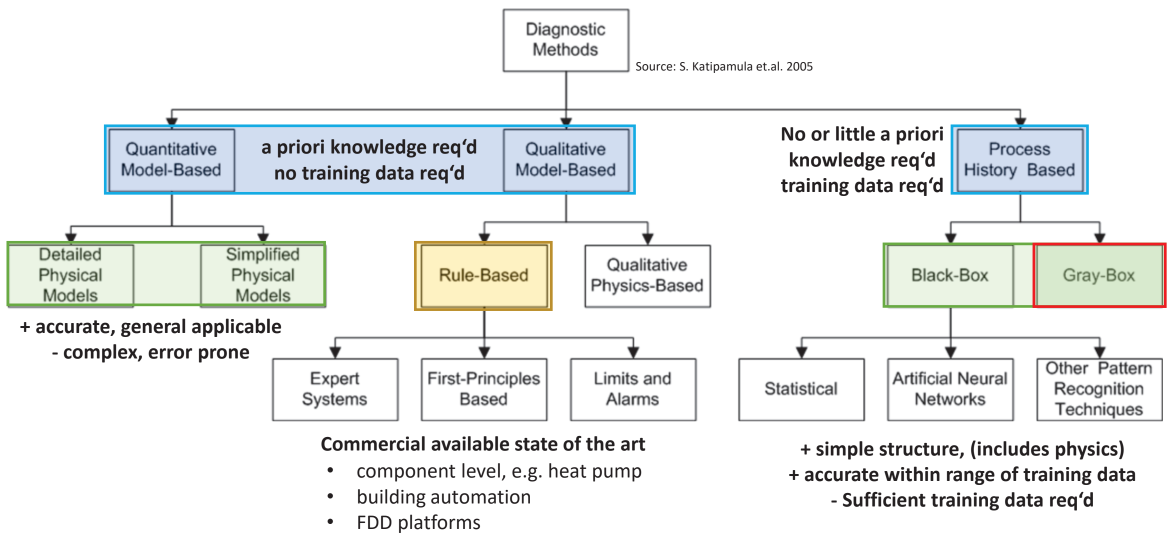
Operation
- Human wrong behavior
  - Wrong set point, schedule
  - Override command
  - Open windows and doors
- Control faults
  - Controller breaks down
  - Control algorithm error
  - Wrong parameters
- HVAC equipment and BAS field devices faults
  - Motors and electric devices fail (fan, pump, heater, etc.)
  - Dampers/valves stuck, leak, reversed
  - Sensors fail
  - Heating and cooling equipment fail (heat pump, boiler, chiller, etc.)

Source: Gao, T. (2020)

universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen

2

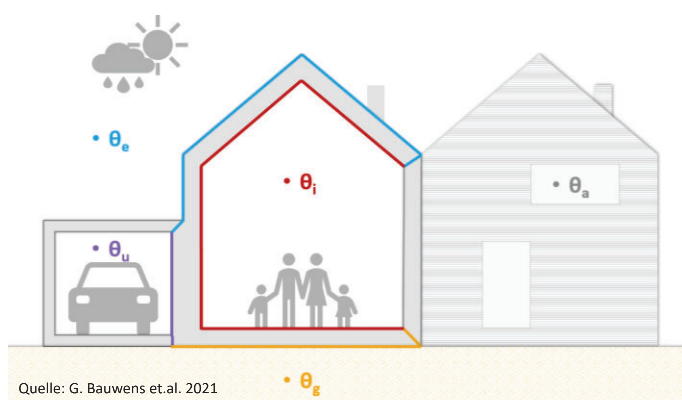
Fault Detection and Diagnosis (FDD) methods



Thermal grey box model

Basic idea: energy balance

- **Transmission losses** } $\tilde{\Phi}_{tr}$
- **Infiltration**
- **Solar gains** Φ_{sol}
- **Internal heat gains** Φ_{int}
- **Ventilation** Φ_{vent}
- **Heating / Cooling** Φ_{heat}



Quelle: G. Bauwens et.al. 2021

Stationary $\sum \boldsymbol{\Phi} = \mathbf{0}$

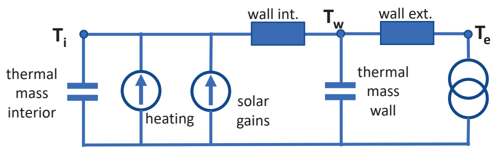
Dynamic $\sum \boldsymbol{\Phi} = \mathbf{C}\,\frac{d\boldsymbol{T_i}}{d\boldsymbol{t}}$

-> Introduce simple model for transmission heat losses

$$\frac{dT_i}{dt} C_i = \Phi_{heat} + \Phi_{sol} + \frac{(T_e - T_i)}{R_{wi}}$$

Thermal greybox model using state space model representation

Simplified physical representation



$$\frac{dT_i}{dt} C_i = \dot{Q}_{heat} + \dot{Q}_{sol} + \frac{(T_w - T_i)}{R_{wi}}$$

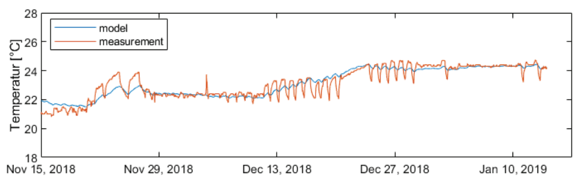
$$\frac{dT_w}{dt} C_w = \frac{(T_i - T_w)}{R_{wi}} + \frac{(T_e - T_w)}{R_{we}}$$

State space representation (LTI system)

$$\dot{x} = A \cdot x + B \cdot u \qquad y = C \cdot x + D \cdot u \qquad x = \begin{pmatrix} T_i \\ T_w \end{pmatrix} \qquad u = \begin{pmatrix} T_e \\ \dot{Q}_{heat} \\ \dot{Q}_{sol} \end{pmatrix}$$

$$A = \begin{bmatrix} -\frac{1}{C_i R_{wi}} & \frac{1}{C_i R_{wi}} \\ \frac{1}{C_w R_{wi}} & -\left(\frac{1}{C_w R_{wi}} + \frac{1}{C_w R_{we}}\right) \end{bmatrix} \qquad B = \begin{bmatrix} \frac{1}{C_i} & \frac{1}{C_i} & 0 \\ 0 & 0 & \frac{1}{C_w R_{we}} \end{bmatrix} \qquad C = [1 \quad 0] \qquad D = [0 \quad 0 \quad 0]$$

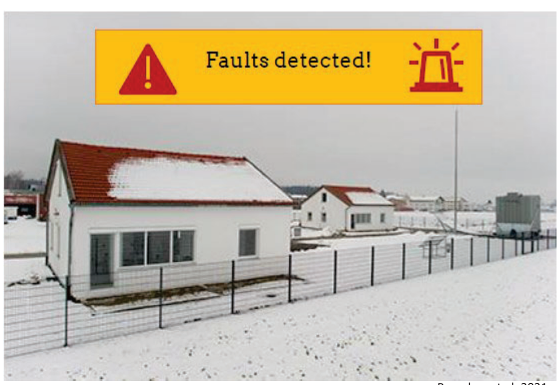
Use existing parameter identification tools (MATLAB)



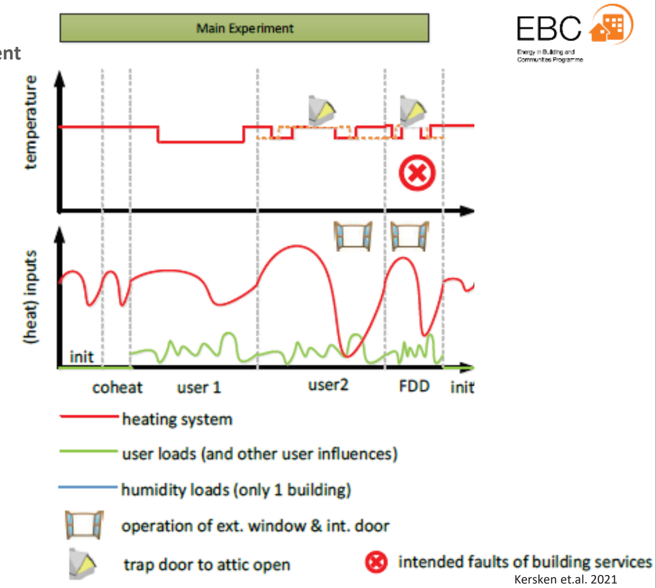
universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen

Thermal grey box models for FDD

see IEA EBC Annex 71 – Building energy performance assessment based on in-situ measurements



Reynders et.al. 2021



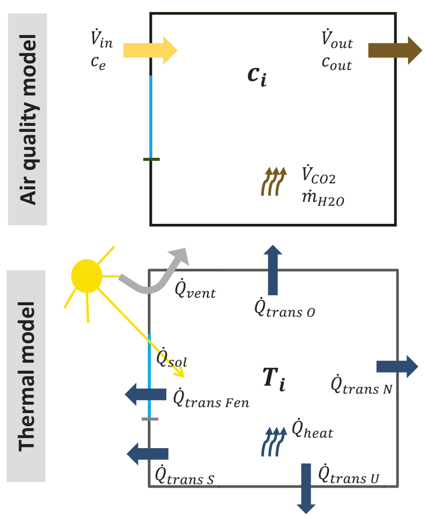
Kersken et.al. 2021

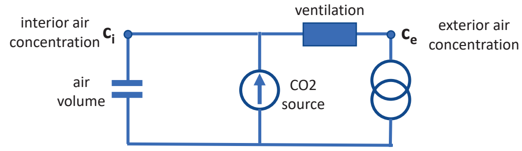
universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen

https://www.iea-ebc.org/projects/project?AnnexID=71

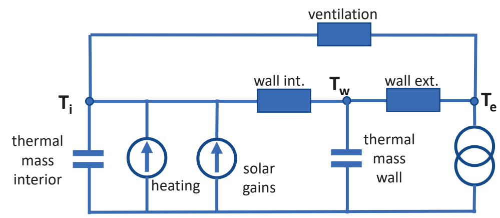
universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen

Idea: Combine thermal building model with air quality model





$$\frac{dc_i}{dt}V = \dot V_{CO2} + (c_e - c_i)\cdot \dot V$$



$$\frac{dT_i}{dt}C_i = \dot Q_{heat} + \dot Q_{sol} + \frac{(T_w - T_i)}{R_{wi}} + \dot V c_L (T_e - T_i)$$

$$\frac{dT_w}{dt}C_w = \frac{(T_i - T_w)}{R_{wi}} + \frac{(T_e - T_w)}{R_{we}}$$

make use of common data source (CO2 sensor)

detect anomalous air flows

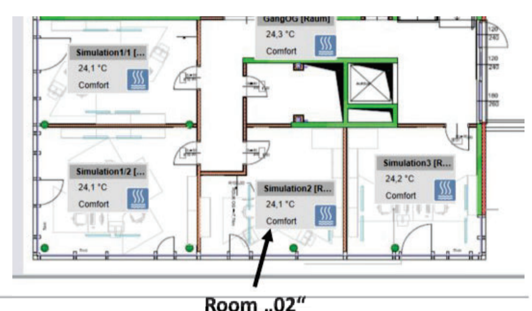
Challenge:
Not necessarily time invariant

universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen

Seite 7

Preliminary testing of this IEQ grey-box model for FD

Fault		Start	Duration
Temperature sensor faulty	Sensor outputs +2 K (artificial)	2022-12-01 11:15	60 hrs
CO_2 sensor faulty	Sensor outputs +200 ppm (artificial)	2022-02-24 11:15	60 hrs
Window left open	Window was left open unintentionally (real occurrence)	2022-09-29 7:40 2022-09-30 7:40	8 hrs 6 hrs

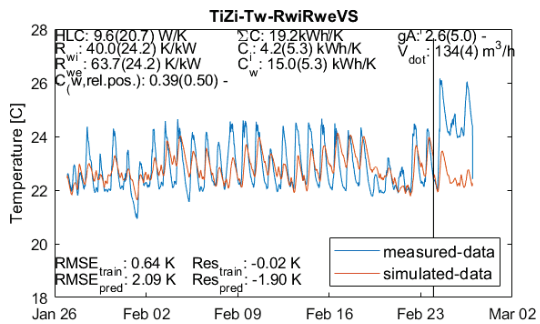


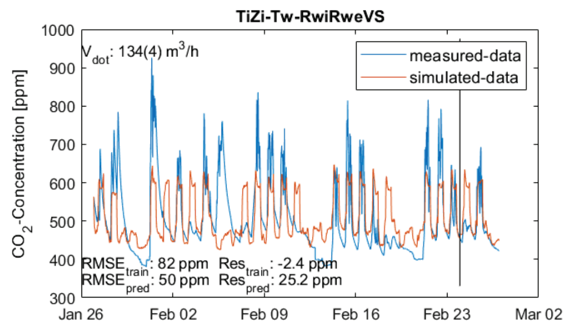
Can this model be used to detect „faults" (anomalies)?
How does it perform compared to other prediction models?

universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen

Seite 8

Testing this IEQ grey-box model for FD - preliminary results
T-sensor fault: +2K





Training Predicton

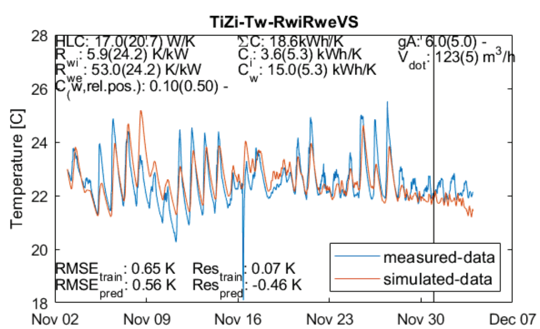
RMS_t << RMS_p

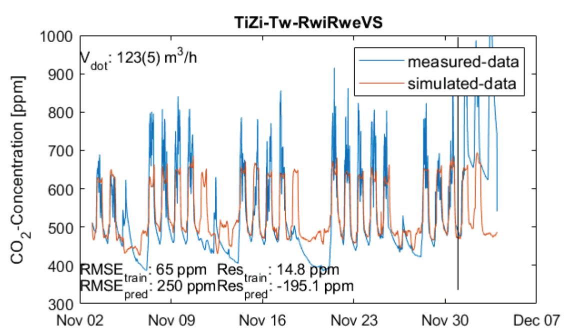
Training Predicton

RMS_t ~ RMS_p

Simulation error (RMS) depends on „how accuarte the occupancy was modelled"

Testing this IEQ grey-box model for FD - preliminary results
CO2-sensor fault: +200 ppm





Training Predicton

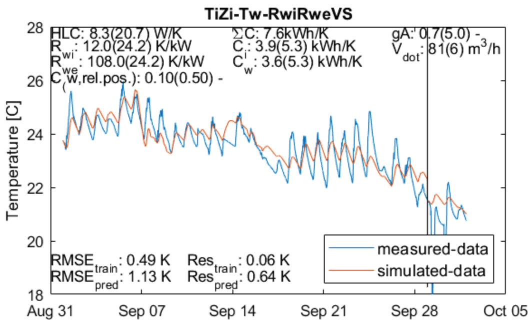
RMS_t ~ RMS_p

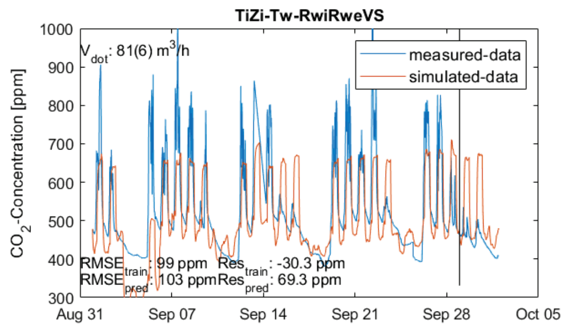
Training Predicton

RMS_t << RMS_p

RMS high because of inaccurate occupancy modelling

Testing this IEQ grey-box model for FD - preliminary results
Window open





Training Predicton

RMS_t << RMS_p

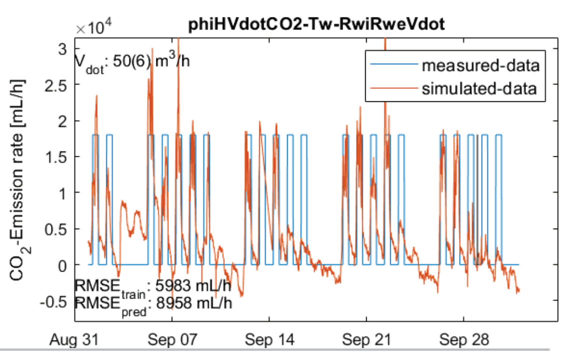
Training Predicton

RMS_t ~ RMS_p

RMS high because of inaccurate occupancy modelling

Summary

- Presented & tested idea on how therman grey box model can be extended to include CO2 conc.
- Operational data used to train a physics based model (parameters have physical meaning)
- Models can be used to predict T and CO2 when trying to detect anomalies
- Variations are possible: output energy use, emissionsrate, (i.e. occupancy)…
- Further work is needed:
  - test with more realistic faults
  - improve identification procedure
  - extend model with further variables (e.g. rH)
  - deal with time invariant volume flow



universität innsbruck
Arbeitsbereich für Energieeffizientes Bauen

TU WIEN TECHNISCHE UNIVERSITÄT WIEN

FH Salzburg Smart Building

FORSCHUNG Burgenland RESEARCH & INNOVATION

Austrian National Project

AFOM - Automatisierte Fehler & Optimierungsanalyse durch Messwerterfassung

Thank You!

Bundesministerium Verkehr, Innovation und Technologie

IEA FORSCHUNGS KOOPERATION

FFG Forschung wirkt.

www.uibk.ac.at/bauphysik

14

Building models in „different shades of grey“

White-Box — Grey-Box — Black-Box

White-Box

Physical parameters
material, geometry, construction,..

physics | Input data/BC (weather, …)

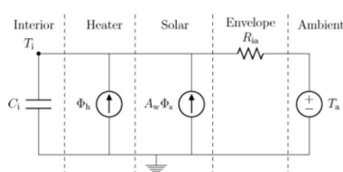
EnergyPlus
TRNSYS
IDAICE
Modellica
…

Predicts all states in any BC

Grey-Box

Training data
(e.g. temperature, heating)

physics simplified | Input data/BC (weather, …)



Predicts certain state(s) within limited BC

Black-Box

Training data
(e.g. temperatur or heating)

math | Input data/BC (weather, …)

Linear Regr.
ARX / ARMAX
ANN
SVM
Random forest
…

Predicts certain state(s) within BC strictly limited to training data

Physical parameter identification
Quality control of as-built condition

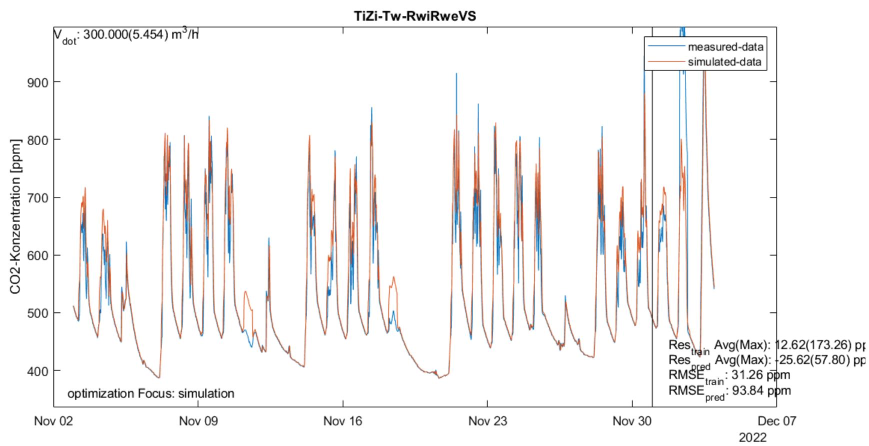
Building behaviour identification
Model predictive control, Fault detection and diagnosis

universität innsbruck Arbeitsbereich für Energieeffizientes Bauen

Accuray and use of such models was investigated in https://www.iea-ebc.org/projects/project?AnnexID=71

15

Model with adaptable volumeflow



DTU

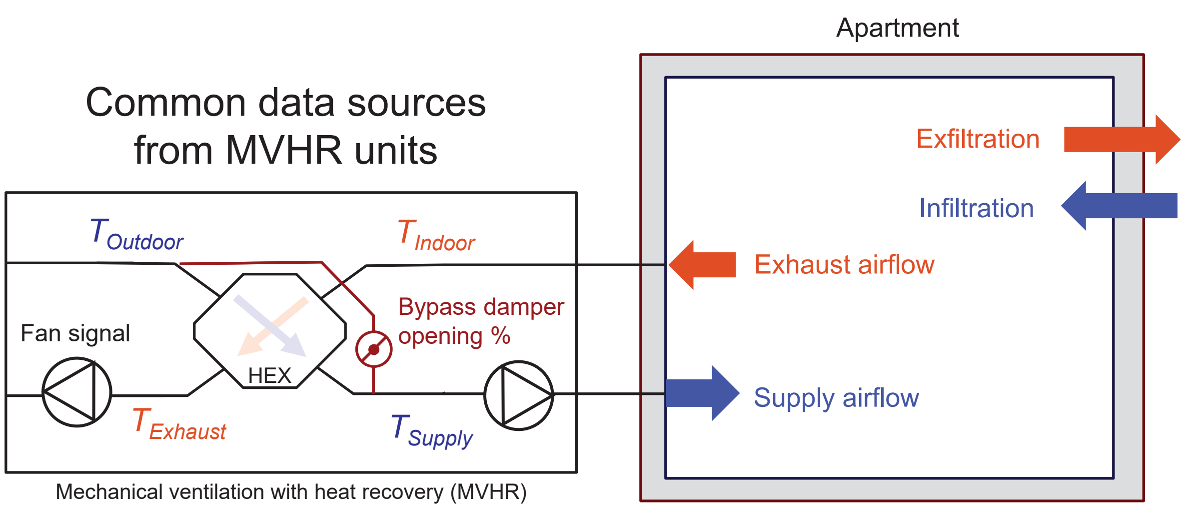
Evaluation of supply temperature set-points and airflow imbalance using smart ventilation data

3.10.2023
AIVC 2023 Conference Copenhagen
Topical Session - Real performance of (smart) residential ventilation – performance assurance, fault detection, continuous commissioning

Kevin M. Smith, Technical University of Denmark, kevs@dtu.dk
Jakub Kolarik, Technical University of Denmark

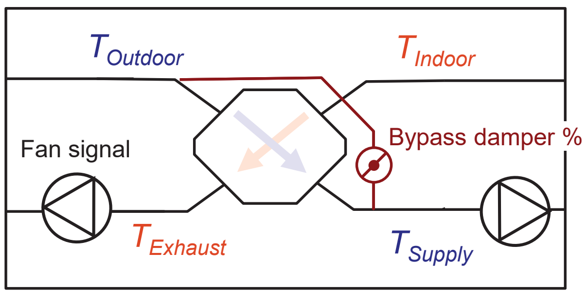
DTU

Common data sources from MVHR units



Mechanical ventilation with heat recovery (MVHR)

DTU

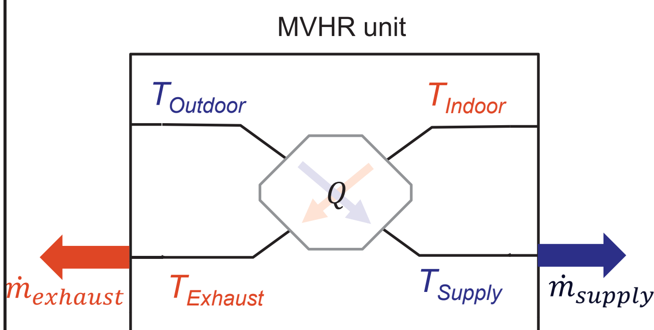


Hypothesis

We use this data to balance airflows and maximise heat recovery

DTU

Energy balance



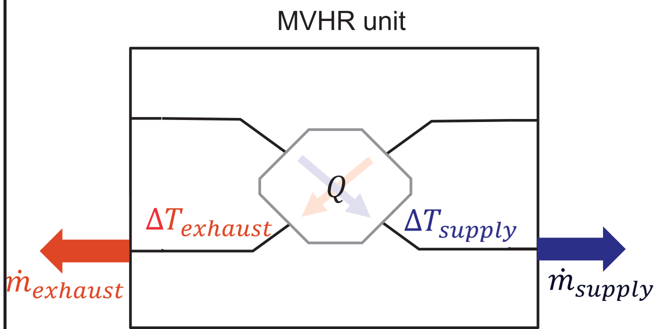
$$Q_{supply} = -Q_{exhaust}$$

$$Q_{supply} = \dot{m}_{supply}\, c_p \left(T_{supply} - T_{outdoor}\right)$$

$$-Q_{exhaust} = \dot{m}_{exhaust}\, c_p \left(T_{indoor} - T_{exhaust}\right)$$

DTU

Energy balance



$$Q_{supply} = -Q_{exhaust}$$

$$Q_{supply} = \dot{m}_{supply}\, c_p\, \Delta T_{supply}$$

$$-Q_{exhaust} = \dot{m}_{exhaust}\, c_p\, \Delta T_{exhaust}$$

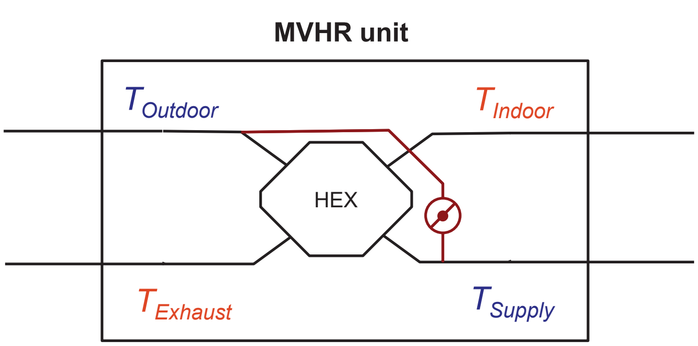
Since, $c_{p\,supply} \approx c_{p\,exhaust}$

$$\boldsymbol{Flow\ ratio, Fr} = \frac{\dot{m}_{supply}}{\dot{m}_{exhaust}} = \frac{\Delta T_{exhaust}}{\Delta T_{supply}}$$

DTU

Highest accuracy when…

$$\boldsymbol{Fr} = \frac{\dot{m}_{supply}}{\dot{m}_{exhaust}} = \frac{\Delta T_{exhaust}}{\Delta T_{supply}}$$



Cold weather

- Outdoor < 10°C

No bypass flow

- Damper position ≠ 0

Dry heat exchange

- Exhaust > Indoor dewpoint

DTU

Simple indicator for airflow balance

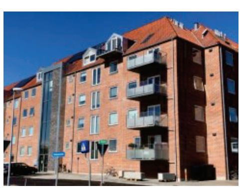
Flow ratio, $$Fr = \frac{\dot{m}_{supply}}{\dot{m}_{exhaust}} \approx \frac{\Delta T_{exhaust}}{\Delta T_{supply}}$$

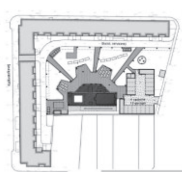
Balanced ventilation in cool climates targeting a slight underpressure

$$0.95 < Fr < 1.0$$

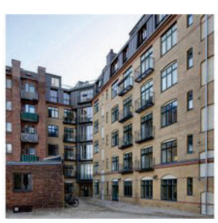
DTU

Exploration in two renovation case studies in Denmark





- ~100 public rental apartments
- Expected 50% heat savings

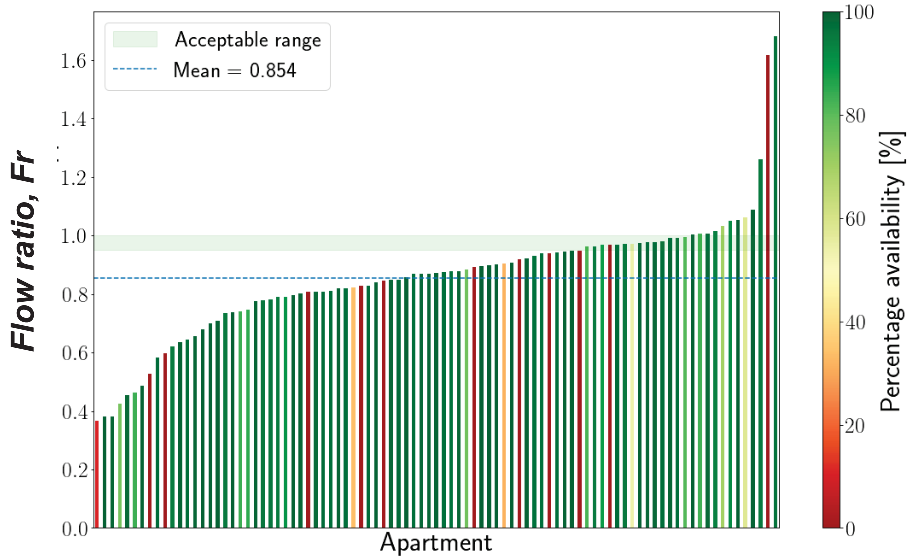


- 42 private rental apartments
- DGNB silver & DK Renovation Class 1

Internet-connected MVHR unit in each apartment

DTU

1st case study – Flow ratio in 100 apartments



DTU

2nd case study

- Observed poor initial comissioning of airflows in 42 apartment MVHR units

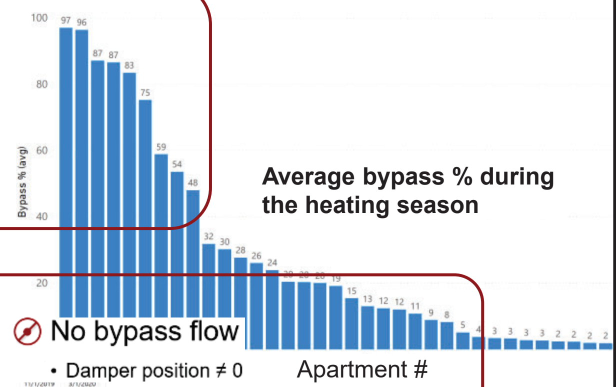
Rum	Luft-mængde [m3/h]	Støj dB	Fugt %	El W
Stue	70			
Køk.	-63			
Bad	-65			
Sove.	48			
Køk.	-52			
Bad	-65		41 %	
Stue	58			
Sove.	42			
Sove.	48			
Køk.	-63			
Bad	-45		49 %	50 W
Stue.	48			
Sove.	45			
Køk.	-68			
Bad	-74		40 %	55 W
Stue	58			
Sove.	58			
Køk.	-69			
Bad	-48		45 %	60 W
Stue	65			
Sove.	64			
Køk.	-74			
Bad	-96		41 %	
Sove.	74			
Sove2.	65			
Køk	-76			

- Re-commissioning didn't improve balance of airflows

2nd case study: 42 apartment MVHR units

First check the bypass operation

- Power BI dashboard indicated >50% average bypass in many units.
- In one stairwell: The supply-temperature sensor was not mounted in the duct.



Average bypass % during the heating season

- In the apartments with constant partial bypass of the heat exchanger: Need to set a higher supply temperature.

Estimated flow ratio, Fr

DTU

Balancing airflows by adjusting fan speeds

For a given fan, based on the fan affinity laws:

$$airflow \;\propto\; fan\ speed \;\propto\; fan\ signal$$

Adjust: $\left(\frac{\mathbf{0.95}}{\boldsymbol{Fr_{existing}}}\right)(fan\ signal)_{\boldsymbol{supply}}$ **OR** $\left(\frac{\boldsymbol{Fr_{existing}}}{\mathbf{0.95}}\right)(fan\ signal)_{\boldsymbol{exhaust}}$

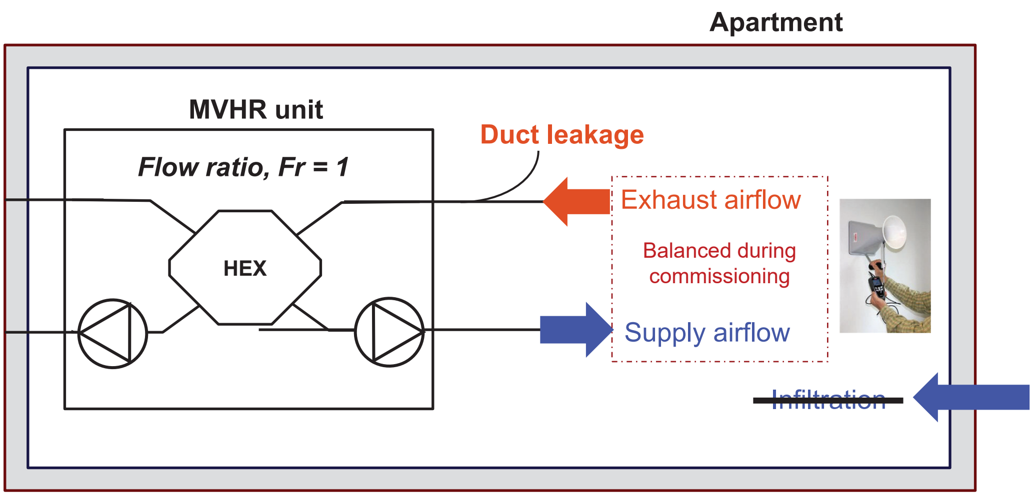
DTU

Results of the balancing method

Anonymised apartment	Balance (Fr) before	Balance (Fr) after scaling
C1	0.72	1
C5	0.79	0.95
C10	0.78	0.93
E0	0.78	0.97
E1	0.81	0.95
E2	0.7	1
E4	0.65	0.95
Average	**0.75**	**0.96**

DTU

Advantage: Accounts for duct leakage



DTU

Risks with automatic balancing

Closed diffuser

- Masking errors/faults (clogged ducts/valves, closed vents)
- Adjusting the wrong airflow.
  Which is the more correct airflow – supply or exhaust?

Conclusions

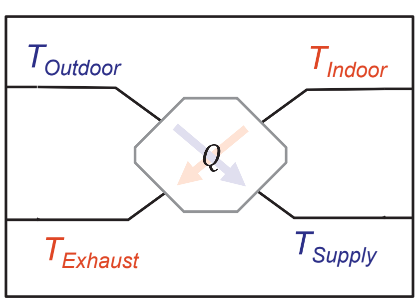
- Typical data from MVHR units can indicate faults and flow imbalances – rarely used in practice
- A scaling method could assist balancing of supply and exhaust – yet to be validated with real heating measurements
- Great care must be taken when automatically balancing to avoid exacerbating issues that demand physical repair

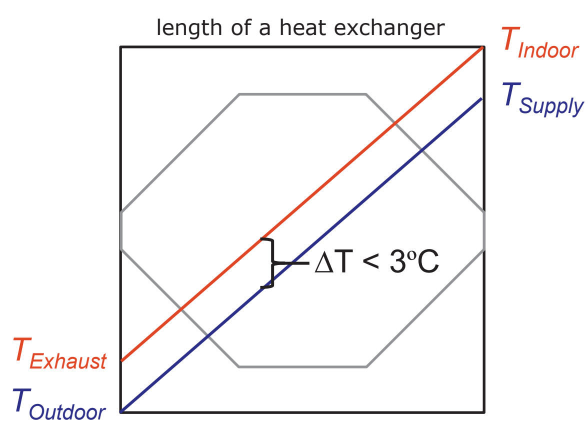
Future work

- Validation
- Clustering analysis
- Fault detection and automatic balancing

19

Temperatures along the length of a heat exchanger





$$1.00 < \rho_{outdoor}/\rho_{exhaust} < 1.02$$

20

DTU

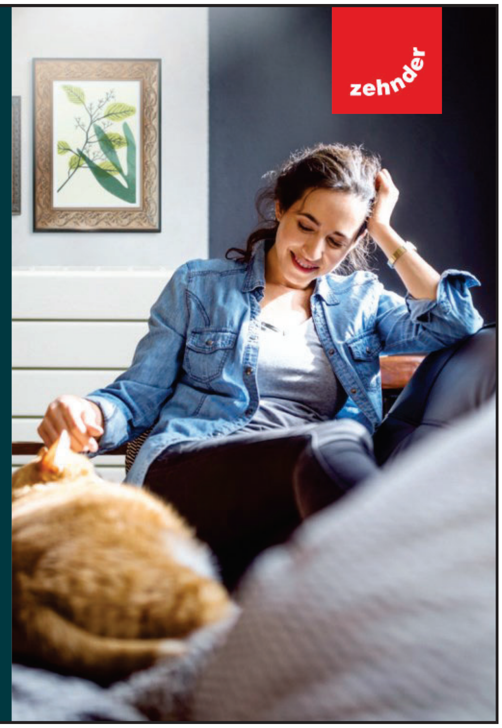
Results of data-driven balancing method

Anonymised apartment	Balance (Fr) before	Balance (Fr) after scaling
C1	0.72	1.00
C5	0.79	0.95
C10	0.78	0.93
E0	0.78	0.97
E1	0.81	0.95
E2	0.70	1.00
E4	0.65	0.95
Average	**0.75**	**0.96**

AIVC Conference 2023 in Copenhagen

Technologies in balanced ventilation systems to maintain optimal performance in energy and comfort

Bart Cremers
Knowledge Consultant Ventilation technologies



zehnder

Introduction

Observing installed base since 1980's vs. Monitoring performance of currently sold units

since 1980 | since 2015

Technologies since 2015:

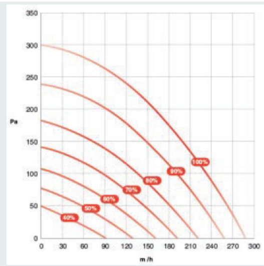
1. Automated fan speed adjustment during commissioning
2. Balance in mass flow rate rather than volume flow rate
3. Automated fan speed correction (FlowControl)
4. Comfort levels instead of values
5. Adaptive comfort technology
6. Modulating bypass technology
7. Season detection
8. Filter change warning

prolonged optimal performance in bringing fresh air, energy savings and comfort

1. Automated fan speed adjustment during commissioning

Commissioning before 2015

100 m³/h →



→ Return fan 42%

→ Supply fan 37%

manually by installer (or not?)

Commissioning after 2015

100 m³/h — automatically by commissioning wizard →

Return fan 42%

Supply fan 37%

2. Balance in mass flow rate rather than volume flow rate

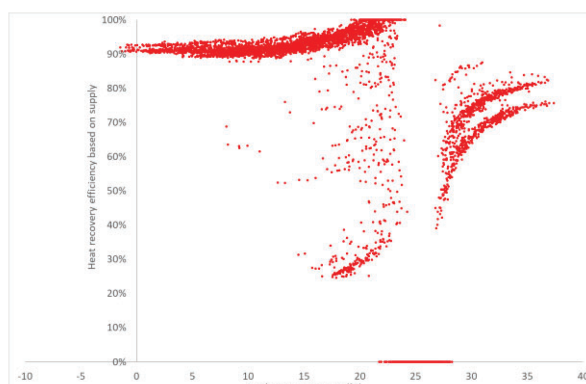
Commissioning before 2015:
During commissioning of existing units, air volumes are measured, that means that during the year the mass unbalance can easily be 8%(!), giving undesired variations in recovery efficiency

$$\frac{\dot{V}_{supply}}{\dot{V}_{extract}} = 1$$

Commissioning after 2015:

Commissioning is done with volume air flow (m³/h), but unit measures and balances internally in mass air flow (kg/s)

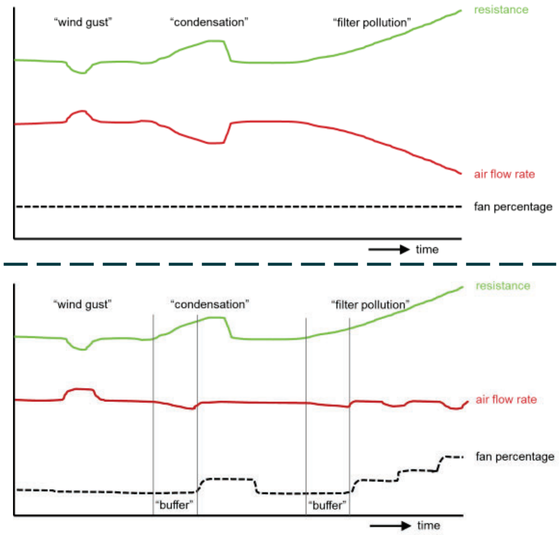
$$\frac{\dot{m}_{supply}}{\dot{m}_{extract}} = 1$$



3. Automated fan speed correction (Flow Control)

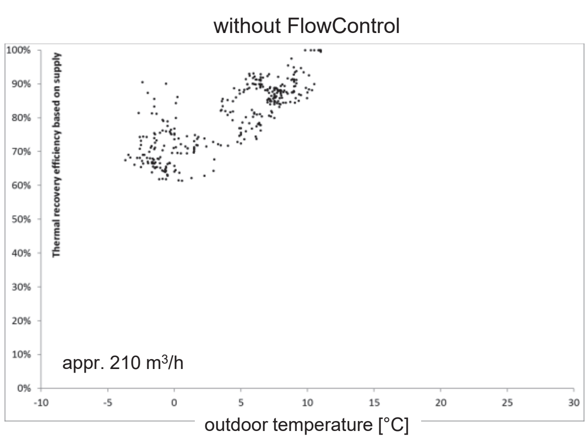
Flow rate behaviour before 2015

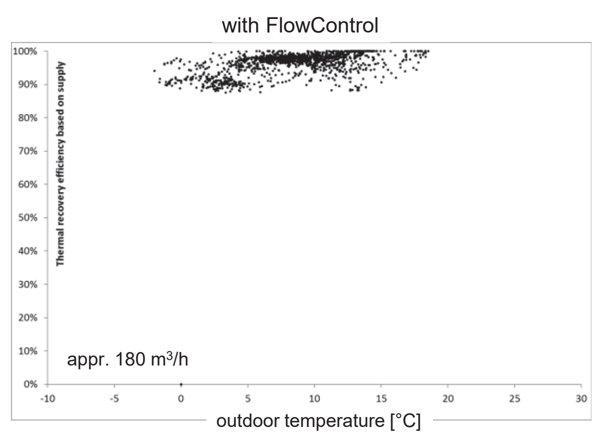
Flow control after 2015



always the best climate

3. Automated fan speed correction (Flow Control)





Cremers B.E. and Bakker T., Technologies to overcome effects of condensation in exchangers of ventilation units - analysis of monitored field studies, Proceedings of AIVC Conference 2017 in Nottingham, England

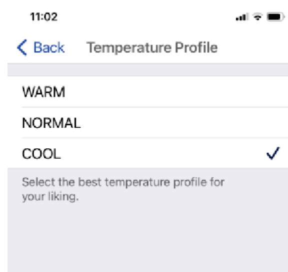
always the best climate

4. Comfort levels instead of values

Before 2015: The comfort temperature is set with a temperature value

20 °C?	*21 °C?*	*16 °C?*	*27 °C?*

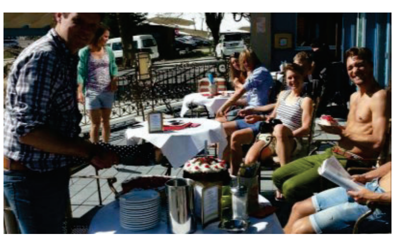
After 2015: The comfort is set with a comfort profile



always the best climate

5. Adaptive comfort technology

Fixed temperature leads to excessive cooling costs,
unhealthy indoor temperatures and discomfort during heat waves



≠

2 days ago	yesterday	today
11°C	10°C	15°C

≠

2 days ago	yesterday	today
19°C	19°C	15°C

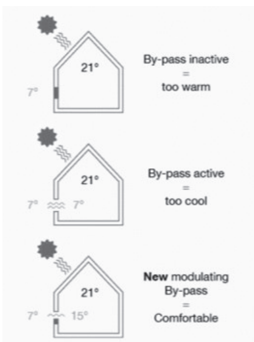
Today people feel warm

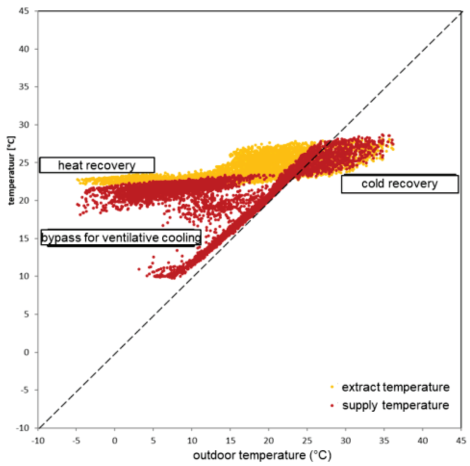
Today people feel chilly

always the best climate

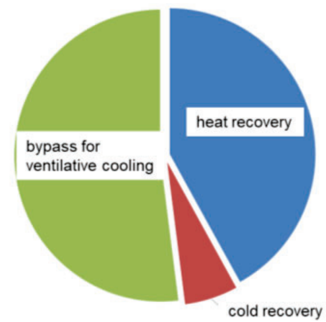
6. Modulating bypass technology

Modulating by-pass

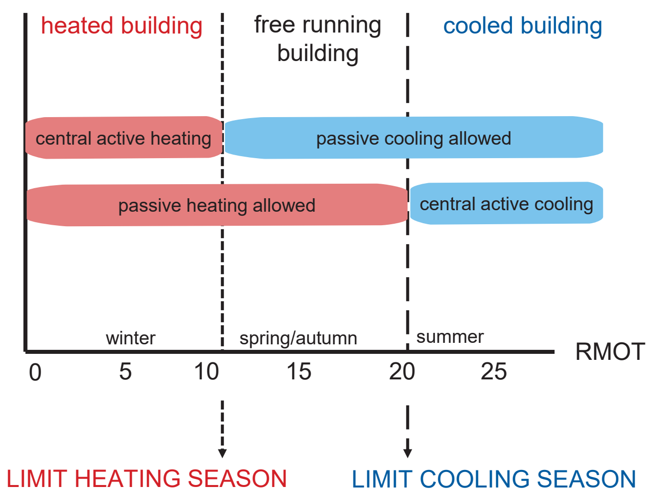




Distribution of hours in one year



7. Season detection

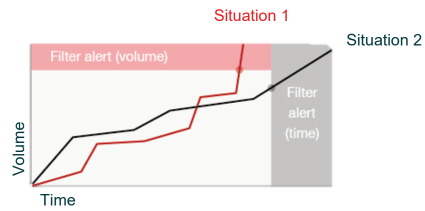


Filter

Filter change warning before 2015 based on time only

Filter change warning after 2015 based on time and flow rate

1. Warning signal after half a year
2. Warning signal after amount of m^3 has passed the filter
3. Warning signal when fan speed is much higher than before (resistance guard)
4. Warning signal when fan speed has exceed a limit (noise guard)



always the best climate

Summary

Technologies since 2015:

1. Automated fan speed adjustment during commissioning
2. Balance in mass flow rate rather than volume flow rate
3. Automated fan speed correction (FlowControl)
4. Comfort levels instead of values
5. Adaptive comfort technology
6. Modulating bypass technology
7. Season detection
8. Filter change warning

prolonged optimal performance in bringing fresh air, energy savings and comfort

always the best climate

PLEIAQ

Topical Session - Building and ductwork airtightness regulations in various countries

AIVC 2023 CONFERENCE COPENHAGEN

4TH OCTOBER 2023

PLEIAQ

NOLWENN HUREL

VIP series on Building & Ductwork Airtightness

Series of Ventilation Information Papers (VIP) published by the AIVC

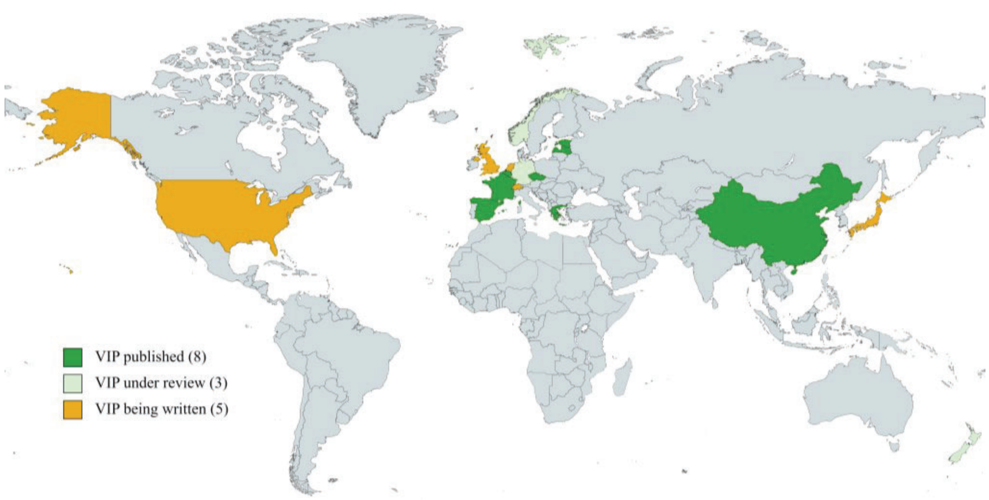
- *"Building and ductwork airtightness - National trends and requirements"*
- Template prepared: **similar structure** for all papers
- Authors found in various countries via the TightVent Airtightness Associations Committee (**TAAC**) and the **AIVC** board members
- Already **8 published papers** (on the AIVC website: https://www.aivc.org/collection-keys/vip)
  - Estonia (VIP 45.1)
  - Spain (VIP 45.2)
  - Czech Republic (VIP 45.3)
  - Belgium (VIP 45.4)
  - Latvia (VIP 45.5)
  - France (VIP 45.6)
  - Greece (VIP 45.7)
  - China (VIP 45.8)

VIP content

For both BUILDING and DUCTWORK airtightness, it details :

- **national requirements and drivers**: airtightness indicator, requirements in the regulation, energy programs, airtightness justifications, sanctions, etc.;
- if it is included in the **energy calculations** and how;
- the **airtightness test protocol**: qualification for the testers, guidelines, requirements on measuring devices;
- **tests performed**: tested buildings/ductworks, database, evolution with time;
- **guidelines** to build airtight buildings/ductworks.

More publications expected (around 16 countries)



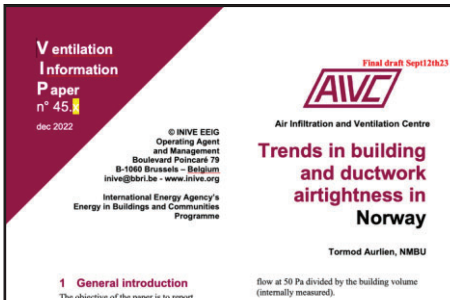
Topical session program:

Building and ductwork airtightness - National trends and requirements in:

- **Norway –** Tormod Aurlien (NMBU) **12’ (+5’ for questions)**
- **The Netherlands –** Niek-Jan Bink (ACIN) **12’ (+5’)**
- **Spain –** Irene Poza Casado (University of Valladolid) **12’ (+5’)**
- **Latvia –** Andrejs Nitiievskis (IRBEST) **12’ (+5’)**

Air tightness and its impact on energy consumption in multi-family residential buildings in Montenegro - Esad Tombarević (University of Montenegro) **5’ (+5’)**

Oct. 3rd 23 TA/-


V entilation
I nformation
P aper
n° 45.
dec 2022

© INIVE EEIG
Operating Agent and Management
Boulevard Poincaré 79
B-1060 Brussels – Belgium
inive@bbri.be - www.inive.org

International Energy Agency's Energy in Buildings and Communities Programme

Final draft Sept12th23

AIVC
Air Infiltration and Ventilation Centre

Trends in building and ductwork airtightness in Norway

Tormod Aurlien, NMBU

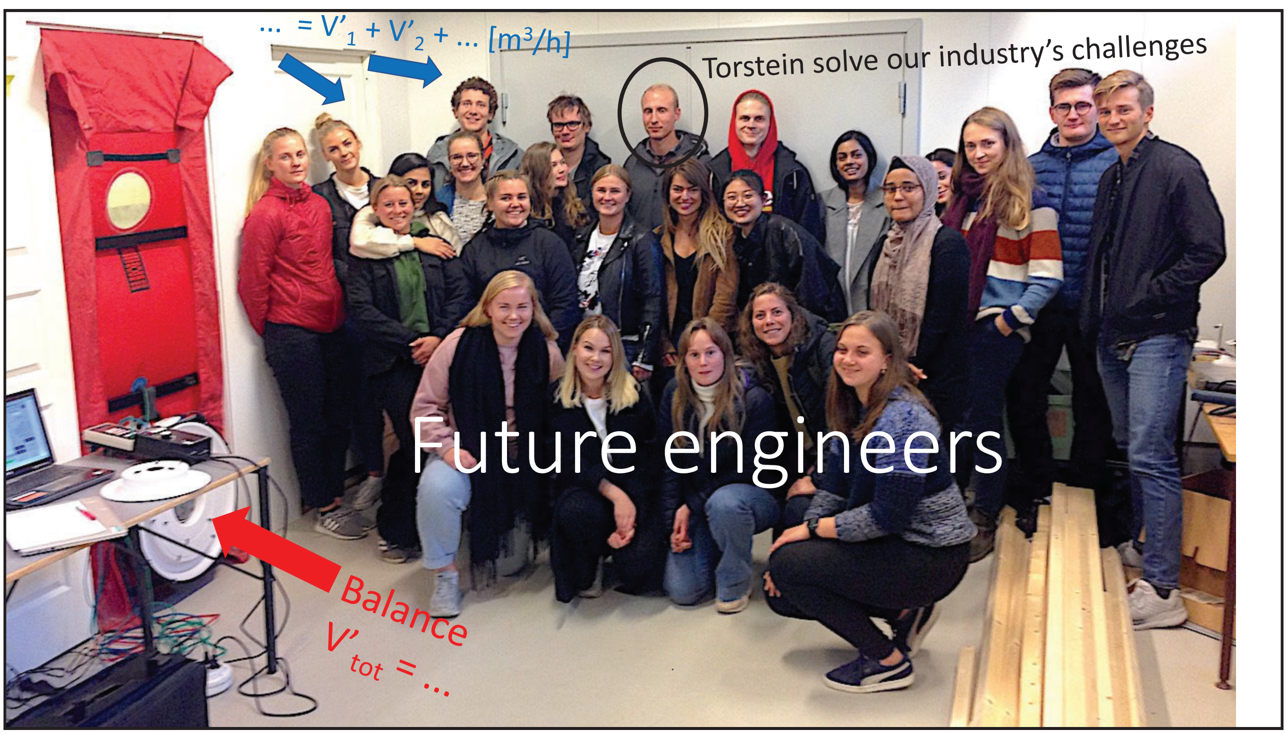
1 General introduction

flow at 50 Pa divided by the building volume (internally measured).

Building and ductwork airtightness - National trends and requirements in:

- Norway – Tormod.Aurlien@nmbu.no

1



2


V entilation
I nformation
P aper
n° 45.
dec 2022

© INIVE EEIG
Operating Agent
and Management
Boulevard Poincaré 79
B-1060 Brussels – Belgium
inive@bbri.be - www.inive.org

International Energy Agency's
Energy in Buildings and Communities
Programme

Final draft Sept12th23

AIVC

Air Infiltration and Ventilation Centre

Trends in building and ductwork airtightness in Norway

Tormod Aurlien, NMBU

1 General introduction

flow at 50 Pa divided by the building volume (internally measured).

Indicators and requirements

- Norway, being a cold and windy nation, required **wind barriers** in constructions (as part of regulations from the 1920s)
- Indicator: leakage number $n_{50} = V'_{50} / V$ (and when the volume is large, n_{50} becomes small)

Regulations

- for detached houses, gradually in steps from $n_{50} \leq 4$ /h to $n_{50} \leq 0.6$ /h (10 years back)
- $n_{50} \leq 0.6$ /h for all dwellings, if simplified documentation (= "passive-house"-level !)
- all buildings must have airtightness $n_{50} \leq 1.5$ /h (unchanged since 1980 for larger buildings)
- extensive refurbishment of existing buildings is an important green challenge

3

Drivers, justifications and sanctions

- We have had low-energy and passive-house labelling
- (the difference from minimum requirements for ordinary new buildings is often not large)
- EU taxonomy, and BREEAM compliance
  "…air tightness measurement and thermography that are needed to prove a significant contribution to stopping climate change…"
- "**All** new buildings shall be tested"
  (Less than 100% is probably measured in practice..?)
- The penalty of not fulfilling documented airtightness requirements is that no *use permit* should be granted (in theory)

4

EP-calculation

- $n_{inf} = n_{50} * 0{,}07$ [ach/h] ($V'_{inf} = n_{inf} * V$ [m^3/h] …)

  ↖ James Bond-number ☺
- more nuanced when making energy *budget*
- Wind-speed etc is not part of calculation according to our national EPC Standard (NS3031)
- *n_{50} requirement levels* are used as default input to the EP-calculation
- EP-calculation is performed long before actual building, and measuring..!
- and costly repairing..?

Protocol, Qualification and Equipment

- Tests and protocol often comply with ISO 9972,
  not always (but then then for good reasons :)
- No official Norwegian qualification scheme
- ⇠ Simplified methods: depressurization at Flow 1, 2 and 3 (and corresponding Δp_1, Δp_2, and Δp_3)
- ↖ Discover leaks in wind barrier, in *early windtight stage*: easy to repair !

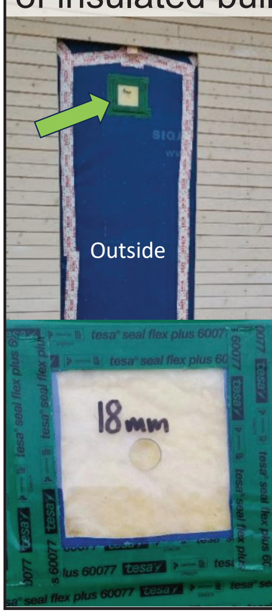
Concluding remarks

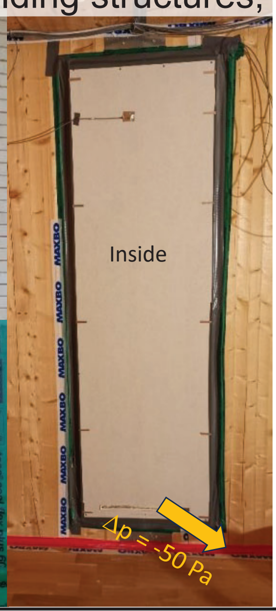
- Builders avoid measuring single flats, and instead measure the whole building, with all doors to the stairway open ☹
  (A large volume gives a large number below the fractional line, and a "nice" n_{50}-value)
- The air tightness quality may be very unevenly distributed, and (systematic) errors should not be camouflaged!
- *Internal* building air leakages should also receive increased focus.
  - Important factors when trying to control unnecessary energy misuse and reduced thermal comfort from wind and thermal stack effects
  - Internal airtightness reduces spread of infection, smell, fire gases, noise etc.
- Normalising on external surface area has some advantages (Swedish approach)
- Have we lost our Norwegian airtightness momentum..?

7

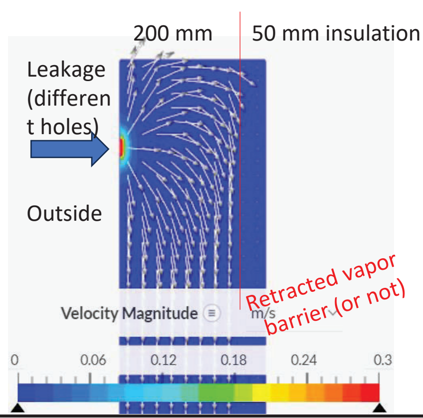
Torstein Hagen:
Locating air leakages in wind barriers by thermography of insulated building structures, NMBU, Ås, 2022

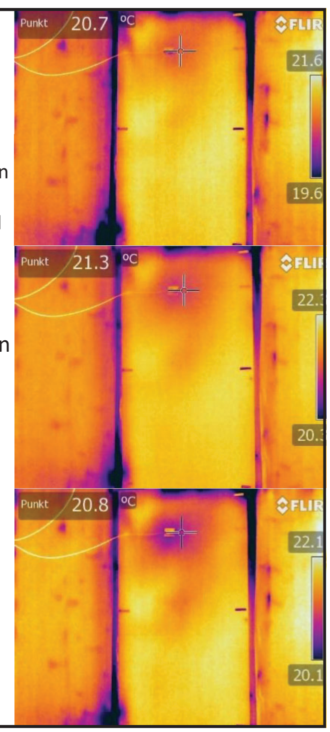
Extract from Master thesis (in Norwegian)





It takes very long time with Δp = -50Pa before an outside hole is detectable by the camera on the inside, especially with the vapour barrier placed in this way.
Depressurisation in *early windtight stage*, is a better strategy to ensure airtight wind barrier.

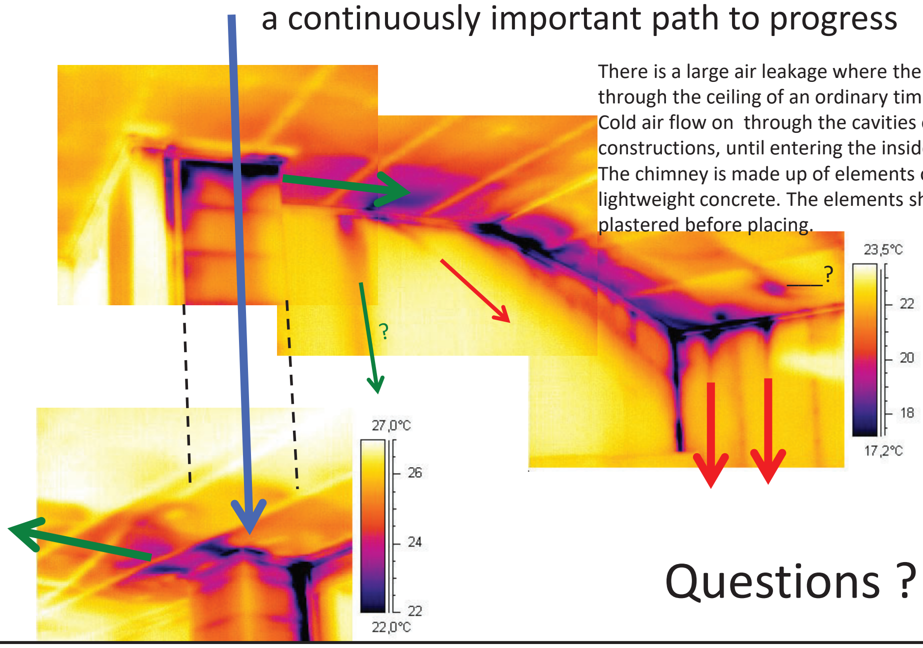




8

Locating and analyzing flow path

a continuously important path to progress



There is a large air leakage where the chimney passes through the ceiling of an ordinary timber frame house. Cold air flow on through the cavities of the constructions, until entering the inside.
The chimney is made up of elements of very porous lightweight concrete. The elements should have been plastered before placing.

Questions ?

3 Ductwork airtightness

Air tightness of ventilation ducts is probably not an important topic in Norway, the way we build: We use spiro ducts with gaskets and the duct system is usually within the heat-insulated building construction. Small leakages may more be a topic related to internal vent adjustment and to a very small degree influencing energy or air quality.

Building and ductwork airtightness in the Netherlands: national trends and requirements

Niek-Jan Bink, Rob Dam, and Marcus Lightfoot

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

1

Contents

1. Legislation
2. Building airtightness in the Netherlands
3. Duct airtightness in the Netherlands

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

2

Legislation

3

The Dutch Building Code 2012

contains regulations on building structures in the areas of safety, health, usability, energy efficiency and the environment.

The Building Code sets minimum requirements for newly built structures and for existing structures when they are rebuilt.

4

Building Works Environment Decree

The Building Decree 2012 becomes the Building Works Environment Decree (Bbl). With the introduction of the Environment Act expected on January 1, 2024, the current Building Decree 2012 will expire and the technical building regulations will be included in the Building Works Environment Decree, or Bbl for short.

Tools to meet Building Code regulations

To comply with the requirements of the 2012 Building Code, you can use:

- **NEN standards**.
- Recognized quality declarations.
- Equivalent solutions.
- Dutch practice guidelines (NPRs).
- **Dutch Technical Agreements (NTAs).**

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings
retrotec
ubbink
ACIN instrumenten

NEN standards

NEN standards are Dutch agreements that market parties make among themselves on a voluntary basis concerning the quality and safety of their products, services and processes.

As a neutral body, NEN makes an inventory of which standards (including NEN standards) are needed.

NEN standards are generally applicable standards, they are not generally binding regulations and therefore need not be published.

NEN-EN: 1:1 copy of European standard

7

NTA

NTAs are guidelines that deal with the practical elaboration of a standard from the Buildings Decree.

NTA 8800:2023 is the method for determining the energy performance of buildings, which can be used, among other things, to demonstrate compliance with BENG requirements. The intention is to designate NTA 8800:2023 in the building regulations as of July 1, 2023. NTA 8800 is freely available.

8

Building Quality Assurance Act (Wkb)

The Wkb, aiming at enhancing construction quality and transparency was originally accepted by the Senate in May 2019. Implementation was postponed to July 1, 2023, and then again to January 1, 2024 for new constructions and July 1, 2024 for renovations.

The law's impact remains a topic of discussion, particularly concerning private quality assurance and construction liability.

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

retrotec
ubbink
ACIN instrumenten

9

Building Quality Assurance Act (Wkb)

Key features include:

- The introduction of Private Quality Assurance.
  This law shifts the responsibility for supervising the quality of construction works from the municipality to private quality assurance companies.
- Strengthening the position of the building consumer.
  Builders become more clearly responsible for the quality of their construction works as a result of the law. Upon delivery, the builder must demonstrate that construction has been carried out in accordance with building regulations
- Lower regulatory burden on municipalities.
  As supervision shifts to private parties, the municipality will be primarily concerned with the supervision of spatial planning and less with the technical aspects of construction.
- Amendment in the Civil Code:
  clarifying the contractor's liability for hidden defects.

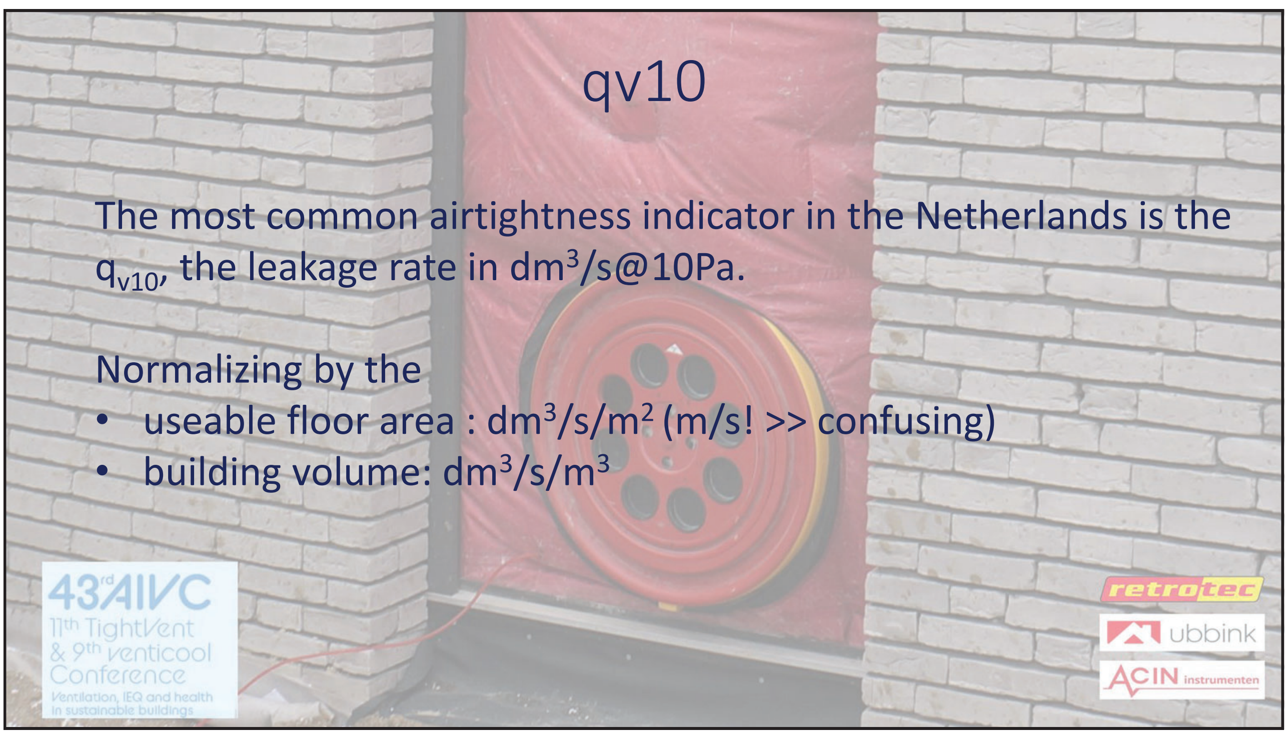
43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

retrotec
ubbink
ACIN instrumenten

10


Building Airtightness in the Netherlands
43rd AIVC
11th TightVent
& 9th venticool
Conference
Ventilation, IEQ and health
in sustainable buildings
retrotec
ubbink
ACIN instrumenten

11


qv10
The most common airtightness indicator in the Netherlands is the q_{v10}, the leakage rate in dm^3/s@10Pa.
Normalizing by the
• useable floor area : $dm^3/s/m^2$ (m/s! >> confusing)
• building volume: $dm^3/s/m^3$
43rd AIVC
11th TightVent
& 9th venticool
Conference
Ventilation, IEQ and health
in sustainable buildings
retrotec
ubbink
ACIN instrumenten

12

Airtightness requirements

The Building Decree demands based on building volume

< 500 m^3 : q_{v10} = 0.2m^3/s (200 l/s) as q_{v10} value

> 500 m^3 : q_{v10} kar = q_{v10} (500/Vb)

The q_{v10} should be measured as per the NEN 2686 standard (which mainly follows the ISO-9972)

13

< 500 m^3 : q_{v10} = 0.2m^3/s (200 l/s) as q_{v10} value

> 500 m^3 : q_{v10} kar = q_{v10} * (500/Vb)

V (m3)	qv (m3/s)	ACH	qv10,kar (m3/s)
200	0,2	3,6	0,2
500	0,2	1,4	0,2
2000	0,8	1,4	0,2

0,8*500/2000

14

NTA8800 Energy Performance of Buildings

- NTA8800 is the Dutch method for determining the energy performance of buildings, to demonstrate compliance with the BENG requirements.
- Building airtightness: either NEN-2686 or calculation

15

NTA8800 Energy Performance of Buildings

- This leakage rate as per this construction law is not considered stringent, but is considered as a minimum baseline.
- The EPC calculation per building (as per NTA8800) is generally stricter and hence it is common that leakage rates of <0.6l/s q_{v10} are used for the calculations.

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings
retrotec
ubbink
ACIN instrumenten

16

NTA8800 Energy Performance of Buildings

In the NTA8800 [3] (used for the EPC calculation) there is a specific reference to a correction factor (as part of a formula) for the leakage rate based on the year of construction:

The formula used is $q_{v10}ref = \mathit{f}type \times \mathit{fy} \times q_{v10}calc$ where *f*type is a correction factor for the building type and *fy* is the correction factor for the age of the building.

17

Year of construction/renovation	Correction factor fy
<1970	3,0
1970 - <1980	2,5
1980 - <1990	2,0
1990 - <2000	1,5
2000 - < 2010	1,0
>2010	0,7

18

Building Airtightness

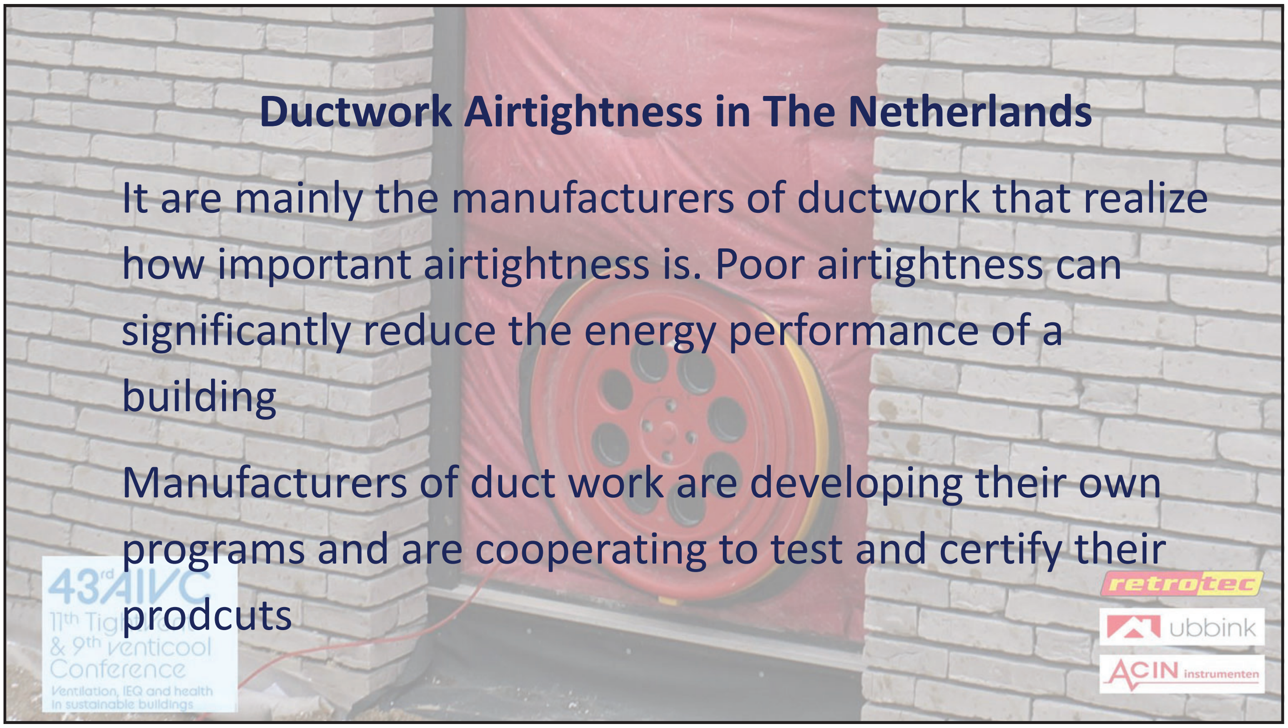
- The only actual requirement is for buildings to comply to the building code, and for the tests to be performed as per the relevant standard.
- no mandatory qualification scheme for airtightness testers.
- Local initiatives have been started with some of them well on their way.
- At the moment building airtightness testing is not considered as a regulated profession

19

Duct Airtightness

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings
retrotec
ubbink
ACIN instrumenten

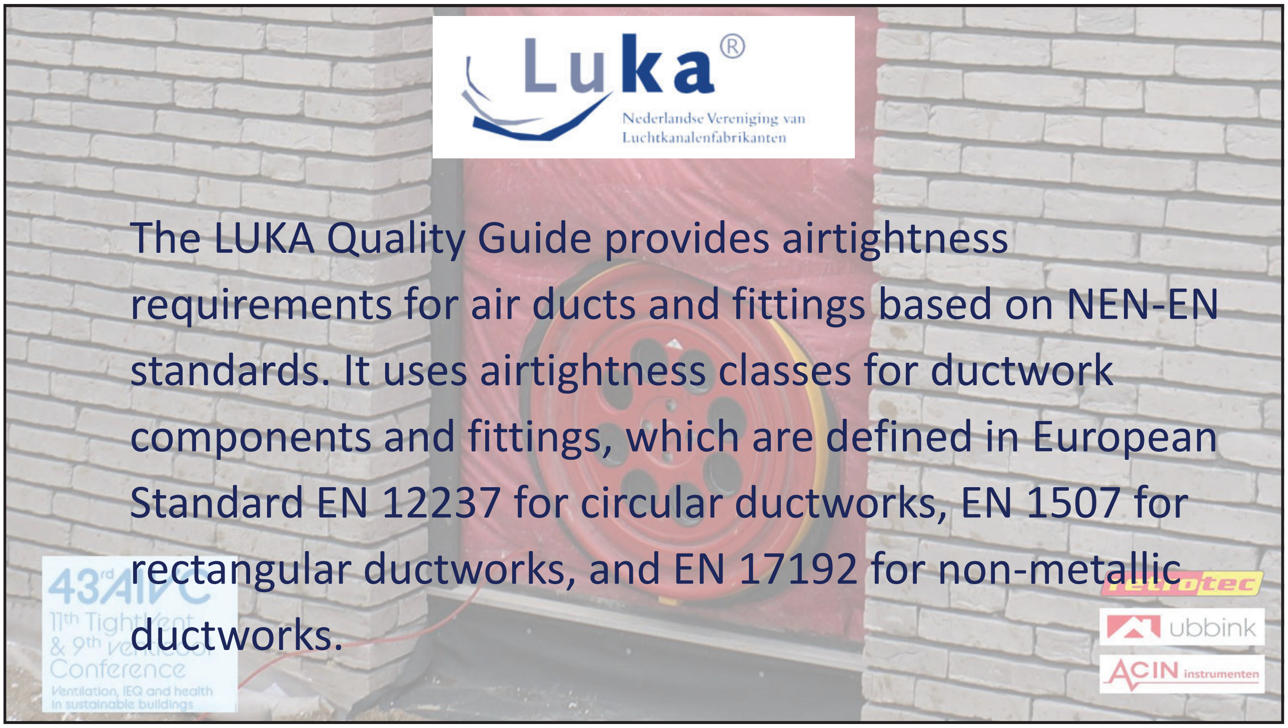
20


Ductwork Airtightness in The Netherlands
It are mainly the manufacturers of ductwork that realize how important airtightness is. Poor airtightness can significantly reduce the energy performance of a building
Manufacturers of duct work are developing their own programs and are cooperating to test and certify their prodcuts
43rd AIVC
& 9th venticool
Conference
Ventilation, IEQ and health in sustainable buildings
retrotec
ubbink
ACIN instrumenten

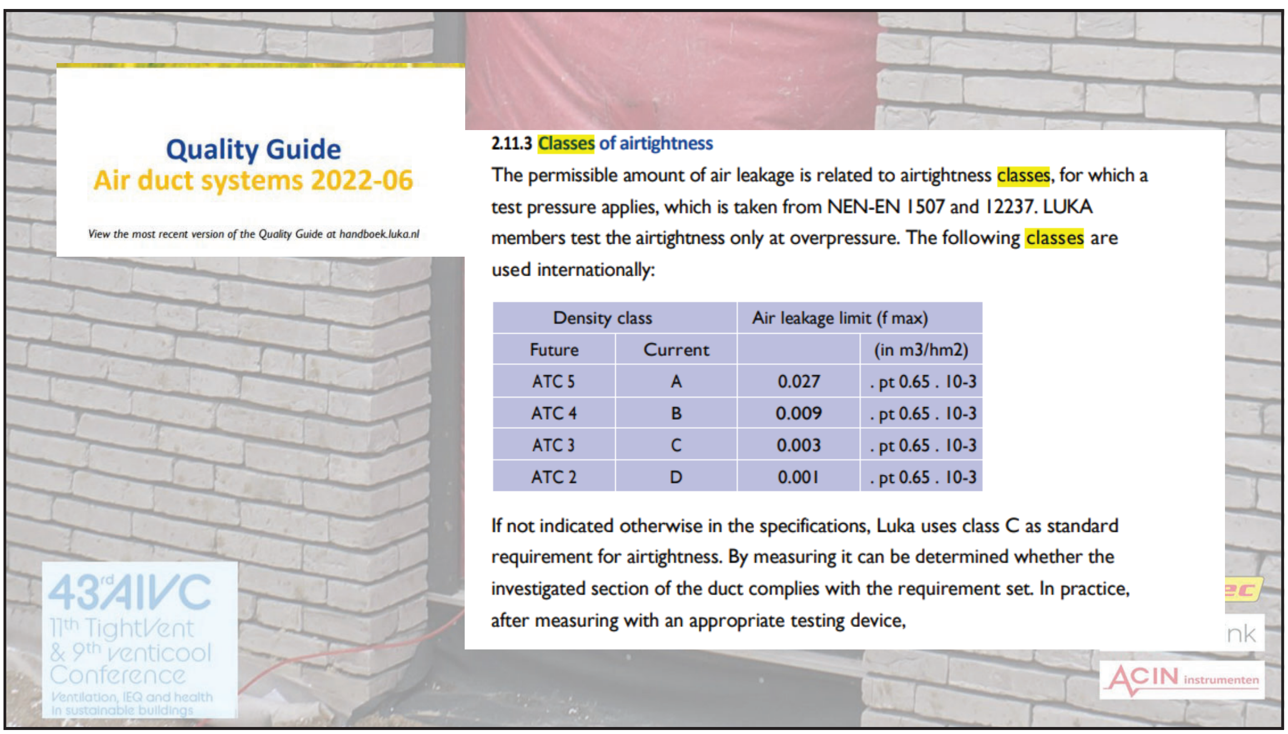
21


No specific regulation in the Netherlands that directly addresses ductwork airtightness, there are several NEN standards
The NTA8800 regulation, which came into force in 2021, focuses on the energy performance of buildings
43rd AIVC
11th TightVent
& 9th venticool
Conference
Ventilation, IEQ and health in sustainable buildings
retrotec
ubbink
ACIN instrumenten

22



23



Quality Guide
Air duct systems 2022-06

View the most recent version of the Quality Guide at handboek.luka.nl

2.11.3 Classes of airtightness

The permissible amount of air leakage is related to airtightness classes, for which a test pressure applies, which is taken from NEN-EN 1507 and 12237. LUKA members test the airtightness only at overpressure. The following classes are used internationally:

Density class		Air leakage limit (f max)	
Future	Current		(in m3/hm2)
ATC 5	A	0.027	. pt 0.65 . 10-3
ATC 4	B	0.009	. pt 0.65 . 10-3
ATC 3	C	0.003	. pt 0.65 . 10-3
ATC 2	D	0.001	. pt 0.65 . 10-3

If not indicated otherwise in the specifications, Luka uses class C as standard requirement for airtightness. By measuring it can be determined whether the investigated section of the duct complies with the requirement set. In practice, after measuring with an appropriate testing device,

24

NTA8800 Energy Performance of Buildings

Focus is on thermal loss, not fan energy use or sound production

Impact of ductwork leakage on the fan energy use and sound production of central mechanical ventilation units in houses

Valérie Leprince[1*], Marcus Lightfoot[2], Jelmer de Jong[3]

1 PLEIAQ
84 C Av de la Libération
69330 Meyzieu, France
**Corresponding author: valerie.leprince@pleiaq.net*

2 Ubbink - Centrotherm
Verhuellweg 9
6984 AA Doesburg, the Netherlands

3 Brink Climate Systems
Wethouder Wassebaliestraat 8
7951SN Staphorst, the Netherlands

25

To validate the airtightness value of ducts, the LUKA handbook recommends:

- Systematic Testing: testing the whole system (advisable)
- Sampling: specific sections of the ductwork can be tested focusing on complex areas like joins or points where the duct changes direction.
- visual inspections.
- in some circumstances, testing might only be undertaken if mandated by the building owners or another responsible entity.

26

LUKA ensures the quality control of ductwork airtightness through a combination of internal policies, adherence to international standards, regular inspections by TÜV Rheinland Nederland B.V., and the provision of training and skill development opportunities for staff.

TÜVRheinland®
Precisely Right.

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

retrotec
ubbink
ACIN instrumenten

27

- The LUKA Quality Guide sets forth airtightness requirements for air ducts and fittings based on NEN-EN standards.
- The Netherlands does not have specific energy programs or subsidies directly targeting ductwork airtightness. It only is indirectly addressed via energy performance regulations and building codes.
- The LUKA handbook has established protocols for checking and ensuring the airtightness of ducts and takes action against non-compliant members.

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

retrotec
ubbink
ACIN instrumenten

28

Duct Airtightness in the Netherlands

- The only actual requirement is for buildings to comply to the building code, and for the tests to be performed as per the relevant standard.
- Residential duct airtightness testing does not exist
- All initiatives come from duct manufacturers

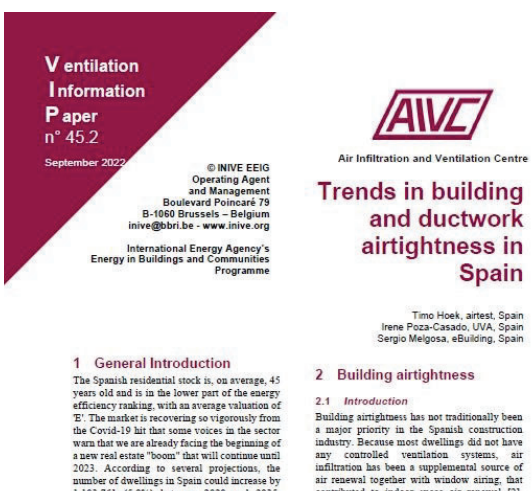
BUILDING AND DUCTWORK AIRTIGHTNESS IN SPAIN

NATIONAL TRENDS AND REQUIREMENTS

Irene Poza Casado, Universidad de Valladolid

43rd AIVC -11th TightVent & 9th venticool Conference: *Ventilation, IEQ and health in sustainable buildings*
October 4-5, 2023 Aalborg University, Copenhagen, Denmark

UVa



Ventilation Information Paper n° 45.2

September 2022

© INIVE EEIG
Operating Agent
and Management
Boulevard Poincaré 79
B-1060 Brussels – Belgium
inive@bbri.be - www.inive.org

International Energy Agency's
Energy in Buildings and Communities
Programme

Air Infiltration and Ventilation Centre

Trends in building and ductwork airtightness in Spain

Timo Hoek, airtest, Spain
Irene Poza-Casado, UVA, Spain
Sergio Melgosa, eBuilding, Spain

1 General Introduction

The Spanish residential stock is, on average, 45 years old and is in the lower part of the energy efficiency ranking, with an average valuation of 'E'. The market is recovering so vigorously from the Covid-19 hit that some voices in the sector warn that we are already facing the beginning of a new real estate "boom" that will continue until 2023. According to several projections, the number of dwellings in Spain could increase by 1.103.761 (5.9%) between 2020 and 2035.

2 Building airtightness

2.1 Introduction

Building airtightness has not traditionally been a major priority in the Spanish construction industry. Because most dwellings did not have any controlled ventilation systems, air infiltration has been a supplemental source of air renewal together with window airing, that contributed to indoor space air renewal [2].

VIP 45.2: Trends in building and ductwork airtightness in Spain

https://www.aivc.org/resource/vip-452-trends-building-and-ductwork-airtightness-spain

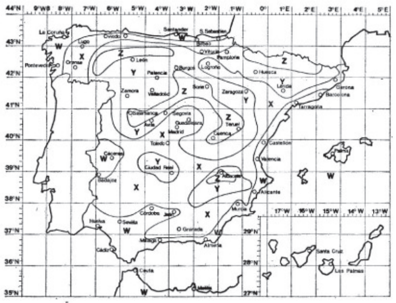
Structure

- Context
- Building airtightness requirements
  - Window airtightness
  - Envelope airtightness
    - Building airtightness justification
- Ductwork airtightness requirements
- Conclusions and challenges

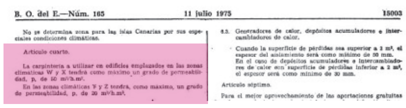
Context

- No traditional awareness of airtightness
  - Infiltration as a source of air renewal
- Energy reduction for a decarbonised system: nZEB
  - Heat transmission:
    - Improvement of construction materials. Traditional systems still prevail
    - Increased proportion of air infiltration losses (up to 25% of the heating demand)
- Controlled ventilation strategies since 2006

Building airtightness requirements



- Window permeability regulation since 1975 (RD 1490/1975)
- 2020: whole building airtightness limitation - nZEB



B. O. del E.—Núm. 165 | 11 julio 1975 | 15003

No se determina zona para las islas Canarias por sus especiales condiciones climáticas.

Artículo cuarto.

La carpintería a utilizar en edificios emplazados en las zonas climáticas W y X tendrá como máximo un grado de permeabilidad, p, de 50 m³/h.m².

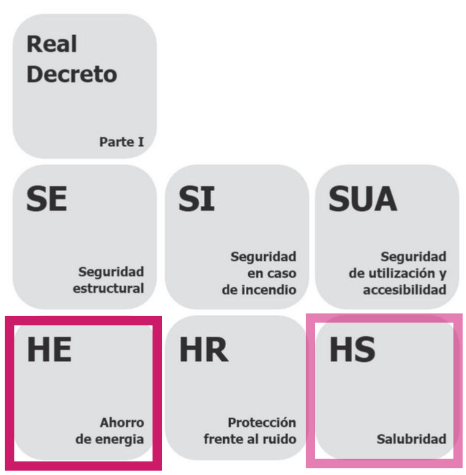
En las zonas climáticas Y y Z tendrá, como máximo, un grado de permeabilidad, p, de 20 m³/h.m².

6.3. Generadores de calor, depósitos acumuladores e intercambiadores de calor.

Cuando la superficie de pérdidas sea superior a 2 m², el espesor del aislamiento será como mínimo de 50 mm. En el caso de depósitos acumuladores e intercambiadores de calor con superficie de pérdidas inferior a 2 m², el espesor será como mínimo de 30 mm.

Artículo séptimo.

Para el mejor aprovechamiento de las aportaciones gratuitas



Windows airtightness

Maximum airtightness values of windows per climate zone in winter (m³/h·m²) at a pressure difference of 100 Pa

Zone α	Zone A	Zone B	Zone C	Zone D	Zone E
≤ 27	**≤ 27**	**≤ 27**	**≤ 9**	**≤ 9**	**≤ 9**

where: q_{100} is the reference air permeability at a pressure difference of 100 Pa $[m^3/h\ m^2]$. *Note*: according to UNE-EN 12207, the permeability limit values correspond to Class 2 (≤ 27 $m^3/h\ m^2$) and Class 3 (≤ 9 $m^3/h\ m^2$). If a window has a rolling shutter, its permeability value should also include it. Climate zones A, B, C, D and E refer to Continental Spain. Zone α refers to the Canary Islands.

Envelope airtightness

- New residential buildings >120m²
- Based on compacity (Volume/Area)

Maximum n_{50} $[h^{-1}]$ values at a pressure difference of 50 Pa

Compacity V/A [m³/m²]	n_{50}
V/A <= 2	**6**
V/A >= 4	**3**

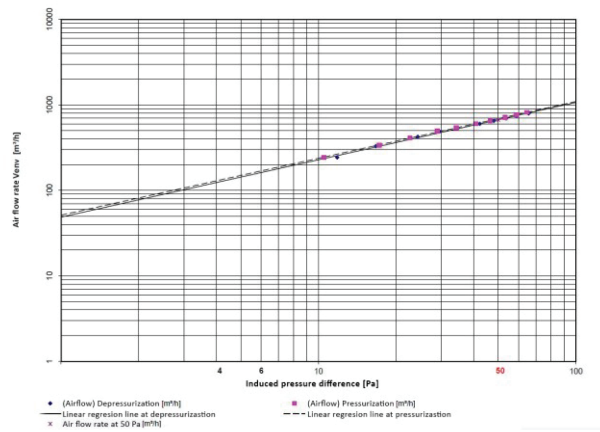
where: n_{50} is the air change rate at 50 Pa $[h^{-1}]$; V is the internal volume of a building or part of a building $[m^3]$; A_{ET} is the sum of areas of the thermal building envelope with heat exchange with the outdoor air. Therefore, internal partitions and the envelope area in contact with other adjacent spaces or buildings are excluded $[m^2]$. Note: the limit permeability values for intermediate V/A values can be obtained by interpolation.

Building airtightness justification

OPTION A

BlowerDoor test

- ISO 9972, Method 2
- No other specification
- No qualification scheme for testers
- No airtightness database
- No quality control system



Building airtightness justification

OPTION B

Analytically

$$n_{50} = 0.629 \cdot \frac{C_0 \cdot A_0 + C_h \cdot A_h}{V}$$

- This is the widespread approach
- Input values of the energy performance calculation

where:

n_{50} is the calculated air change rate at 50 Pa $[h^{-1}]$

V is the internal volume $[m^3]$

C_0 is the airflow coefficient of the opaque part of the thermal envelope at a reference pressure of 100 Pa $[m^3/h\,m^2]$. Reference values:

- New or existing buildings with improved airtightness, C_0 = 16 $m^3/h\,m^2$
- Existing buildings C_0 = 29 $m^3/h\,m^2$

A_0 is the sum of areas of the opaque thermal building envelope $[m^2]$

C_h is the permeability of doors and windows in the thermal building envelope at a reference pressure of 100 Pa $[m^3/h\,m^2]$

A_h is the sum of the area of the doors and windows of the thermal building envelope $[m^2]$. The thermal building envelope consists of the building parts with heat exchange with the outdoor air. Therefore, **internal partitions in contact with adjacent indoor spaces or buildings are excluded**.

Analytical model validation

I. Poza-Casado et al. — Building and Environment 223 (2022) 109435

- Airtightness test results were compared to calculated values
- Lack of linear association between the values of the CTE model and the test values

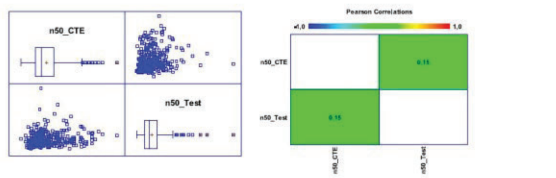


Fig. 1. Correlation analysis between the n_{50} values obtained from pressurization tests and those computed using the CTE model.

Poza-Casado, I., Rodríguez-del-Tío, P., Fernández-Temprano, M., Padilla-Marcos, M.-Á., & Meiss, A. (2022). An envelope airtightness predictive model for residential buildings in Spain. *Building and Environment, 223(July), 109435.* https://doi.org/10.1016/j.buildenv.2022.109435

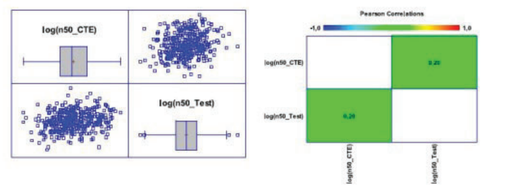
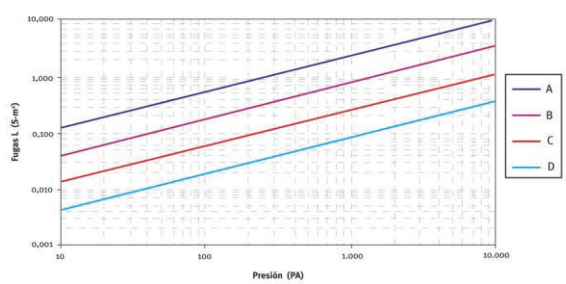


Fig. 2. Correlation analysis between the logarithms of the n_{50} values obtained in the pressurization tests and those computed using the CTE model.

Ductwork airtightness requirements

- Residential buildings:
  - CTE – DB HS3 (2007)
  - “Ducts must be airtight for its designed pressure”
  - “Airtightness must be checked every 5 years”
- Other buildings:
  - *Reglamento de Instalaciones térmicas de los edificios* (RITE) – 2007
  - At least Class B
  - Tests are required (UNE-EN 12599:01)
  - No awareness



Conclusions and challenges

- Raised awareness for the past few years
- Positive progress towards energy-efficient buildings

43rd AIVC -11th TightVent & 9th venticool Conference: Ventilation, IEQ and health in sustainable buildings
Building and ductwork airtightness in Spain: national trends and requirements – Irene Poza-Casado

UVa

13

Conclusions and challenges

- Gaps:
  - Application only for a small share of buildings
  - Limit values not too stringent
  - Unrealistic analytical approach – not mandatory testing
  - No airtightness database: no data on airtightness improvement
  - Qualification frame for testers
  - No quality control system
  - No inspections

43rd AIVC -11th TightVent & 9th venticool Conference: Ventilation, IEQ and health in sustainable buildings
Building and ductwork airtightness in Spain: national trends and requirements – Irene Poza-Casado

UVa

14

Thank you!

irene.poza@uva.es

*Funding: MOVILIDAD INVESTIGADORES E INVESTIGADORAS UVa-BANCO SANTANDER 2023

Building and ductwork airtightness in Latvia: national trends and requirements

43TH AIVC CONFERENCE

OCTOBER 4-5, 2023

NOLWENN HUREL
PLEIAQ/INIVE

ANDREJS NITIJEVSKIS
VLADISLAVS KEVISS
IRBEST LTD

Introduction – Building market in Latvia

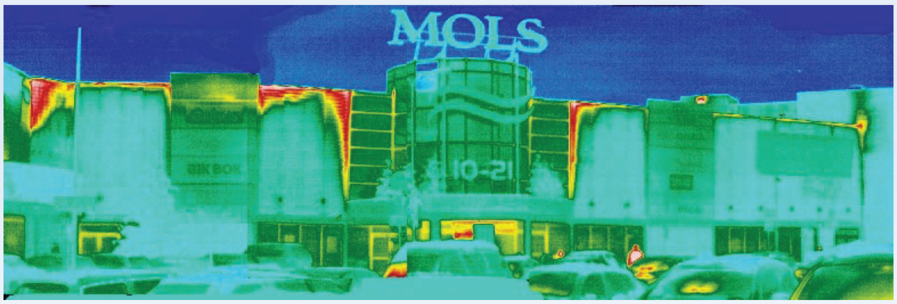
- **Population**: 1,9 million
- **Residential buildings**: about 3000 building permits delivered / year
  (2/3 for single dwellings; 1/3 for multifamily)
- **Non-residential buildings**: about 45% of the construction activity
- **Total investment** : 1.2 billion €

Per cent variation of investment in real terms
investment Mln. € fixed prices

Sectors	2019a	2016	2017	2018	2019a
Building	1,232	-2.5	12.1	19.9	9.7
1.1. Housebuilding	287	2.1	-10.1	32.2	6.0
1.1.1. New	174	10.6	13.7	3.6	7.1
1.1.2. R&M	113	-8.6	-46.6	126.0	4.3
1.2. Non residential (c)	945	-4.1	20.5	16.4	10.8
1.2.1. Private	NA	NA	NA	NA	NA
1.2.2. Public	NA	NA	NA	NA	NA

a: estimate - b: forecast - c: incl. R&M

Building airtightness



Introduction on building airtightness

- **2010:** requirement of blower door tests for buildings renovated with EU funds
  → interest in building airtightness starting
- **2015:** Latvian Construction Standard (LBN 002-01) on thermal insulation and airtightness became stricter
- **2021:** government recommendation to provide airtightness tests for the commissioning of all public buildings > 5000 m^3

Source: Retrotec

Introduction on building airtightness

- **2010:** requirement of blower door tests for buildings renovated with EU funds
  → interest in building airtightness starting
- **2015:** Latvian Construction Standard (LBN 002-01) on thermal insulation and airtightness became stricter
- **2021:** government recommendation to provide airtightness tests for the commissioning of all public buildings > 5000 m^3

Airtightness indicator: q_{50} **($m^3/(h.m^2)$)**

→ Leakage flowrate at 50 Pa divided by the total envelope area (incl. floors)

n_{50} (h^{-1}) also used for some project

Requirements in the regulation

From 2001 to 2015:

- $q_{50} \leq 3,0$ $m^3/(h.m^2)$ for **dwellings, hospitals, kindergartens, homes for the elderly**
- $q_{50} \leq 4,0$ $m^3/(h.m^2)$ for other **public** buildings
- $q_{50} \leq 6,0$ $m^3/(h.m^2)$ for **industrial** buildings
- Mechanical ventilation for buildings with $q_{50} < 3$ $m^3/(h.m^2)$

Since 2015:

- $q_{50} \leq 3,0$ $m^3/(h.m^2)$ for buildings with **natural** ventilation (airing);
- $q_{50} \leq 2,0$ $m^3/(h.m^2)$ for buildings with **mechanical** ventilation;
- $q_{50} \leq 1,5$ $m^3/(h.m^2)$ for buildings with mechanical ventilation equipped with a **heat recovery system**;
- $q_{50} \leq 4,0$ $m^3/(h.m^2)$ for **industrial buildings**
- ~~Mechanical ventilation for buildings with $q_{50} < 3$ $m^3/(h.m^2)$~~

Update in 2019: same requirements regarding airtightness

Airtightness test

So there are **mandatory airtightness requirements** for all new buildings…

… but **no mandatory testing**!

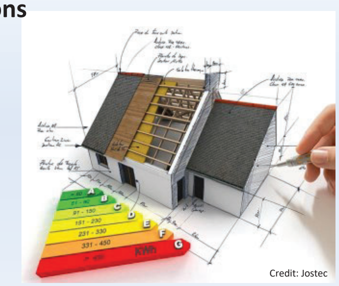
- **No sanctions** in case a building does not comply with the requirements
- Only the owner/developer or construction regulator can initiate and write requirements to **perform airtightness tests for new projects**
  (Requirements usually described initially in the **project documentation)**

Incentives for building airtightness

- **2021:** government recommendation to provide airtightness tests for the commissioning of all public buildings > 5000 m^3
- **Since January 2022**: the city of Riga (capital) gives a **90% discount on property taxes** for:
  - **newly built detached houses classified as NZEB**
    (for a period of 5 years from the commissioning of the building)
  - **apartment in multi-family buildings for which the insulation of all facades has been performed after its commissioning**
    (as energy retrofit reaching better than class C)
    Discount applied throughout the period of validity of the energy certificate, with a maximum of 10 years.

Building airtightness in the EP calculation

- Airtightness is an **input of the Energy Performance (EP) calculations**



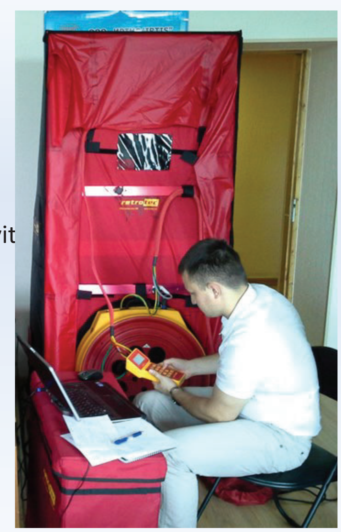
- **Default values**: requirements provided in the Latvian construction standard

  - $q_{50} \leq 3{,}0$ m³/(h.m²) for buildings with **natural** ventilation (airing);
  - $q_{50} \leq 2{,}0$ m³/(h.m²) for buildings with **mechanical** ventilation;
  - $q_{50} \leq 1{,}5$ m³/(h.m²) for buildings with mechanical ventilation equipped with a **heat recovery system**;
  - $q_{50} \leq 4{,}0$ m³/(h.m²) for **industrial buildings**

- Possible to use **lower air permeability values** if a test is performed

→ the rather favourable default values are **not encouraging airtightness testing**

Building airtightness test protocol



- **No national qualification scheme** for airtightness testers
  Currently there are approximately:
  - **8 persons** qualified by the manufacturer program **Retrotec**;
  - **2 persons** qualified by the Air Tightness Testing & Measurement Association (**ATTMA**)

  Only some of them are testing building airtightness as their main activit

- **No national guidelines** to perform the airtightness test
  Tests should be performed in accordance with **EN 9972:2016**
  Method 2: "by closing all the windows, doors, hatches in the building"

Building airtightness tests performed

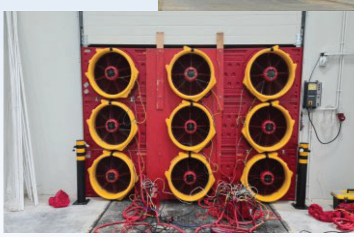
Estimation of the percentage of buildings tested (no official data available):

- **70-80%** of **public** buildings (new or renovated)
- **5-10%** of **industrial** buildings;
- **5-15%** of **dwellings** (single-family houses and multi-apartment buildings)

Conclusion

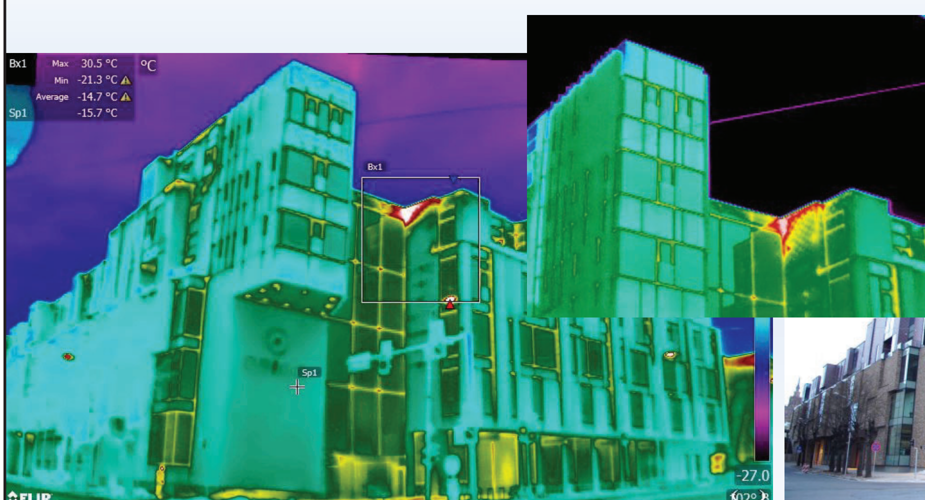
- Personal experience **of >2000** tests proved the reasonableness of the **q50 ≤ 1,5 m3/(h.m²)** as a to be a motivating tool for quality of an building envelope
- e.g. Lithuania - **n50 ≤ 0.6 h-1 - too strong for small buildings but too weak for large building**
- Mandatory **airtightness requirements** but **no mandatory tests** → still very few buildings tested
- Currently: airtightness **stimulated by the taxes reduction** for NZEB in Riga

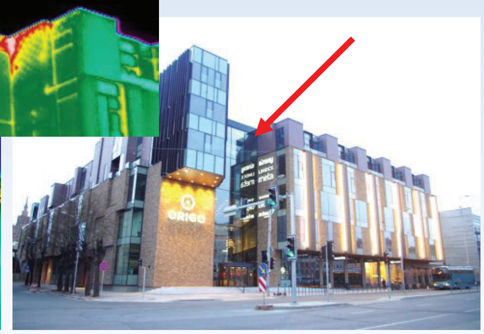
Test of Large Building V=1.75 million m³

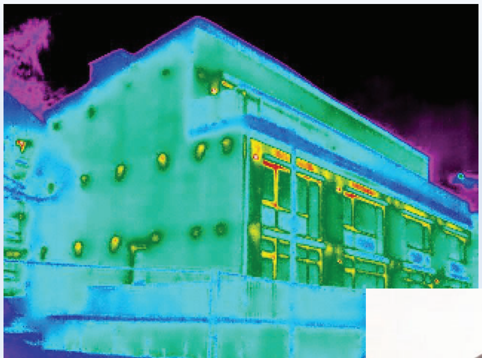


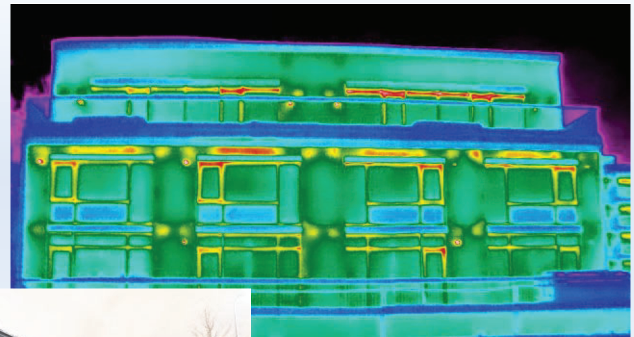
Symbol	Unit	Test Results
q_{E50}	Specific leakage rate at 50 Pa, q_{E50} [m³/h.m²]	0.88
n_{50}	Air change rate at 50 Pa, h^{-1}	0.14

Blower Door + Thermography









October 4, 2023 15 Andrejs Nitijevskis

Ductwork airtightness

October 4, 2023 16 Andrejs Nitijevskis

Ventilation ductwork airtightness

- **Not really taken into account** so far
  - No national regulations/guidelines
  - No requirements on airtightness levels
- **Reference document**: European standard LVS EN 12237
- Only **rare cases** in which **customers initiate a ductwork airtightness test**
- **No progress foreseen** in the next years

Thank you!

Andrejs Nitijevskis
ATTMA L2 certified tester
www.irbest.eu

43rd AIVC -11th TightVent & 9th venticool Conference
October 4-5, 2023
Aalborg University, Copenhagen, Denmark
Ventilation, IEQ and health in sustainable buildings

Sesion 3B – Topical Session: Building and ductwork airtightness regulations in various countries

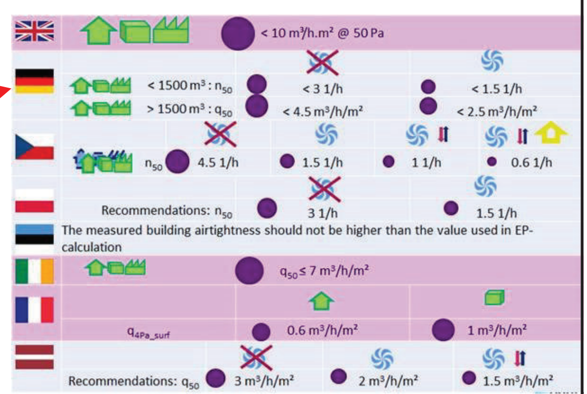
Air tightness and its impact on energy consumption in multi-family residential buildings in Montenegro

Esad Tombarević, Igor Vušanović, Miloš Krivokapić
University of Montenegro, Faculty of Mechanical Engineering
e-mail: esad.tombarevic@ucg.ac.me

Building and ductwork airtightnes in Montenegro

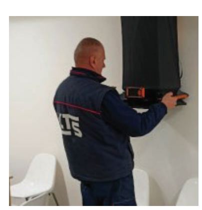
Building envelope airtightness

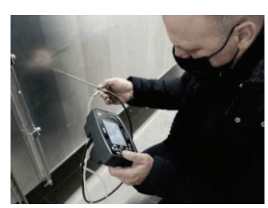
- Montenegro has warm climate and proper attention has not been paid to air tightness of buiildings
- Rulebook on minimum energy efficiency requirements for buildings (Official Gazette, No. 23/2013)
- Airtightness requirement in Montenegro
  - without mechanical ventilation $ACH_{50}=3\ h^{-1}$
  - with mechanical ventilation $ACH_{50}=1.5\ h^{-1}$
- MEST EN ISO 9972:2017 is adopted
- Blower door tests are not mandatory (performed only on several buildings for which the investor aimed for the LEED certificate)



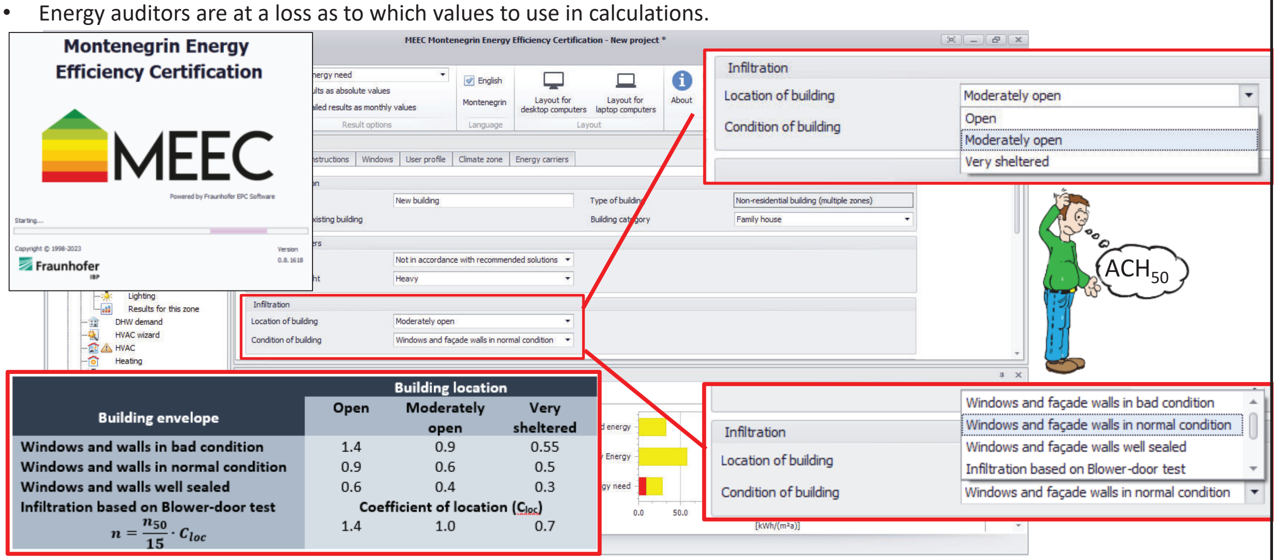
Ductwork airtightness

- MEST EN 1507:2012 and MEST EN 12237:2012 are adopted
- There is only one company which has tests for leakege of air ducts in the scope of its acreditation (according to ISO 17020)
- Tests are not mandatory (performed only on several buildings for which the investor aimed for the LEED certificate)





- Building's airtightness significantly affects the building's energy consumption due to air infiltration
- National software for calculation of the energy performance of buildings takes into account infiltration
- Energy auditors are at a loss as to which values to use in calculations.



Building envelope	Building location: Open	Moderately open	Very sheltered
Windows and walls in bad condition	1.4	0.9	0.55
Windows and walls in normal condition	0.9	0.6	0.5
Windows and walls well sealed	0.6	0.4	0.3
Infiltration based on Blower-door test	Coefficient of location (C_{loc})		
$n = \frac{n_{50}}{15} \cdot C_{loc}$	1.4	1.0	0.7

3

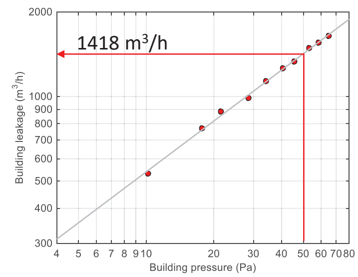
Results of performed blower door tests

No.	Floor area A (m²)	Volume V (m³)	Year of construction	Air leakage rate $\dot{V}_{50}$ (m³/h)	Air change rate n_{50} (h⁻¹)	Specific leakage rate w_{50} (m³/h/m²)	Effective leakage area ELA (cm²)	Building leakage curve: Air leakage coefficient C_L (m³/h/Paⁿ)	Building leakage curve: Air flow exponent n	Windows type
1	53	127	2006	1001	7.87	18.89	228.8	90.6	0.614	Wood
2	43	114	2011	679	5.95	15.78	148.5	57.4	0.631	Aluminium
3	58	162	2012	711	4.38	12.26	150.1	56.9	0.646	PVC
4	68	190	1963	1831	9.63	26.92	453.3	187.6	0.582	Wood
5	68	190	1963	1225	6.45	18.02	280.2	111.0	0.614	Wood/PVC
6	68	190	1963	305	1.60	4.48	63.1	23.6	0.654	PVC
7	85	227	1986	1418	6.25	16.69	334.5	134.8	0.602	Wood
8	85	227	1986	174	0.77	2.05	37.5	14.4	0.637	PVC

4

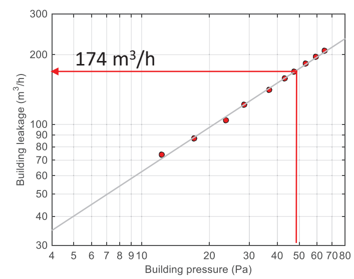
Impact of windows replacement

- external walls are made of cast-in-place reinforced concrete
- Old windows: wooden, double-glazed, no rubber seals, lack of maintenance
- New windows: UPVC windows, 5 chamber profile, 70 mm standard instalation depth, two seals, double glazed low e-glass, all with roller shutters



Before - Wood

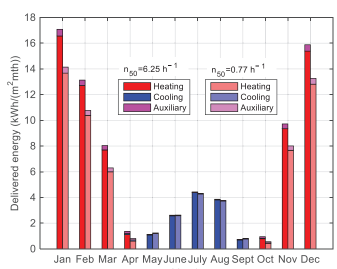
Value	Before	After
Air leakage rate, V_{50} (m³/h)	1418	174
Air change rate, n_{50} (1/h)	6.25	0.77
Air permeability, q_{50} (m³/h/m²)	11.53	1.41
Specific leakage rate, w_{50} (m³/h/m²)	16.69	2.05
Effective leakage area, ELA (cm²)	334.5	37.5
Building Leakage Curve		
Air leakage coefficient, c_L (m³/h/Paⁿ)	134.8	14.4
Air flow exponent, n	0.602	0.637

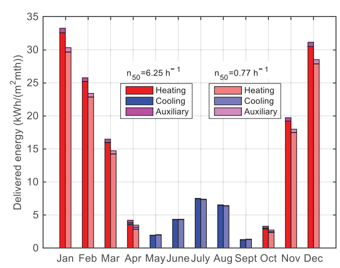


After - PVC

5

Climate zone I (design day –6 °C)





2.3 kWh/m²year for each ACH

Climate Zone	Building Envelope	n_{50} (h⁻¹)	Delivered Energy (kWh/m²·year)			
			Heating	Cooling	Auxiliary	Total
I	Existing thermal envelope	6.25	129.84	21.78	3.82	155.44
		0.77	117.32	21.73	3.58	142.63
	Improved thermal envelope	6.25	63.60	12.67	2.68	78.95
		0.77	51.57	12.67	2.37	66.61

8.2 % reduction

15.6 % reduction

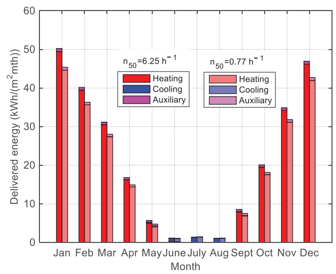
49.2% reduction

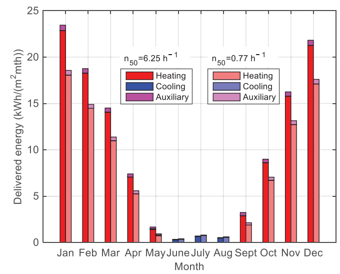
Significant reduction

Negligible reduction

6

Climate zone III (design day temperature −18 °C)





4.6 kWh/m²year for each ACH

Climate Zone	Building Envelope	n_{50} (h^{-1})	Delivered Energy (kWh/m²·year)			
			Heating	Cooling	Auxiliary	Total
III	Existing thermal envelope	6.25	248.67	3.50	6.04	258.21
		0.77	223.85	3.68	5.73	233.26
	Improved thermal envelope	6.25	112.25	1.49	3.92	117.66
		0.77	87.95	1.75	3.41	93.11

9.6 % reduction

20.9 % reduction

Significant reduction

Negligible reduction

54.5% reduction

Conclusions

- The problem of airtightness is ignored in Montenegro
- Windows play a crucial role in maintaining the overal air tightness of a building's envelope
- Windows replacemenrt proves to be an effective measure that improves the airtightness almost to the standard of a passive house
- By icreasing airtightness through windows replacement, energy consumption for heating is significantly reduced, while the reduction in energy consumption for cooling is practically negligible
- In relative terms, the reduction in energy consumption due to the increase in airtightness is more pronounced in colder climates and when the thermal envelope is improved
- Energy consumption increases linearly with increasing air leakage rate (from 2.3 kWh/m²year in Climate zone I to 4.6 kWh/m²year in Climate zone III for a unit reduction of ACH_{50})

Thank you for attention!

IEA EBC Annex 80 - Resilient Cooling

Patryk Czarnecki
Institute of Building Research & Innovation
Vienna, Austria

Institute of Building Research & Innovation ZT-GmbH
AIVC
venticool
the platform for resilient ventilative cooling
INIVE
Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology

2023-10-04

Topical Session
Resilient Cooling of Buildings meets Resilient Cooling in Cities

Institute of Building Research & Innovation ZT-GmbH
AIVC
venticool
the platform for resilient ventilative cooling
INIVE
Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology

Agenda

- Presentation of Technology Profiles
- Resilient Cooling Design Guidelines with Vincenco Corrado
- Resilient Cooling in Cities – New Annex?
- Interactive Part including discussion with Hilde Breesch

Objective and Target Audience - Technology Profiles

What?

- Structured Information about the Essential Resilient Cooling Technologies

Who?

–

Objective and Target Audience - Technology Profiles

What?

– Structured Information about the Essential Resilient Cooling Technologies

Who?

– Planners, Property Owners and Investors, Interested Public

1. Reducing Heat Loads to People and Indoor Environments

1.1. Solar Shading Technologies

1.2. Cool Envelope Materials

1.3. Glazing Technologies

1.4. Ventilated Façades

1.5. Green Roofs and Green Façades

2. Removing Heat from Indoor Environments (Production, Emission and Combined)

2.1. Ventilative Cooling

2.2. Thermal Mass Utilization

2.3. Evaporative Cooling

2.4. Sky Radiative Cooling

2.5. Compression Refrigeration

2.6. Adsorption Chillers

2.7. Natural Heat Sinks

2.8. Radiant Cooling

3. Increasing Personal Comfort Apart from Space Cooling

3.1. Comfort Ventilation and Elevated Air Movement

3.2. Micro-cooling and Personal Comfort Control

4. Removing Latent Heat from Indoor Environments

4.1. Dehumidification

9

Outcome

– 130 pages document with key and concentrated information

– 16 chapters; 1 for each technology

– Already internally reviewed

10

Chapter Structure

- Description
  - Physical principles, function, characteristic applications, relevant subtypes
  - "Abstract" of the full Technology Profile.
- Key Technical Properties
  - Technical properties, system design indicators, qualitative numbers or ranges
  - Characterization of properties which are relevant for designing/purchasing

11

11

Chapter Structure

- Performance and Application
  - Information on the expected effect on whole building performance, especially about qualities of resilience
  - Exemplary quantitative outputs from simulation studies and qualitative statements backed with sources and literature
  - Information about the range of possible applications as well as about limitations including climate dependency and building types
  - Compatibility and incompatibility with other technologies.
  - Availability and expected developments

12

12

Chapter Structure

- Further Reading
  - Links to further information such as other Annex 80 content, websites of relevant interest groups, industry associations, rating associations and others.
  - Specific manufacturers were not included

Qualities of Resilience

Qualities of Resilience

- Absorptive capacity
  - The degree to which a system is able to absorb the impacts of disruptive events and minimize their consequences with little effort.
- Adaptive capacity
  - The ability to adjust undesirable situations by undergoing some changes. The system can learn from the event, evaluate the system performance and modify its configurations, and make it more flexible to future disruptions

Qualities of Resilience

- Restorative capacity
  - The ability to return to normal or improved operation.
- Recovery speed
  - The speed of the recovery process. Recovery may be accelerated if absorption activities are well implemented and the system can quickly mobilize and effectively use all the resources at its disposal.

Simulation Data

- Outcomes from simulations are presented in tables
- Stated as a percentage of reduction

Table 2: Reductions in daily thermal stress in a heat wave without air conditioning, annual HVAC energy use, and annual HVAC carbon emission after application of cool envelope materials to a single-family home in Los Angeles, California circa 2050 [9].

KPI	Baseline	Reduction from cool roof[f]	Reduction from cool wall[g]	Reduction from cool roof + cool wall[f,g]
Daily heat stress[a] [°C·h]	19	3%	7%	10%
Annual HVAC electricity need intensity[b] [kWh/m²]	33	6%	14%	20%
Annual HVAC heating need intensity[c] [kWh/m²]	27	-1%	-4%	-6%
Annual HVAC primary energy intensity[d] [kWh/m²]	98	4%	8%	12%
Annual HVAC carbon emission intensity[e] [kg CO_2e/m²]	15.1	3%	6%	9%

[a] Daily degree hours of exceedance against a standard effective temperature (SET) of 30 °C during a heatwave without AC

[b] Annual HVAC electricity need per unit conditioned floor area

[c] Annual HVAC heating need per unit conditioned floor area

[d] Annual HVAC primary energy usage per unit conditioned floor area based on 2021 eGRID database for California-average primary energy factors of 2.05 for electricity and 1.09 for gas [10]

[e] Annual HVAC carbon emission per unit conditioned floor area based on 2021 eGRID database for California-average CO_2 emission factors of 272 g/kWh electricity and 225 g/kWh [10]

[f] Roof solar reflectance raised to 0.60 (bright-white asphalt shingle) from 0.10 (conventional asphalt shingle)

[g] Wall solar reflectance raised to 0.60 (white paint) from 0.25 (conventional medium-lightness color paint)

Data from: S.H. Lee, R. Levinson, Cool envelope benefits in future typical weather and heatwave conditions for single-family homes in Los Angeles [accepted paper], in: Sixth International Conference on Countermeasures to Urban Heat Islands, RMIT University, Melbourne, Australia, 2023. https://doi.org/10.20357/B7DK6T.

Exemplary Chapter

Exemplary TPS.pdf

Availability

Soon available at:

- IEA EBC Annex 80 Website

  https://annex80.iea-ebc.org/publications

- Venticool Annex 80 Website

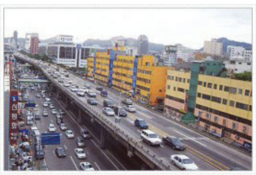
  https://venticool.eu/information-on-annex-80/annex-80-home/

Resilient Cooling Design Guidelines

Preparing a new Annex-Proposal (?)

Resilient Cooling in Cities

Passive Climate Mitigation:	Green, Blue and "White" infrastructures.
Hybrid Cooling:	Hybrid Cooling solutions in time and space including latent cooling.
Heat sinks on urban scale:	Seasonal storage in soil and water. Deep Radiative Cooling.
Urban grids:	Thermal & electric networks.



Cheonggyecheon stream revitalization project. Downtown Seoul, South Korea, 2003 – 2005 Source: https://www.ser-rrc.org/project/south-korea-restoration-of-the-cheonggyecheon-river-in-downtown-seoul/ (04.10.2022), foto credits: City of Seoul.

Preparing a new Annex-Proposal (?)

If you are interested in joining this new Annex, please contact us!

Peter Holzer, peter.holzer@building-research.at
Philipp Stern, philipp.stern@building-research.at
Patryk Czarnecki, patryk.czarnecki@building-research.at

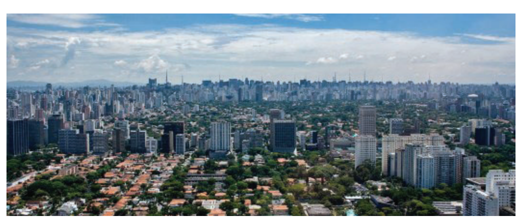
Institute of Building Research & Innovation
Vienna, Austria

Interactive Part

- Please divide in Groups of 3 to 5 people
- Each group receives one case building
- Work on case building for 20 minutes
- Presentation and discussion afterwards (15 minutes)

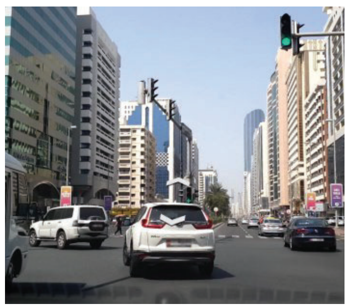
Case Building 1 - São Paulo

- Hot and Humid Climate (ASHARE Climate Zone 2A)
- 15 story residential building with small business on ground floor



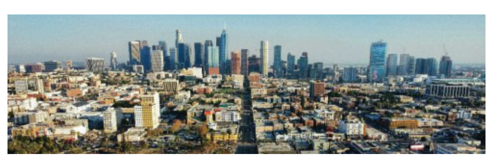
Case Building 2 - Abu Dhabi

- Extremely Hot and Dry Climate (ASHARE Climate Zone 0B)
- 12 story residential building with small business on ground floor



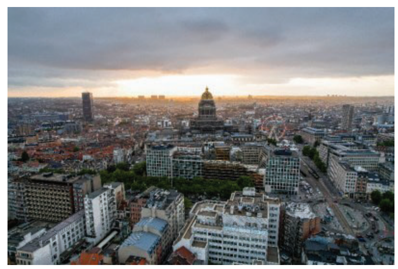
Case Building 3 - Los Angeles

- Warm and Dry Climate (ASHARE Climate Zone 3B)
- 5 story residential building with small business on ground floor



Case Building 4 - Brussels

- Mixed and Humid Climate (ASHARE Climate Zone 4A)
- 9 story residential building with small business on ground floor



27

Interactive Part

You are about to perform a retrofit to make the case building more resilient against heat waves and power outages.

- Are there any measures concerning the building envelop you would implement? If so, which and why?
- Are there any measures concerning the building interior and operation you would implement? If so, which and why?
- Are there any effective measures concerning the surrounding building exterior you would implement? If so, which and why?
- If you could impose any other measures (technical, political, societal, etc.) to improve the resilience against heat waves and power outages in general in urban surroundings, which would that be?

28

Interactive Part – Abu Dhabi

Interactive Part – Sao Paolo

Interactive Part – Los Angeles

31

31

Interactive Part – Brussels

32

Contacts

Annex 80 at VENTICOOL
https://venticool.eu/information-on-annex-80/annex-80-home/

Annex 80 at IEA EBC
https://annex80.iea-ebc.org/

Peter Holzer, peter.holzer@building-research.at

Philipp Stern, philipp.stern@building-research.at

Patryk Czarnecki, patryk.czarnecki@building-research.at

Institute of Building Research & Innovation
Vienna, Austria

Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology

Thank you for your attention.

Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology

IEA EBC Annex 80
Resilient Cooling of Buildings

Resilient Cooling Design Guidelines

Vincenzo Corrado

Politecnico di Torino – Department of Energy

October 2023

POLITECNICO DI TORINO

AIVC

1

1

Introduction

- Within the IEA EBC Annex 80 project, key challenges, opportunities and framework associated with resilient cooling design have been identified and innovative concepts (solutions and strategies) that can help address these challenges have been explored.
- An extensive analysis of different technologies, practices, and building designs has been conducted to determine the most effective solutions for improving the resilience of buildings.
- To this regards, disruptive events and shocks such as heatwaves and power outages are the main points of interest.
- **The drafting of guidelines dedicated to resilient cooling design in buildings will help drive innovation, promote collaboration among different experts, and promote public awareness and engagement around the issue.**

2

2

Scope

The Resilient Cooling Design Guidelines:

- will describe resilient cooling solutions allowing for the reduction of overheating risks as well as the cost-effective, energy-efficient and low-carbon coverage of cooling demands;
- will integrate state-of-the-art knowledge based on the broad consensus of professionals ;
- will address the problem of heat waves and guide designers, building professionals, and owner representatives on the latest developments of low-impact cooling technologies in regard to their choice and sizing;
- will pursue the mission of improving health, comfort, safety, and energy efficiency in buildings and communities.

The main question to be answered is:

- **"How to design a resilient cooling building?"**

3

3

Objectives of the Guidelines

1) To develop resilience cooling definitions for buildings;
2) To propose well-established or new metrics and key performance indicators for the assessment of the design and solutions;
3) To examine and promote simulation tools and methods for evaluation of the design and concepts;
4) To define inputs, weather files, building data, operational data and others, for proper assessment of the performance;
5) To describe technological profiles of sustainable and energy-efficient cooling solutions and strategies;
6) To integrate them into a demonstration case study.

4

REHVA guidebook

REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

- The Resilient Cooling Design Guidelines are proposed as a European Guidebook to be published by REHVA through a joint task force with IEA EBC Annex 80.
- REHVA is the Federation of European Heating, Ventilation and Air Conditioning associations. It acts as an umbrella organization that represent over 120,000 HVAC designers, building services engineers, technicians and experts across 26 European Countries.
- REHVA's mission to help the exchange of technical information and knowledge transfer, and to disseminate the latest technology developments to foster high-quality European engineering practice.
- The most important outcome of this work are the REHVA European Guidebooks, written by REHVA Task forces, which are international groups of REHVA experts cumulating latest European knowledge about various topics in our field. REHVA experts have elaborated 31 guidebooks.

5

5

Target audience

- The target audience of this guidebook is practitioners in the building design and architectural firms, and building services sector, including designers, manufacturers, facility managers, and contractors.
- The market segmentation of the target audience indicates a wide reach of potential readers and beneficiaries.
- Geographically the report caters to EU countries but has a broad scope that can make it a highly used guide beyond Europe. The guide was written to cover the eight climatic zones defined by ASHRAE 169 and significantly contribute to professional building and energy experts in hot climates.

6

6

Potential use of the Guidelines

- The user profile of the target audience includes consulting engineers, firms and national authorities, and building owners and tenants, policymakers, government officers, and building services institutions.
- The guide is developed to address small and mid-size facilities, including residential and commercial buildings.
- Also, the guide is not only useful for new construction but also for existing buildings in regard to their operation, management, and maintenance.

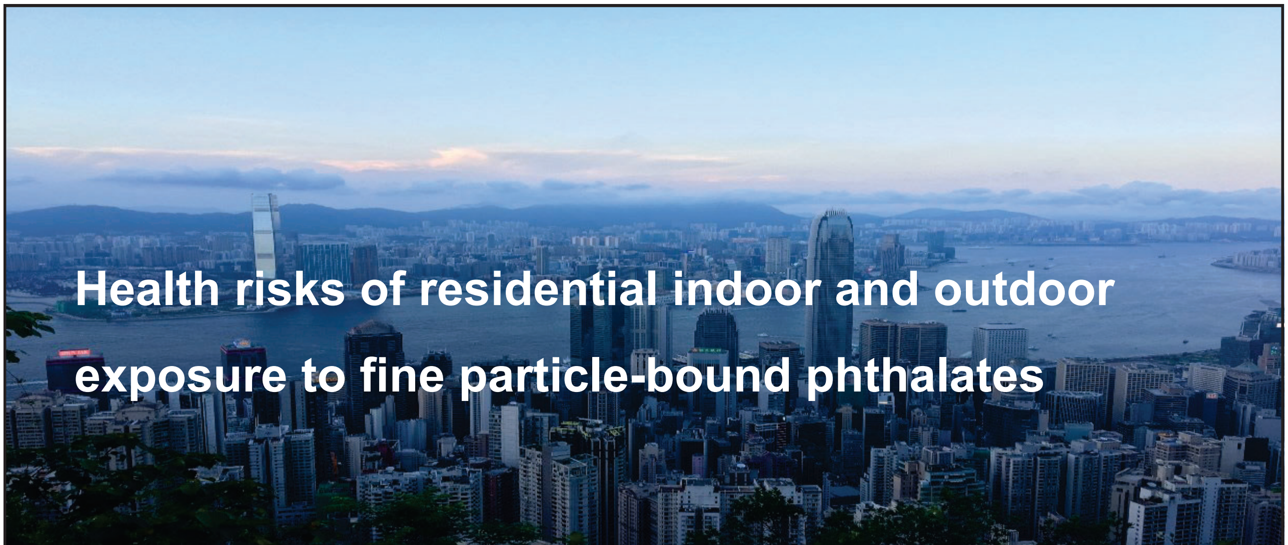
Market of the Guidelines

- This guideline addresses a priority topic, which is reflected in the whole legislative framework of the European Union that assign an important role to buildings for climate mitigation and climate adaptation. The legislative framework of the European Union (EU) reflects the important role of buildings for climate change through several relevant policies.
- The potential customers of the Guidelines include both professionals and cooling technology companies.
- With reference to the European continent only, they can be listed over 500,000 building designers (source ACE) and more than 120,000 HVAC designers and building services engineers (source REHVA).
- As regards cooling technology companies, among the other, about 117,000 people work in the European heat pump industry (source EHPA), more than 450,000 people are employed in the solar shading industry (source ES-SO).

Table of contents

1. Introduction to resilient cooling (general context, design framework)
2. Definition of resilience and disruptions
3. Resilient cooling solutions (strategies, technologies, components)
4. Key performance indicators for evaluation of resilience in buildings
5. Building performance assessment methods and tools (whole building, specific resilient cooling technologies, simulation tools, calibration and validation)
6. Weather data (present vs future climate data, heat waves, urban effects)
7. Occupancy patterns (internal conditions, heat gains, bldg. operation)
8. Building data (description of geometry, constructions, technical bldg. systems)
9. Developed case study 1 & 2

10



Health risks of residential indoor and outdoor exposure to fine particle-bound phthalates

Dr. Jiayao CHEN, Prof. Francesco PILLA

jiayao.chen@ucd.ie; francesco.pilla@ucd.ie

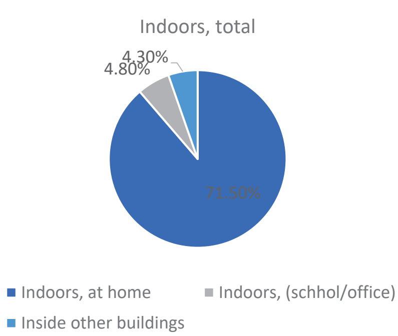
UCD School of Architecture, Planning and Environmental Policy
UCD Spatial Dynamics Lab (SDL)

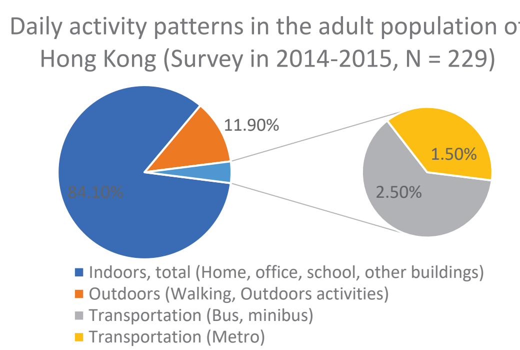
4 October 2023, Conference,
Copenhagen– 43rd AIVC conference

1

Identify the problem

- The negative impacts of phathalates (PAEs) on human health have raised global concerns due to their widespread use in polyvinyl chloride (PVC) products and consumer products (such as commodities, medical products, cosmetics, and personal care products) and in households (building materials, furnishing, household goods) .
- The International Agency for Research on Cancer (IARC) has classified DEHP and BBP as possible human carcinogens (Group B2 and Group C) based on experimental animal studies.





2

Methods/Solutions

- Study design

- Indoor monitoring for $PM_{2.5}$ was conducted in 26 adult subjects (ages 18–63 years) in Hong Kong (Fig. 1).

- Outdoor $PM_{2.5}$ samples were collected concurrently at fixed sites in the same district as residential indoors.

- Sampling and instruments

- Mini-Volume air sampler was placed at ~1.5 m above the ground in the participants' living room and operated at a flow rate of 5 (±0.25) L/min for 24 h. Two to four samples were obtained from each household, leading to 63 sets of indoor $PM_{2.5}$ samples, with 63 sets of outdoor $PM_{2.5}$ samples collected.

- Analytical methods

- A punch (0.526–2.630 cm^2) of the exposed quartz filter was subjected to particle-phase organic compound determination employing the thermal desorption–gas chromatography/mass spectrometer (TD–GC/MS) method.

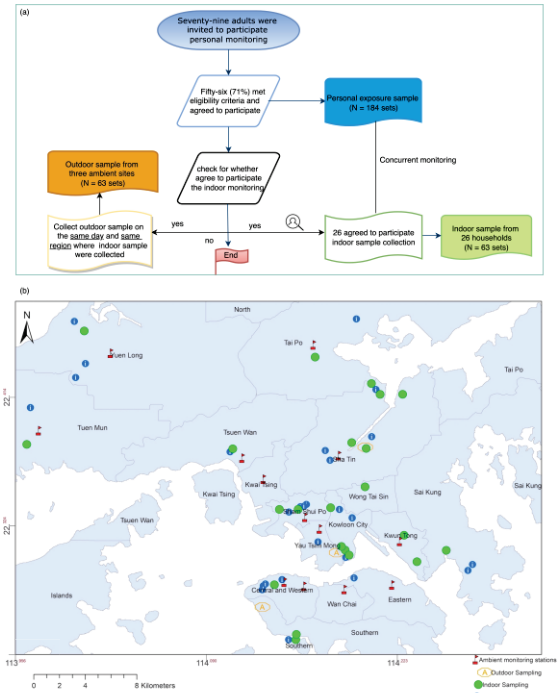
- Statistical analysis

- PCA for source identification

- Health risk assessment:

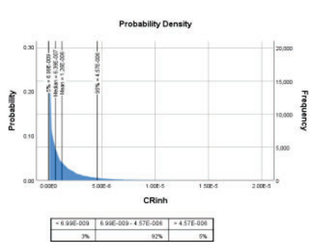
$$EC_i = \frac{C_i \times ET \times EF \times ED}{AT} \quad (Eq. 1)$$

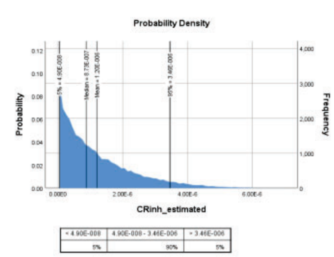
$$DI_{i\_inh} = \frac{EC_i \times IR_{inh} \times EF \times ED}{BW \times T \times CF} \quad (Eq. 2)$$



Results & Discussion

- DEHP [di(2-ethylhexyl) phthalate] was the most abundant PAE congener (80.3%–85.0%).
- Low-molecular-weight (LMW) PAEs (i.e., DMP, DEP) tended to be present in the gas phase.
- Strong correlations for DEHP with DnBP (rs = 0.88; $p < 0.01$) (e.g., household products, plasticizers), BBP (rs = 0.83; $p < 0.01$) (PVC flooring), and DnOP (rs = 0.87; $p < 0.01$) (polymer products) were shown in residential indoor.
- The highest average I/O ratio was shown for DnBP (4.8), suggesting indoor DnBP source.
- Outdoor monitoring at fixed sites could not capture indoor origin pollutants.
- The inhalation cancer risks attributable to measured and estimated personal exposure to DEHP exceeded the U.S. EPA's benchmark (1×10^{-6}).





Thank you!

Acknowledgements: This study was supported by the National Natural Science Foundation of China (Grant No. 41907181). Full article: https://www.mdpi.com/1660-4601/19/20/13425

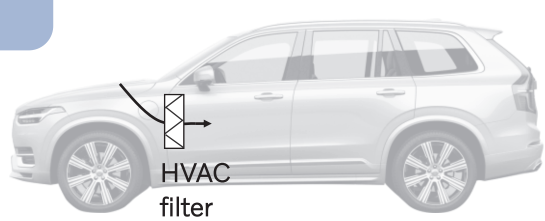
UCD School of Architecture, Planning and Environmental Policy
UCD Spatial Dynamics Lab (SDL)

HEPA filters to improve vehicle cabin air quality -advantages and limitations

Dixin Wei, Anders Löfvendahl
Volvo Cars, Chalmers University of Technology
dixin.wei@volvocars.com

Vehicle cabin air quality

Ambient pollutants
- PM
- NO_2
- CO



PM: particulate matter

Vehicle Measurements

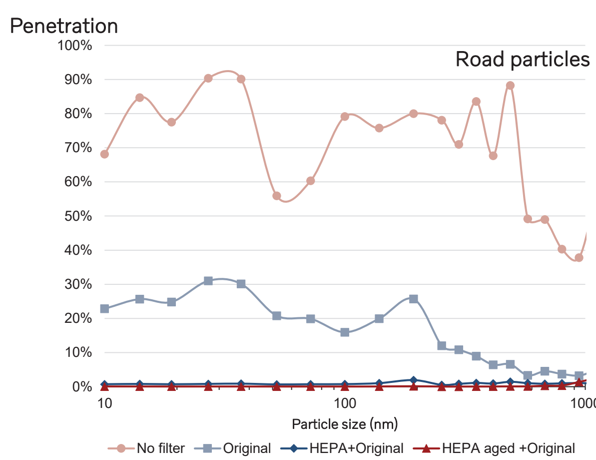
Front storage in BEV

10/9/2023 Dixin Wei, Volvo Cars, dixin.wei@volvocars.com

VOLVO

3

Results- Vehicle Measurements



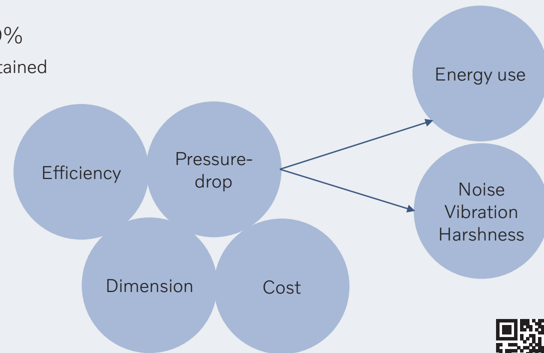
Dixin Wei, Volvo Cars, dixin.wei@volvocars.com

4

VOLVO

Conclusions

- EPA, HEPA filter -> efficiency above 99%
- Aged HEPA filter -> performance maintained
- Balance in practical application



Scan for more info

Dixin Wei, Volvo Cars, dixin.wei@volvocars.com

Experimental study of an innovative wet scrubber concept in regards to particle filtration and pressure loss

Nhat Nguyen, Martin Kremer, Hendrik Fuhrmann, Philipp Ostmann, Dirk Müller

RWTH Aachen University, E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate, Aachen, Germany

Nhat Nguyen

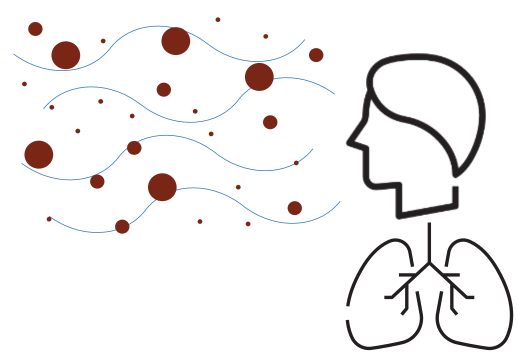
EBC | Institute for Energy Efficient Buildings and Indoor Climate | E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

1

Motivation
Health issues due to particulate pollutants and VOCs

- Fine and coarse particles penetrate deep into the respiratory tract
  - Increasing mortality & morbidity [1]
  - Removal of particles to reduce risk to human health
- Wet scrubbers can filter both solid and liquid pollutants
  - High energy demand
- Increasing removal efficiencies for new concepts
  - Shift focus to energy efficiency

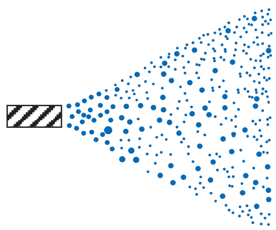
→ Investigating wet scrubber concept with low energy demand and resulting particle removal efficiencies



[1] World Health Organization (2016). Ambient air pollution: a global assessment of exposure and burden of disease.

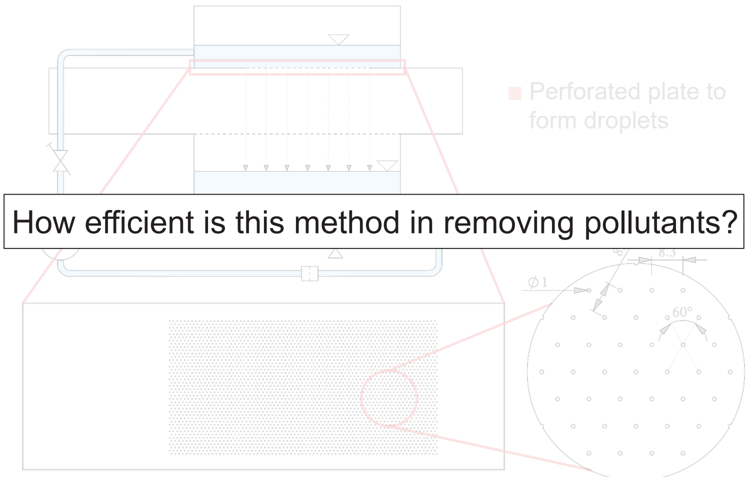
Different wet scrubber concept
Perforated plate instead of atomization

Conventional Wet Scrubbers



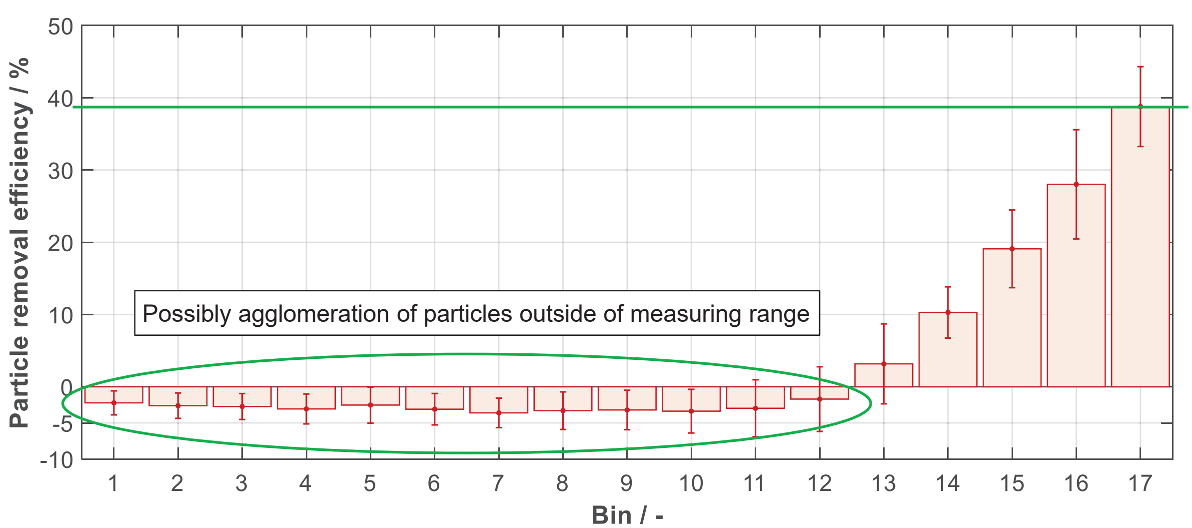
- Atomization of injected water
  - High energy demand
  - High pressure losses
- High removal efficiencies

New Wet Scrubber Concept



3

Results: Particle Removal Efficiency



4

Conclusions and Outlook

Conclusions:

- Overall low particle removal efficiencies due to low number of droplets
- Investigated wet scrubber concept has low pressure losses

Outlook:

- Future studies: Investigation of negative particle removal efficiencies
- Future studies: Increasing particle removal by modifying dripping behavior and droplet size

Thank You For Your Attention!

Nhat Nguyen, M.Sc.
Research Associate, Team Ventilation Systems

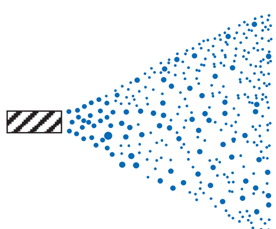
T +49 241 80-49799
F +49 241 80-49769
nhat.nguyen@eonerc.rwth-aachen.de

E.ON Energy Research Center · Institute for Energy Efficient Buildings and Indoor Climate

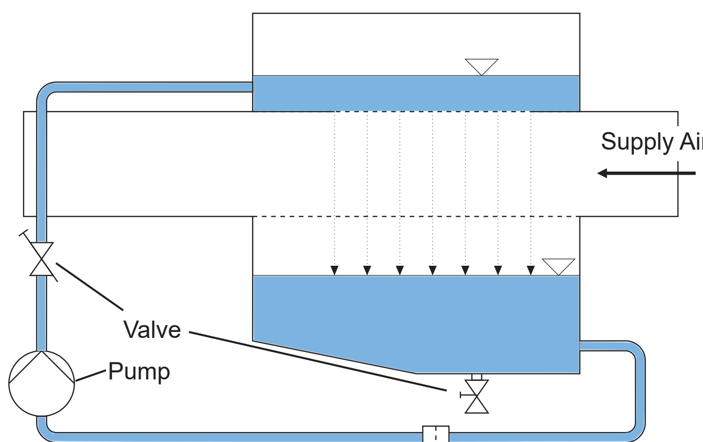
Mathieustrasse 10
52074 Aachen
Germany
www.eonerc.rwth-aachen.de/ebc

Different wet scrubber concept
Perforated plate instead of atomization

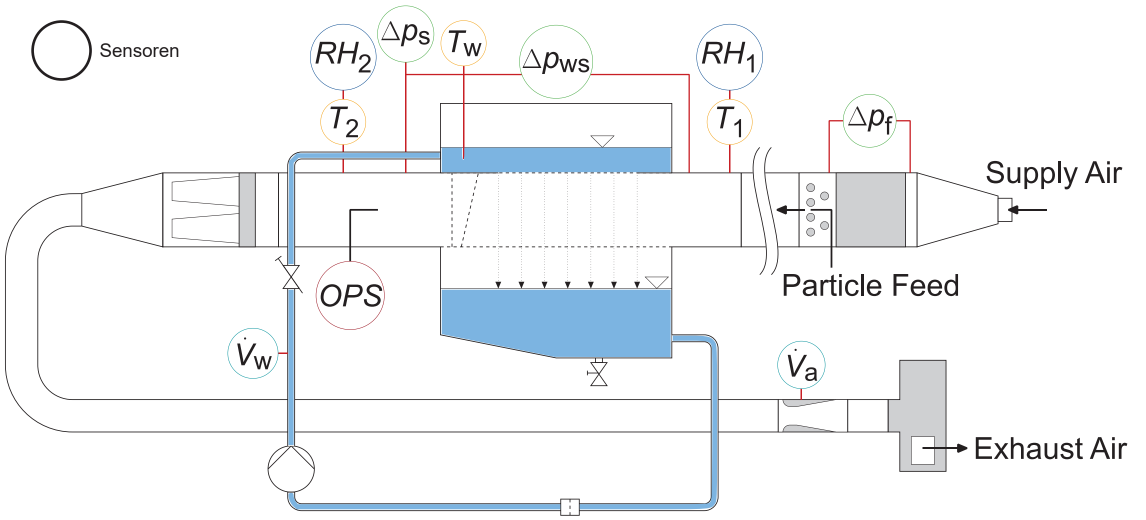
Conventional Wet Scrubbers	New Wet Scrubber Concept



- Atomization of injected water
  - High energy demand
  - High pressure losses
- High interface area between water and pollutants

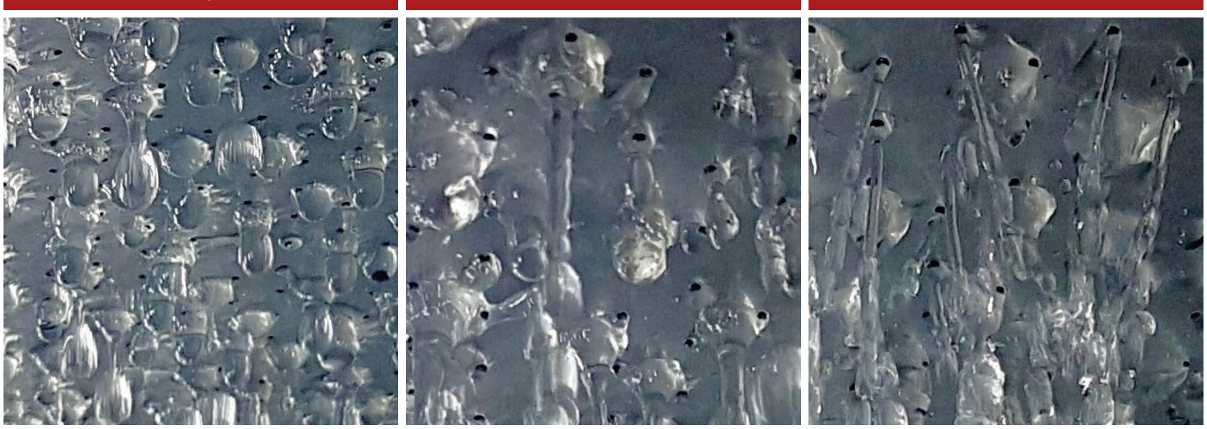


Schematic of test bench



Droplet Behavior

$2\ m^3/h$	$4\ m^3/h$	$6\ m^3/h$



- Droplets larger than holes of perforated plate due to surface wetting → water accumulation before dripping

An evaluation of CO_2 emission rates by Chilean school children

Nicolás Carrasco[1], Constanza Molina[*1], and Benjamin Jones[2]

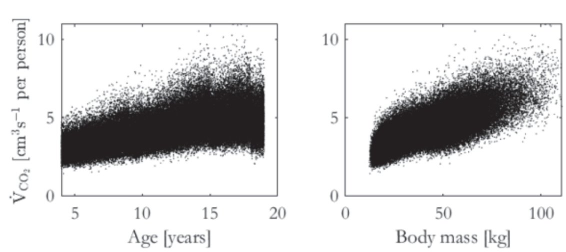
*cdmolina@uc.cl

1 Pontificia Universidad Católica de Chile   2 Department of Architecture and Built Environment, University of Nottingham, England

AIVC2023

Introduction

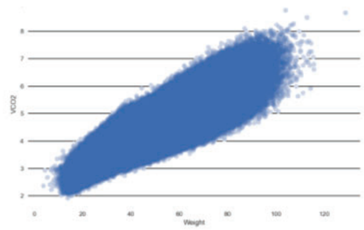
- Carbon dioxide (CO_2) levels are used to estimate ventilation rates in occupied spaces.
- Recent research showed children's CO_2 emission rates vary significantly between ages 4-19 due to body mass changes.
- One study derived US child **emission rates of 3.1-5.1 ppm m^3 s^{-1} per person** using government weight data.
- *As US child body mass may differ from other countries, emission rates based on US data may not apply elsewhere*



Are the expected CO_2 concentrations in Chilean schools different from those in US schools?

Method

Multiple simulation of classrooms of
29 students
from 5 to 18 years of age,
until a normal distribution is obtained for their means



$$\dot{V}_{CO_2} = BMR \cdot M \cdot RQ \cdot VO_2 \cdot T \cdot P^{-1}$$

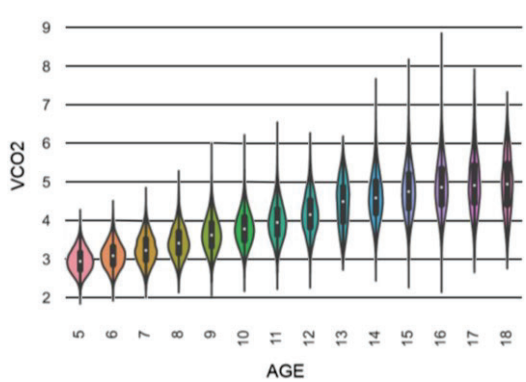
$$Q_o = \dot{V}_{CO_2}\left(C_{i,ss} - C_o\right)^{-1} = \dot{V}_{CO_2} C_{e,ss}^{-1}$$

Body mass, BMR, is the most important input in emission rates.

Qo for US and Chilean classrooms following **ASHRAE Standard 62.1** adds per capita airflow and 0.6L/s per unit floor area,
and the **ASHRAE Standard 241** focuses on controlling infectious aerosols with 20L/s per person.

Then, compared both Chile and US samples to see if there are significant differences in emission rates and $C_{e,ss}^{-1}$.

Results and conclusions



Age	Median $\dot{V}_{CO_2}$		Excess concentration, $C_{e,ss}$ ppm			
			ASHRAE 62.1		ASHRAE 241	
	USA	Chile	USA	Chile	USA	Chile
5	3.1	3.0	420	490	160	150
6	3.3	3.1	440	510	160	160
7	3.4	3.2	460	540	170	160
8	3.6	3.4	490	570	180	170
9	3.9	3.6	580	600	200	180
10	3.9	3.8	580	630	200	190
11	4.1	4.0	610	660	210	200
12	4.3	4.2	640	700	220	210
13	4.5	4.4	670	740	230	220
14	4.8	4.6	720	760	240	230
15	5.0	4.8	750	790	250	240
16	4.9	4.9	730	810	250	240
17	5.0	5.0	750	830	250	250
18	5.1	5.0	760	830	260	250

There is very little difference between countries for the same standard

Thank you

Nicolás Carrasco[1], Constanza Molina[*1], and Benjamin Jones[2]

1 Pontificia Universidad Católica de Chile 2 Department of Architecture and Built Environment, University of Nottingham, England

* Corresponding author: Constanza Molina cdmolina@uc.cl

Part of this work and presentation was financed by ECCUC / PUC University

The Effects of Bedroom Mechanical Ventilation on Health and Sleep Quality

Jeong Won Kim, Dankook University
Sun Ho Kim, Dankook University
Yong Kyu Biak, Seoil University
Hyeun Jun Moon, Dankook University

Speaker: Jeong Won Kim
12210197@dankook.ac.kr

Background

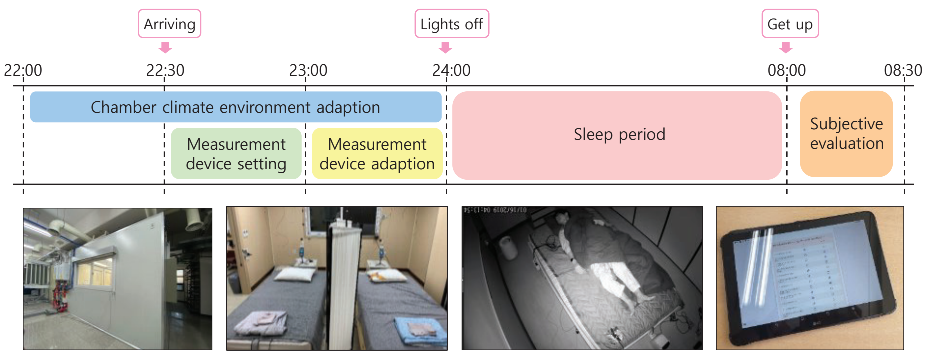
- **Healthy Indoor air quality**
  - Humans typically spend about one-third of their total time sleeping
  - Pursuit healthy indoor air quality(IAQ) as improve the quality of life
  - Adverse health effects
    - Poor sleep: energy restoration, physical and mental recovery, maintaining bodily functions, etc.
    - CO_2: Dyspnea, psychological and physical fatigue, etc.

- **Comfort sleep environment**
  - Ensuring good indoor air quality is important for maintaining the quality of sleep.
  - However, occupants may not always consciously implement planned ventilation in their bedrooms.

➡ **This study aims to analyse the difference in sleep efficiency based on the operation of bedroom ventilation systems in the intermediate season.**

Method

- **Experimental design**
  - 2-hour indoor temperature acclimation for each experimental condition.
  - Elimination of any disruptive factors during sleep for each experimental condition from midnight (00:00) to 8:00 AM (total 8 hours).
  - Conducting a sleep satisfaction survey.

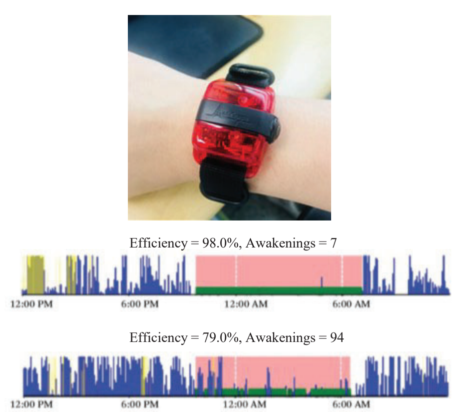


<Experimental procedure>

3

Method

- **Sleep assessment methodology**
  - Quantifying sleep efficiency using the wrist-worn Actigraph device equipped with a 3-axis accelerometer sensor.
  - Utilizing the previously developed survey items from the Subjective sleep quality assessment (Zilli et al., 2009).



<Sleep efficiency(Actigraph)>

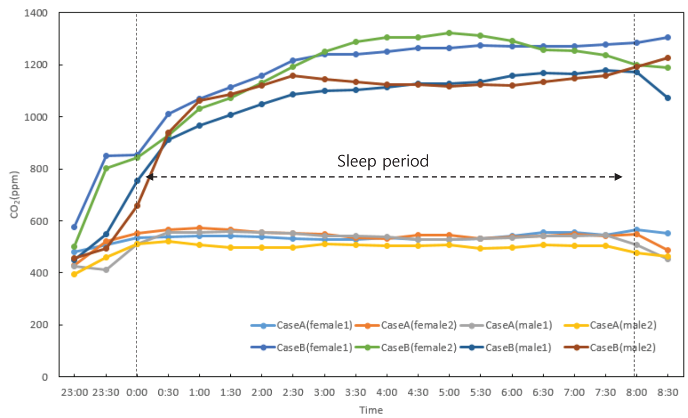
Questions	Score
1. How was your sleep like last night? (Calmness of sleep)	1-5
2. How easy was it to fall asleep last night? (Ease of falling asleep)	1-5
3. How easy was it to wake up this morning? (Ease of awakening)	1-5
4. Did you feel refreshed after waking? (Freshness after awakening)	1-5
5. Are you satisfied with your last night's sleep? (Satisfaction about sleep)	1-5
6. Do you think you get enough sleep? (Sufficient sleep)	Yes(1) or No(0)

<Subjective Sleep Quality Assessment survey>

4

Result

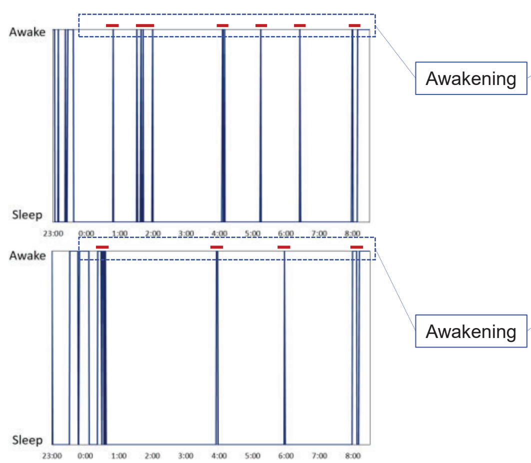
- **Sleep environment**
  - Case A: Ventilation On(2.78ACH), Case B: Ventilation Off
  - Case A : CO_2 ranged from 492 to 537 ppm
  - Case B : CO_2 ranged from 1,019 to 1,152 ppm



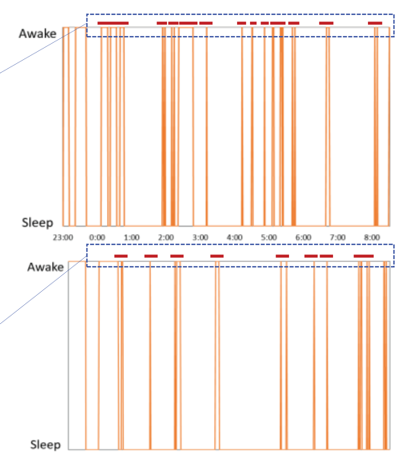
<CO_2 Concentration>

Result

- **Awakening during sleep**
  - Decreased by 66% in awakening
    - Case A averages 17.5, Case B average 52.3



<Subject's Sleep State(CaseA)>

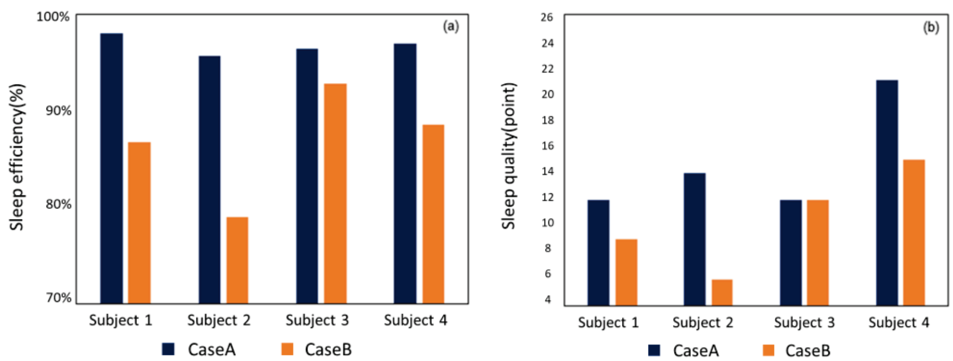


<Subject's Sleep State(CaseB)>

Result

- **Comparison of ventilation and without ventilation**

  - Increased by 17.5% in sleep efficiency
    - Case A average 97%, Case B average 86%
  - Increased by 57% in sleep quality
    - Case A average 15 points, Case B average 10 points



<Sleep efficiency and quality depending on the operation of the ventilation system>

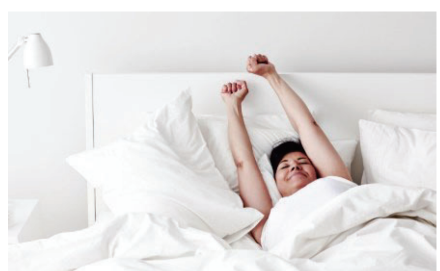
7

Conclusions

- **Sleep experiment considering intermediate season ventilation system**

  - Reduced awakenings during sleep, leading to improved objective sleep efficiency

  - Increase occupant's sleep comfort



- **Further research**

  - Need to expand the number of participants and conduct experiments with various combinations of sleep parameters.

8

Thank you for your attention!

Jeong Won Kim, Dankook University
Sun Ho Kim, Dankook University
Yong Kyu Biak, Seoil University
Hyeun Jun Moon, Dankook University

Speaker: Jeong Won Kim
12210197@dankook.ac.kr

2023 AIVC conference "Ventilation, IEQ and health in sustainable buildings"

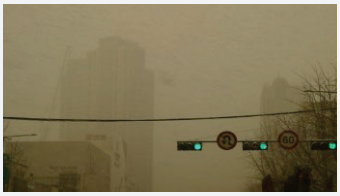
Analysis of PM2.5 indoor-outdoor ratio in lobby floor according to configurations of entrance

2023. 10. 04

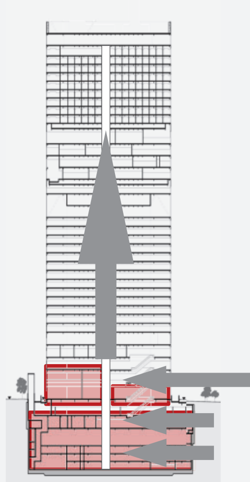
INHA UNIVERSITY
Park, So-Yi
Jo, Jae-Hun
(Email: jhjo@inha.ac.kr)

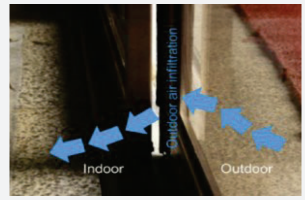
CONTENTS

1. Introduction

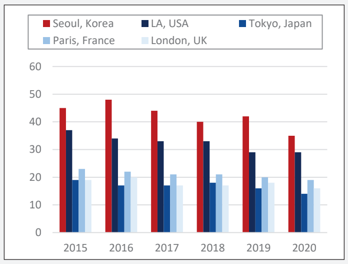


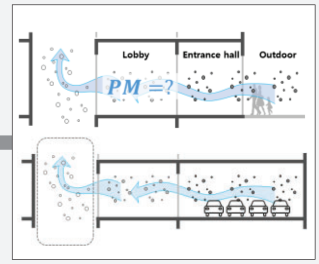
High PM concentrations in outdoor ambient





Pollutant Transfer

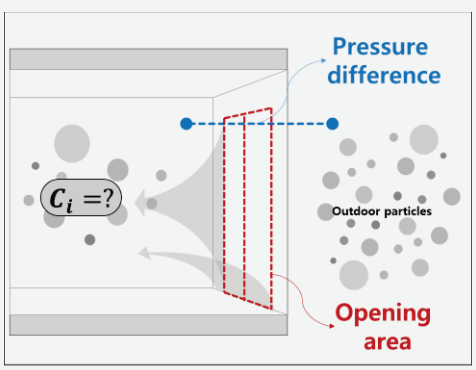




- Outdoor $PM_{2.5}$ has a continuous and significant effect on the indoor environment.
- It is necessary to evaluate the impact of entrance doors on indoor $PM_{2.5}$ to implement appropriate particle control measures.

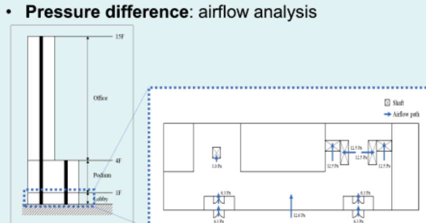
2. Approach

- Penetration of PM through entrance doors



$PM_{2.5}$ I/O ratio for lobby floors was evaluated according to the operation type and configuration of entrance doors

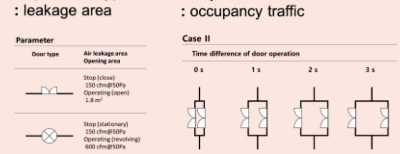
- **Pressure difference**: airflow analysis



- **Opening area:** Case study

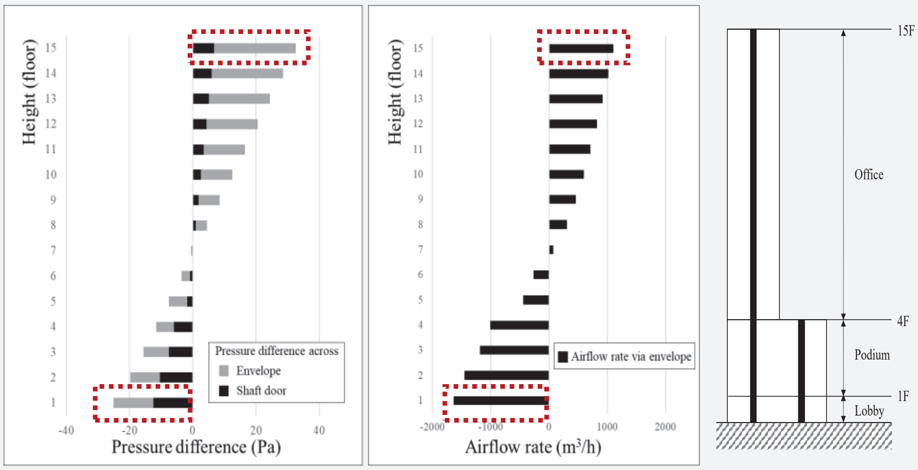
I. Operation type
: leakage area

II. Operation time difference
: occupancy traffic



3. Impact of entrance door on PM2.5 IO ratio

- **Airflow analysis for model building**
  - Lobby level (first floor) had a higher airflow rate (1,634 m3/h) than the top floor (1,102 m3/h) due to entrance doors and a larger envelope area.

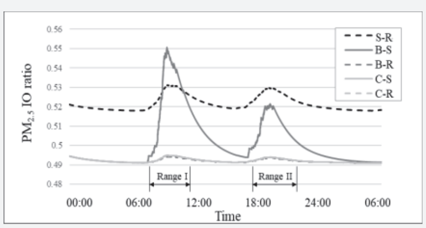


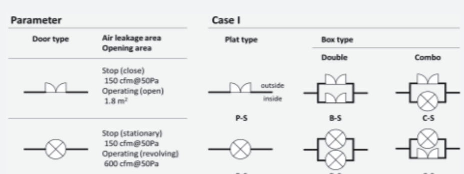
(a) Pressure profile (b) Airflow rate through envelope

3. Impact of entrance door on PM2.5 IO ratio

- **Case study**

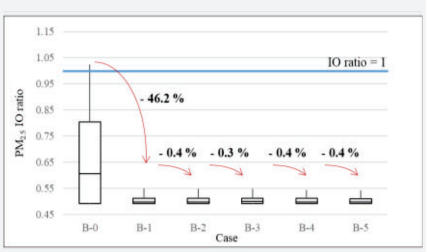
I. Operation type (Air leakage area)

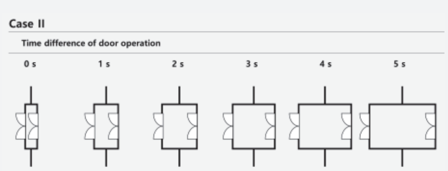




Vestibules can reduce PM concentrations, but consideration needs to be given to occupant traffic and door operation.

II. Operation time difference





Even with a vestibule strategy, depending on the architectural design (door spacing), it can result in a similar performance to a single-type operation.

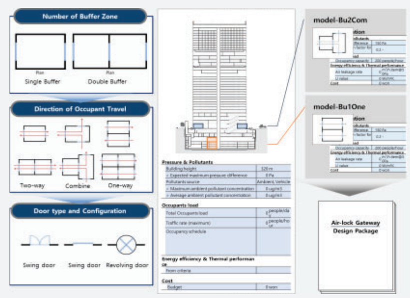
4. Conclusions

The lobby floor's I/O ratio to outdoor PM2.5 concentrations was examined with a case study.

1. Lobby space's penetrated PM2.5 varies due to differing airflow rates from various door operations.
2. A single-type entrance without a vestibule connects directly to outdoor ambient, potentially exposing it to PM2.5 levels equal to or higher than outdoor concentrations.
3. Entrances with vestibules can experience high concentrations if there's no difference in door operating times.

Limitation and Future Work

- Depicting the entire building, door geometry and components are simplified, requiring detailed airflow analysis.
- Development of entrance systems that include architectural design and operational systems to ensure indoor air quality.



Thank you

Proposal of an effort-benefit diagram to compare unit and room air-change rates applied to a literature review

Sven Auerswald
43rd AIVC & 11th tightvent & 9th venticool conference
Copenhagen, 4th of October
www.ise.fraunhofer.de

Agenda

1. Air schange efficiency - absolute
2. Air change efficiency - relative
3. Effort-Benefit-Diagram air exchange - Applied for a literature review

Air change efficiency
absolute

- Efficiency ratio for the air exchange for the whole space j ventilated
- Valid interval: 0 … 1
  - Complete ventilation short-cut: 0
  - Ideal mixed ventilation: 0.5
  - Plug flow condition: 1

$$\varepsilon_j^a = \frac{\tau_j}{\langle \bar{t}_j \rangle} = \frac{1}{2}\frac{\tau_j}{\langle \bar{\alpha}_j \rangle} = \frac{1}{1+\mu_2'^{*}(\tau_j)} = \frac{1}{2}\frac{\langle \bar{n}_j \rangle}{n_j} = \frac{\langle \bar{n}_{e,j} \rangle}{n_j}$$

ε_j^a	Absolute air change efficiency of a system j	[−]
τ_j	Nominal time constant of the system j as a characteristic statistical measure for the time air spends at least within that system	[h]
$\langle \bar{t}_j \rangle$	Average residence time of air within the system j or air age in the exhaust plane of that system	[h]
$\langle \bar{\alpha}_j \rangle$	Average air age within the system j	[h]
$\mu_2'^{*}(\tau_j)$	Dimensionless second order central moment or dimensionless variance of the statistical distribution of residence times outside the system	[−]
$\langle \bar{n}_j \rangle$	Average room air change rate	$[h^{-1}]$
n_j	Nominal air change rate of a system j	$[h^{-1}]$
$\langle \bar{n}_{e,j} \rangle$	Average room air change rate in the exhaust plane of the system j	$[h^{-1}]$

Fraunhofer ISE

Air change efficiency
relative

- Efficiency ratio for the air exchange for a subsystem i inside the space j ventilated.
  - A subzone can be the breathing level.
- Valid interval: 0 … 1
  - ventilation short-cut: 0
  - mixed ventilation: 0.5
  - Plug flow condition: 1

$$\langle \varepsilon_j^a \rangle_i = \frac{\tau_j}{\langle \bar{t}_j \rangle_i} = \frac{1}{2}\frac{\tau_j}{\langle \bar{\alpha}_j \rangle_i} = \frac{1}{2}\frac{\langle \bar{n}_j \rangle_i}{n_j} = \frac{\langle \bar{n}_{e,j} \rangle_i}{n_j}$$

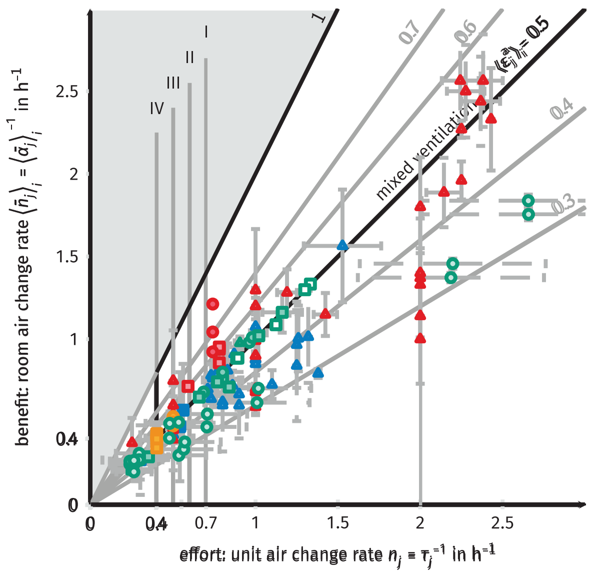
$\langle \varepsilon_j^a \rangle_i$	Relative air change efficiency of a subsystem i in j	[−]
$\langle \bar{t}_j \rangle_i$	Average residence time of air within the subsystem i or air age in the exhaust plane of that subsystem	[h]
$\langle \bar{\alpha}_j \rangle_i$	Average air age within the subsystem i in j	[h]
$\langle \bar{n}_j \rangle_i$	Average room air change rate in the subsystem i	$[h^{-1}]$
n_j	Nominal air change rate of a system j	$[h^{-1}]$
$\langle \bar{n}_{e,j} \rangle_i$	Average room air change rate in the exhaust plane of the subsystem i	$[h^{-1}]$

Fraunhofer ISE

Effort-Benefit-Diagram air exchange
Applied for a literature review

Vertical lines represent the indoor environmental quality categories from EN 16798

- red = test facilities
- orange = simulations residential
- green = measurement residential
- blue = measurement non-residential
- triangle = centralized continuous
- rectangel = decentralized continuous
- round = decentralized alternating



Fraunhofer ISE

Vielen Dank für Ihre Aufmerksamkeit

Sven Auerswald
Energy Efficient Buildings
Building Systems Technology
Fon +49 (0) 761 / 45 88 - 5901
sven.auerswald@ise.fraunhofer.de

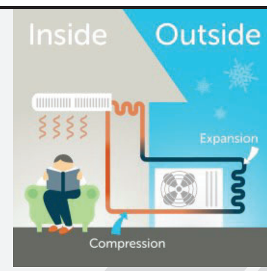
Experimental Investigation of Indoor Air Quality in an Open Office Environment

Altug Alp ERDOGAN
Senior R&D Engineer
ÜNTES Isıtma Klima Soğutma San. Tic. A.Ş.
Ankara/Turkey

Prof. Mustafa Zeki YILMAZOGLU
Gazi University
Ankara/Turkey

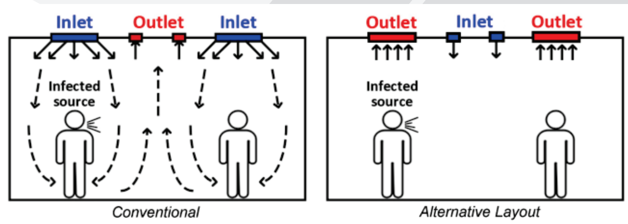
GAZI UNIVERSITY
Faculty of Engineering
Department of Mechanical Engineering

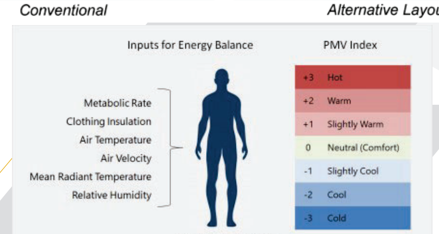
ÜNTES
Building Trust since 1968



INTRODUCTION

- IAQ measurements
- Different ventilation strategy
- Heat pump application in a cold climate





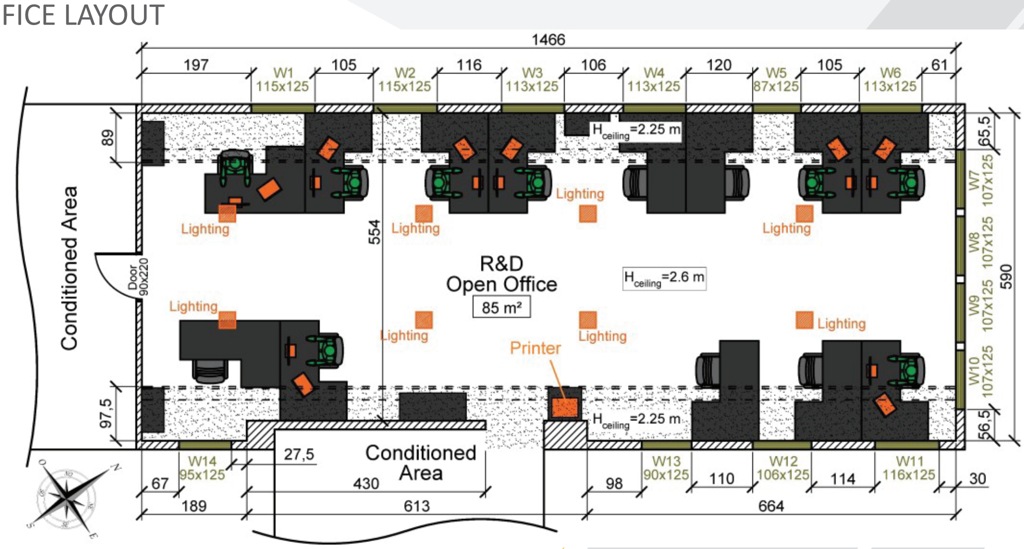
2

Methodology

3

METHODOLOGY

- OFFICE LAYOUT



4

METHODOLOGY

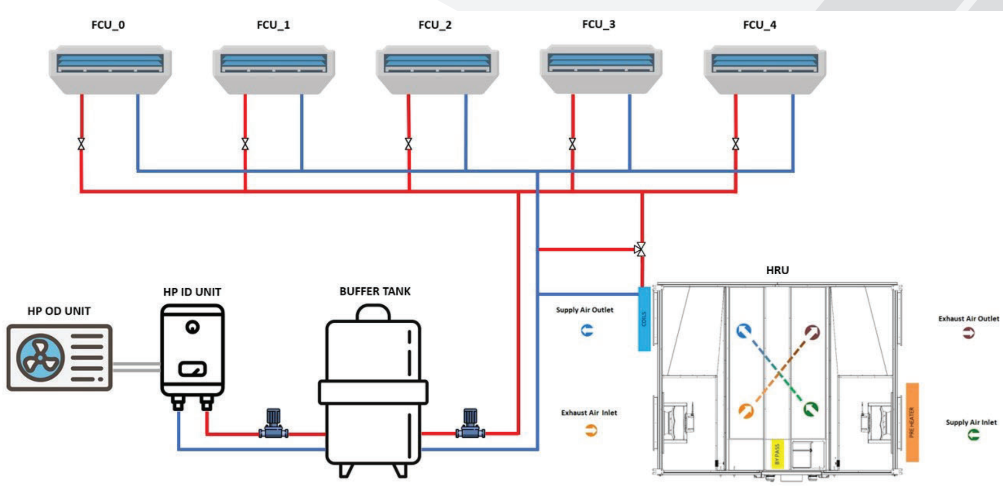
- DESIGN CALCULATIONS

Design Conditions		Outdoor Air Rate		Cooling – Heating Load Calculations				
				Load Source	Load Details	Cooling		Heating
Parameter	Value	Parameter	Value			Sensible	Latent	Sensible
[a]Latitude	40.079 N	[b]q_{occ}	2.5 L/s.person	$Q_{windows}$	18 m^2	2733 W	-	1497 W
[a]Longitude	32.566 E	N_{occ}	13 person	Q_{walls}	48 m^2	80 W	-	369 W
[a]Elevation	843 m	[b]q_{area}	0.3 L/s.m^2	Q_{roof}	84 m^2	1485 W	-	1910 W
Design Heating		Area	85 m^2	$Q_{lighting}$	8 lights	422 W	-	-
[a]DB	-12°C	q_{req}	58 L/s (208.8 m^3/h)	$Q_{equipment}$	8 laptops	500 W	-	-
Setpoint	22°C	[b]E_z	0.8		1 printer			
Design Cooling		[b]E_v	0.66	Q_{occ}	13 people	975 W	780 W	-
[a]DB	31.9°C	[b]q_{calc}	396 m^3/h	Safety	10%	620 W	78 W	378 W
[a]WB	16.8°C			$(Q_{tot})_{space}$	-	6815 W	858 W	4154 W
Setpoint	24°C	q_{safe}	514 m^3/h	$(Q_{tot})_{vent}$	600 m^3/h	976 W		6058 W
		q_{design}	600 m^3/h	Q_{tot}		8649 W		10212 W

[a] The data were retrieved from ASHRAE Climatic Design Conditions website (ASHRAE, 2021).
[b] Values were retrieved from ANSI/ASHRAE Standard 62.1 "Ventilation for Acceptable Indoor Air Quality" (ANSI/ASHRAE, 2019). Minimum air requirements per each occupant (q_{occ}) and per unit area (q_{area}) were obtained by considering the space as an office, whereas the air distribution effectiveness (E_z) and system ventilation efficiency (E_v) were defined by evaluating the ventilation layout described in Figure 1 and Figure 2. The total amount of required outdoor air rate (q_{calc}) was calculated in accordance with the methodology presented in the standard.

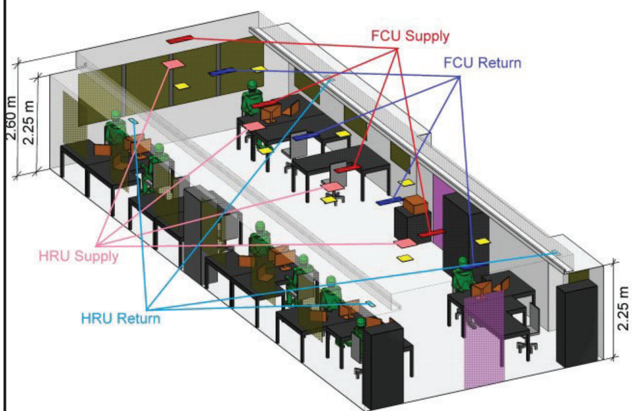
METHODOLOGY

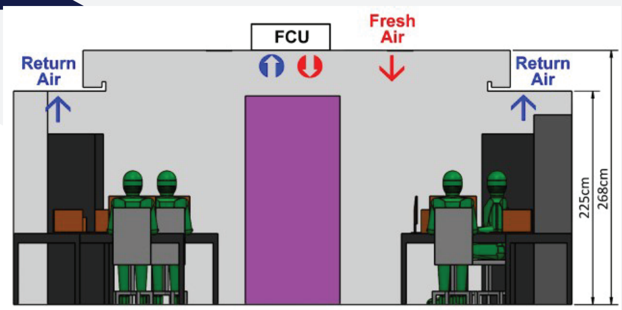
- SCHEMATIC DIAGRAM

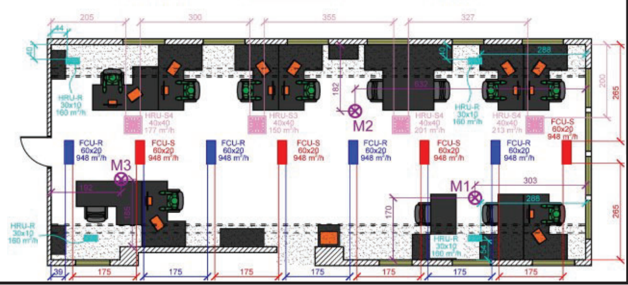


METHODOLOGY

- HVAC LAYOUT







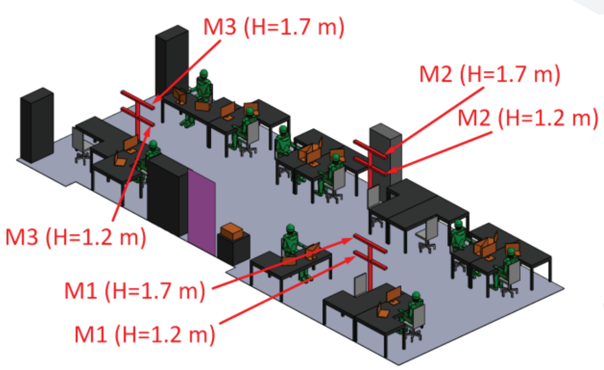
METHODOLOGY

- Device Properties
  - Testo 440
  - Globe Thermometer
    - Emissivity (ε)=0.95
  - CO2 Probe
    - 0-10000 ± 50 ppm
    - 0-50 ± 0.52°C
    - 5%-95% ± 5% RH
  - Turbulence Probe
    - 0-5 ± 0.03 m/s
    - 700-1100 ± 0.1 hPa
  - PMV-PPD calculated

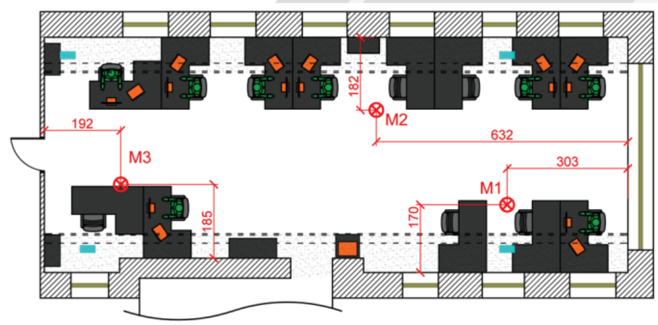
8

METHODOLOGY

- Measurement Locations



Measurement Day	Measurement Location	Measurement Height	Start-Stop Time for HRU
Day 1	M1	1.1 m	10:30 – 18:00
Day 2	M1	1.7 m	09:00 – 18:00
Day 3	M2	1.1 m	08:00 – 18:00
Day 4	M2	1.7 m	08:00 – 18:00
Day 5	M3	1.1 m	08:00 – 18:00
Day 6	M3	1.7 m	11:30 – 18:00



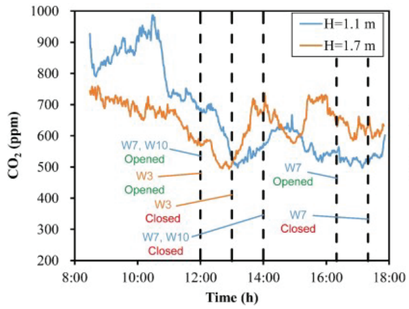
9

Results

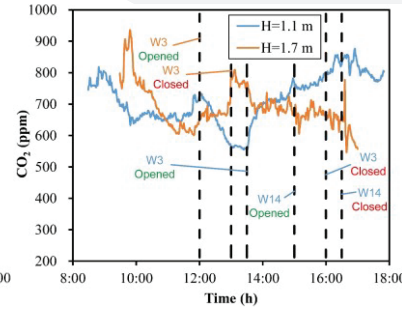
10

RESULTS

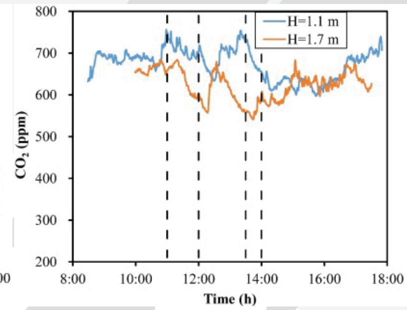
- CO2 measurements



M1



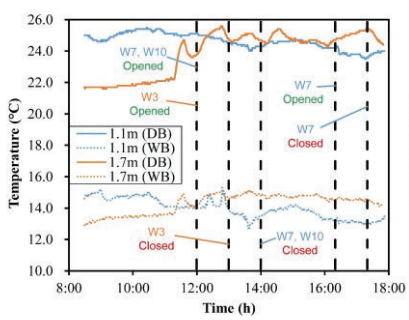
M2



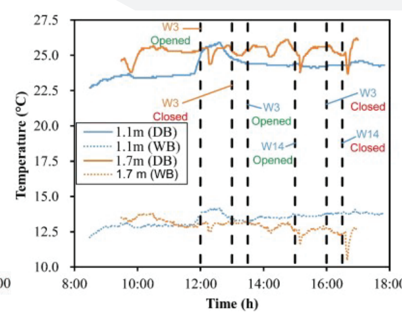
M3

RESULTS

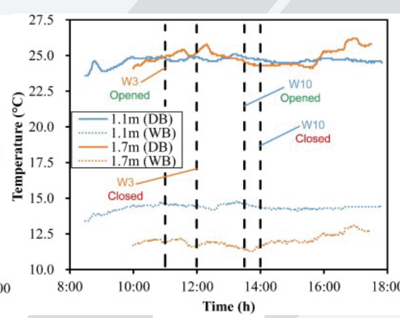
- Temperature measurements



M1



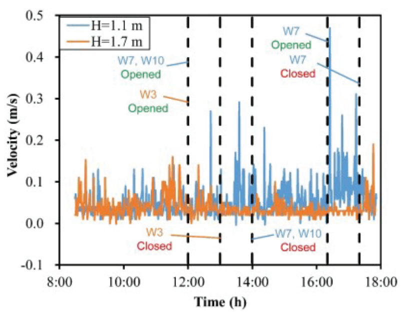
M2



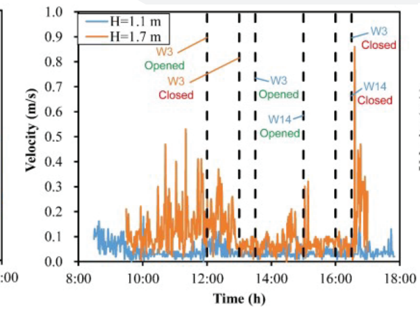
M3

RESULTS

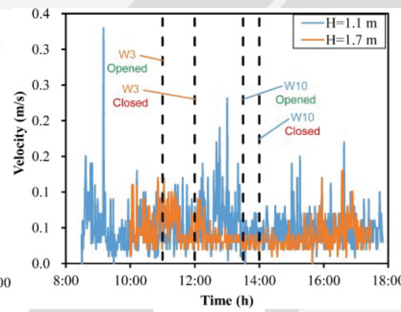
- Velocity measurements



M1



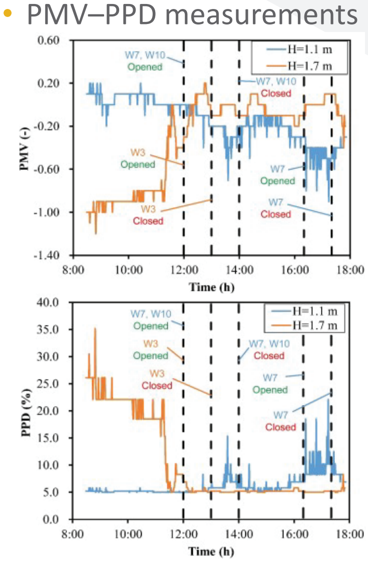
M2



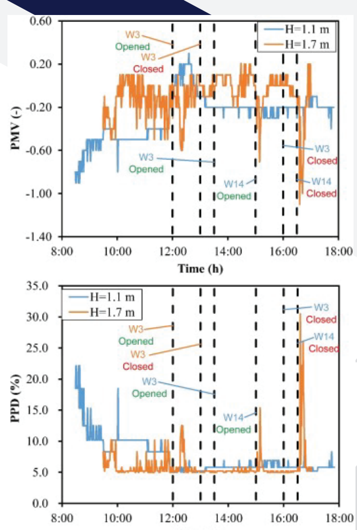
M3

RESULTS

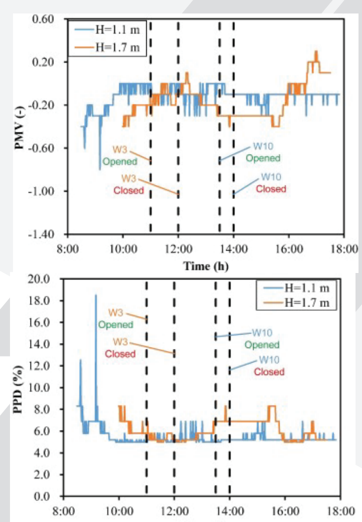
- PMV–PPD measurements



M1



M2



M3

Conclusions

- The alternative supply-exhaust layout can be applicable during epidemic periods.
- CO_2-based ventilation equipments should be considered for Turkish HVAC&R market from energy efficiency aspect.
- Humidifier option for the HRU unit should be considered.

Future Studies

- Evaluation of summer data
- Ventilative cooling
- Particle dispersion

Thank You!

Altug Alp ERDOGAN
+90 553 824 4364
altugerdogan@untes.com.tr
https://en.untes.com.tr/

GAZI UNIVERSITY
Faculty of Engineering
Department of Mechanical Engineering

ÜNTES
Building Trust since 1968
untes UntesKlima untes-international

Hygienic Air Handling Unit Certification Program: the new necessity for a guaranteed indoor air quality

43rd AIVC Conference, October 4-5, 2023, Aalborg University, Copenhagen, Denmark
Ventilation, IEQ and health in sustainable buildings

1

Context

7 millions Death

Per year according to WHO due the IAQ

420 %

Highest Increase in electricity prices in EU compared to 2021

2

Context

25,1 ųg/m³

Concentration of PM 2.5 in Cremona (WHO recommand a maximum of 5 ųg/m³

40 %

HVAC part in building energy consumption

3

Context

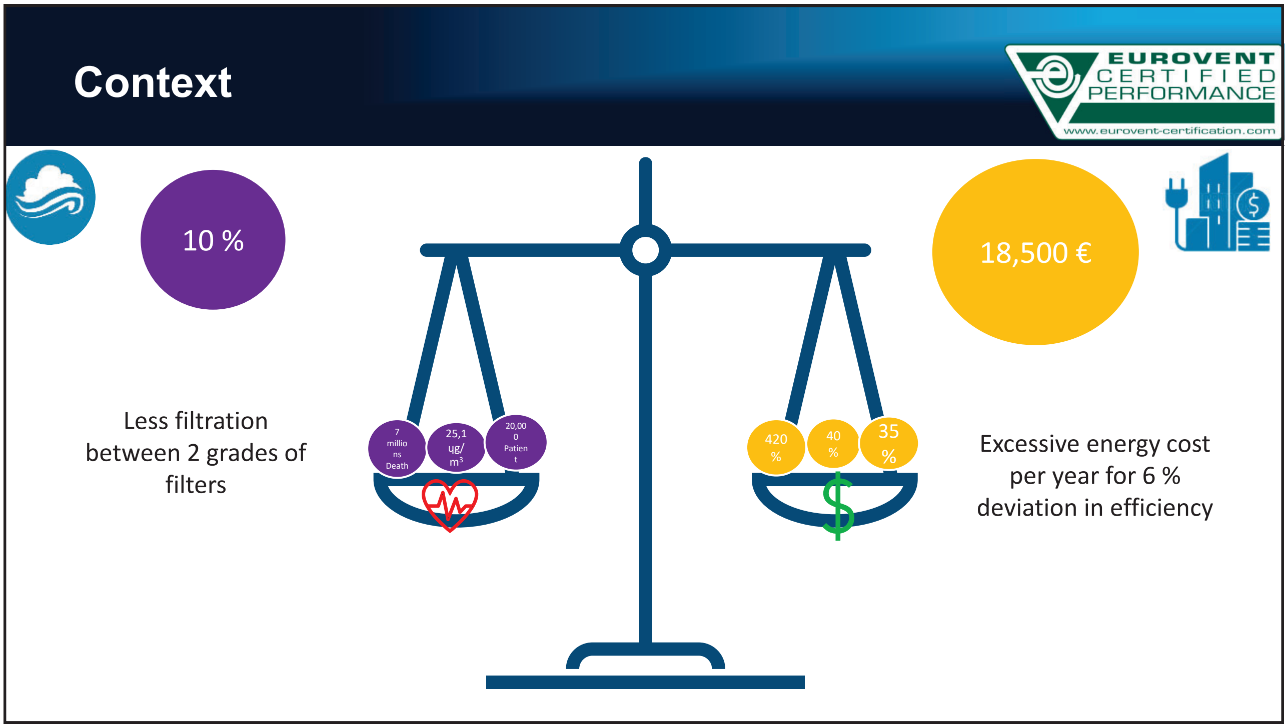
20,000 Patient

Surgical site infection (SSI) cases in EU in 2020

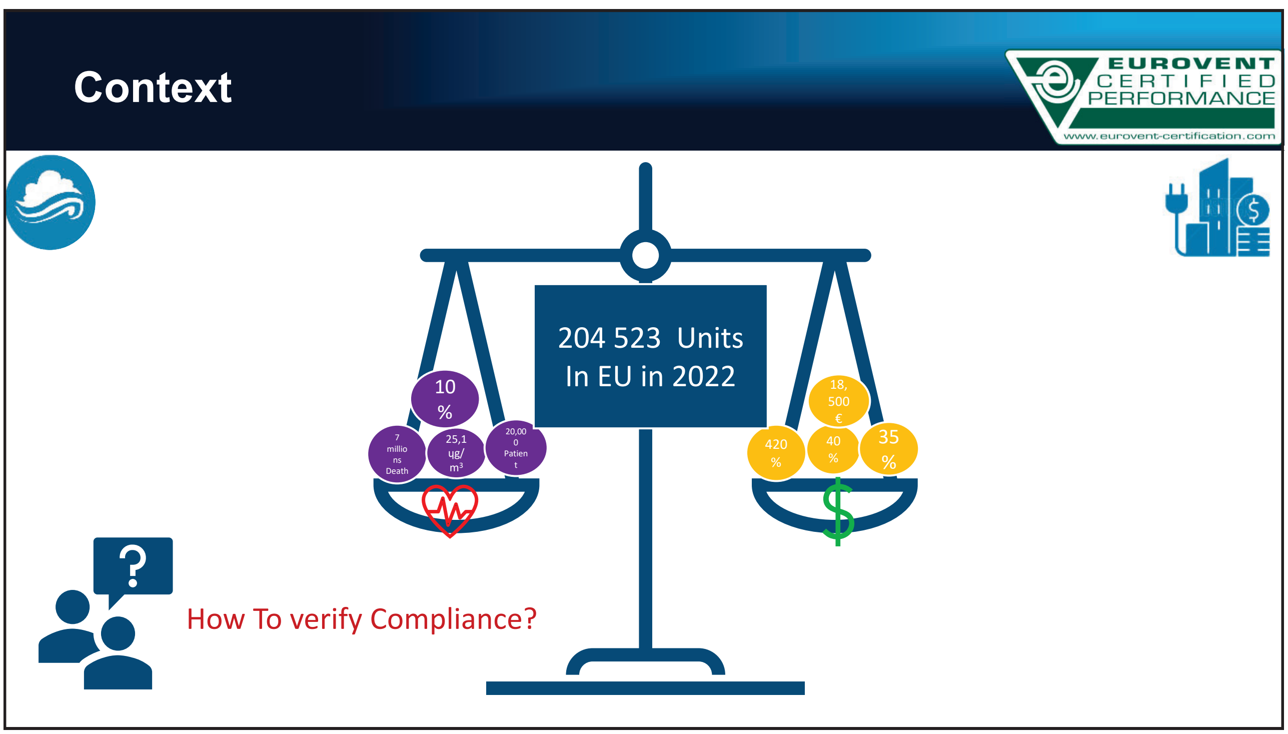
35 %

The part of mechanical ventilation in HVAC consumption

4


Context
EUROVENT CERTIFIED PERFORMANCE
www.eurovent-certification.com
10 %
Less filtration between 2 grades of filters
420 %
40 %
35 %
18,500 €
Excessive energy cost per year for 6 % deviation in efficiency

5


Context
EUROVENT CERTIFIED PERFORMANCE
www.eurovent-certification.com
204 523 Units
In EU in 2022
10 %
18, 500 €
420 %
40 %
35 %
How To verify Compliance?

6

AHU certification program

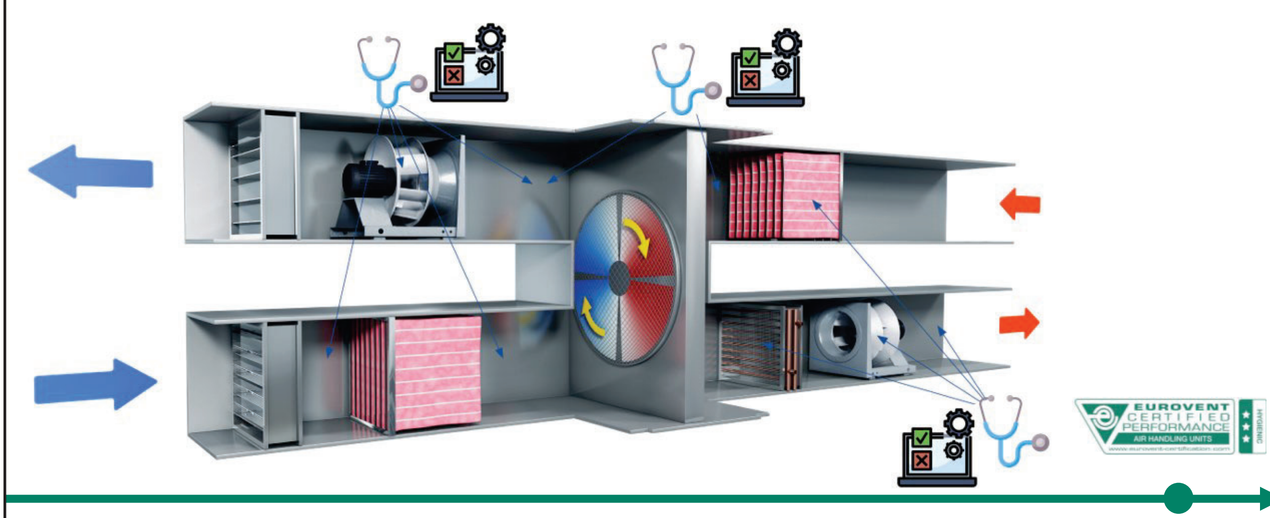
EUROVENT CERTIFIED PERFORMANCE
www.eurovent-certification.com

General	Unit Housing	Air Treatment
✓ Planning ✓ Manufacture ✓ Shipment	✓ Metallic Materials ✓ Non-Metallic Materials ✓ General AHU Arrangement ✓ Inner Casing Surface ✓ Inspection, Maintenance and Cleaning ✓ Filter Maintenance	✓ Filter ✓ Cooling and Heating Coil ✓ Humidifier ✓ Dehumidifier ✓ Heat Recovery System ✓ Fans ✓ Silencer

7

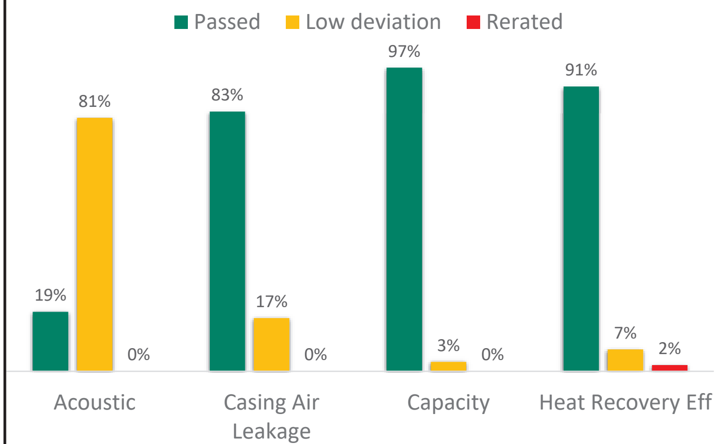
AHU certification program

EUROVENT CERTIFIED PERFORMANCE
www.eurovent-certification.com

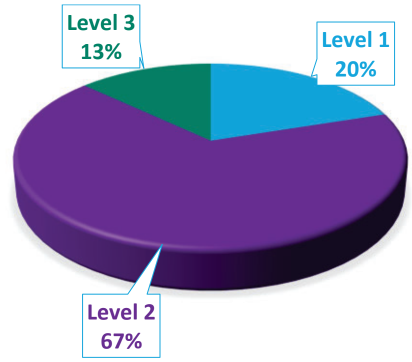


8

2021 Campaign Results



Example of 2021 testing results



Hygienic AHU levels in 2023

9

THANK YOU

10

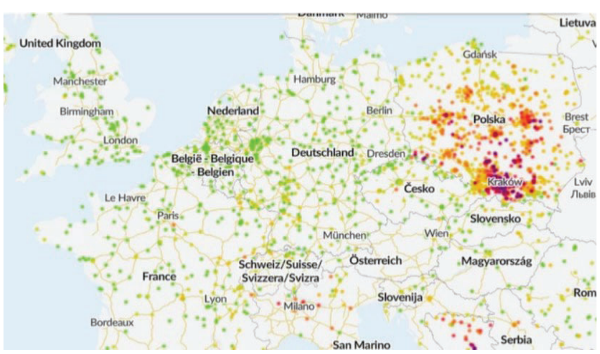
Car traffic or emissions from heating sources:

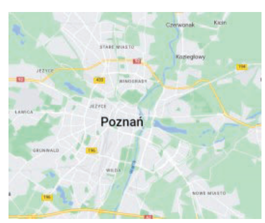
What is responsible for IAQ?

Katarzyna Ratajczak
Faculty of Environmental Engineering and Energy
Maciej Siedlecki
Faculty of Civil and Transport Technology

The objective of short experiment

Assessing the impact of car traffic and heating sources on indoor and outdoor air quality – PM2.5 concentration.





Population: 500,000
Number of motor vehicles: 527,500
The heating network in the city: covers 60% of dwellers with a primary energy ratio of 0.8-0.9
Other heating sources: burning solid fuels and gas

Annual PM2.5: **17.7 $\mu g/m^3$**

May-August PM2.5: **10.1 $\mu g/m^3$**

September-April PM2.5: **22.1 $\mu g/m^3$**

METHODOLOGY

In measurement points assessing:

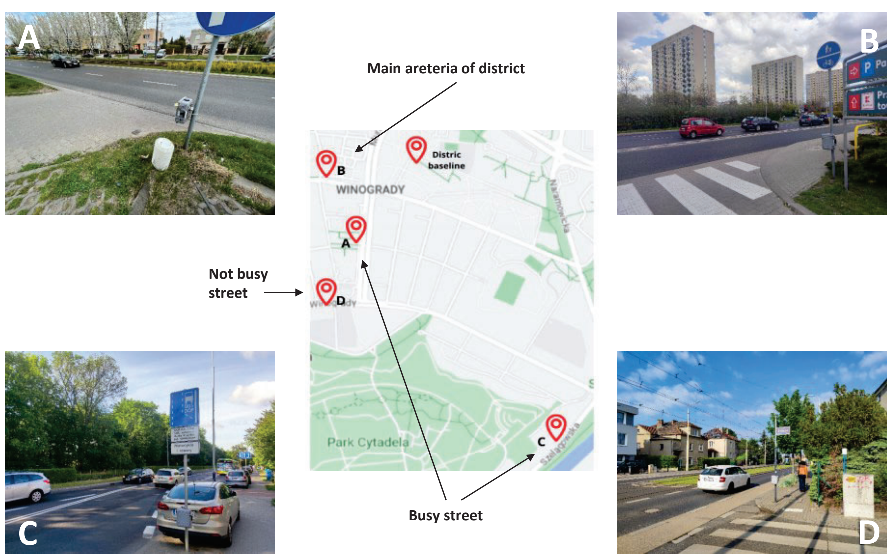
- number of vehicles passing the building (TOPO by Vitronic, Poland)
- PM2.5 concentration in the outdoor air (NEMo Outdoor by Ethera, France)
- PM2.5 concentration in indoor air (NEMo XT by Ethera, France)
- IAQ in rooms located in front of the street
- Off-heating season: temperature 13.5-20.7°C

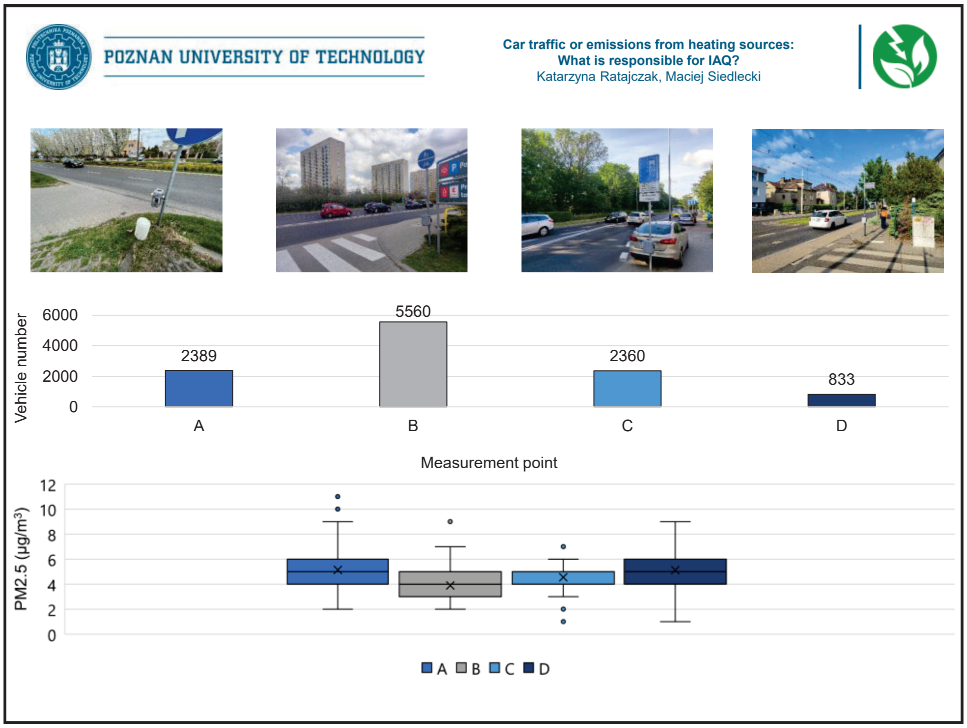
ASSESSMENT CRITERIA

Low PM concentration in the off-heating season → car traffic does not generate high pollution

High PM concentration in the off-heating season → car traffic generates a lot of pollution

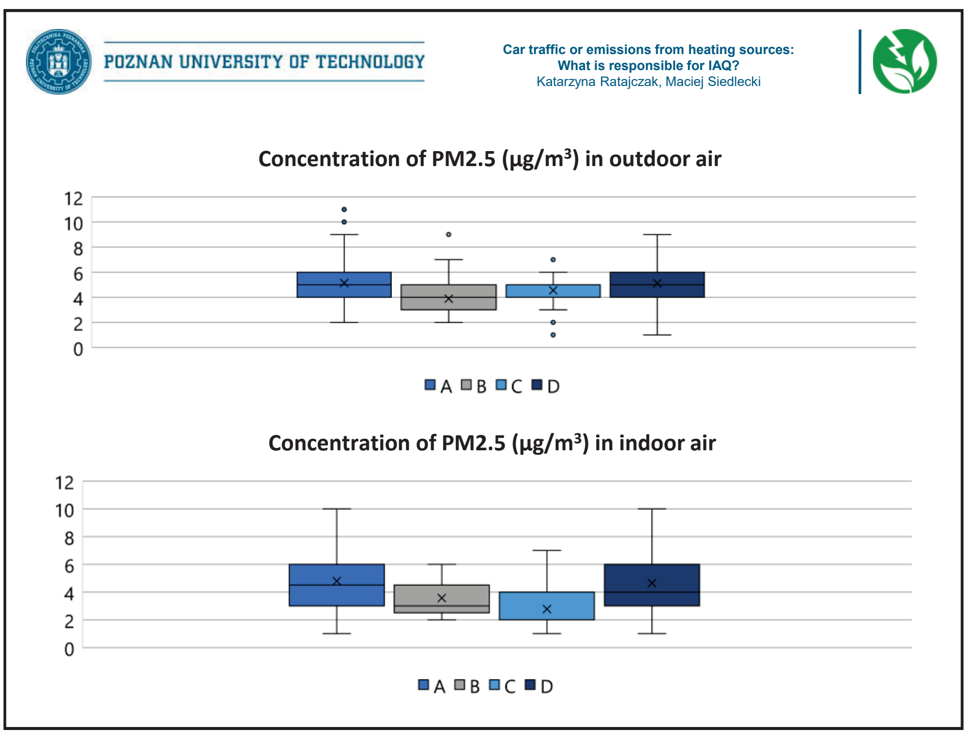
POZNAN UNIVERSITY OF TECHNOLOGY
Car traffic or emissions from heating sources:
What is responsible for IAQ?
Katarzyna Ratajczak, Maciej Siedlecki





POZNAN UNIVERSITY OF TECHNOLOGY
Car traffic or emissions from heating sources:
What is responsible for IAQ?
Katarzyna Ratajczak, Maciej Siedlecki
Vehicle number
6000
4000
2000
0
2389
5560
2360
833
A
B
C
D
Measurement point
PM2.5 (μg/m³)
12
10
8
6
4
2
0
A B C D

5



POZNAN UNIVERSITY OF TECHNOLOGY
Car traffic or emissions from heating sources:
What is responsible for IAQ?
Katarzyna Ratajczak, Maciej Siedlecki
Concentration of PM2.5 (μg/m³) in outdoor air
12
10
8
6
4
2
0
A B C D
Concentration of PM2.5 (μg/m³) in indoor air
12
10
8
6
4
2
0
A B C D

6

CONCLUSIONS

- car traffic does not affect the quality of indoor air in rooms
- assuming that car traffic is similar in May and June to the traffic during winter it can be concluded that poor air quality in winter is caused by the fuels used to heat buildings.

LIMITATIONS

- the measurements lasted only one day
- other parameters like wind speed and direction may affect the results
- we took into account only PM2.5 which is not only parameter of AQ
- research concerns Poland, where the use of low-efficiency heat sources that burn fossil fuels is a huge problem
- we are aware that different socioeconomic conditions may occur in different countries

Car traffic or emissions from heating sources:

What is responsible for IAQ?

Katarzyna Ratajczak
Faculty of Environmental Engineering and Energy
Maciej Siedlecki
Faculty of Civil and Transport Technology

POZNAN UNIVERSITY OF TECHNOLOGY

KU LEUVEN

Monitoring VOCs' concentrations in a circular biobased residential building using low-cost sensors

Yannick THIENPONT (yannick.thienpont@student.kuleuven.be)
Seppe VERBIEST (seppe.verbiest@student.kuleuven.be)

Faculty of Engineering Technology
Ghent Campus

Promotor: Arch. Versele Alexis
Promotor: Prof. dr. ir. Breesch Hilde
Copromotor: Dr. ir. Al-Assaad Douaa

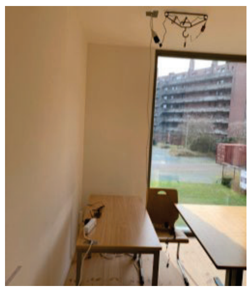
Introduction and objective

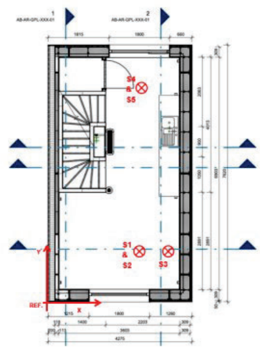
- Biobased materials
  - ➢Laboratory environments
- TVOC concentrations
- Low-cost sensors

Methodology

Interreg — Co-funded by the European Union

- CBCI Living Lab at Campus Ghent (Belgium)
- Biobased building envelope
- Ventilation mechanical extraction
- Sensor location
- Scenarios

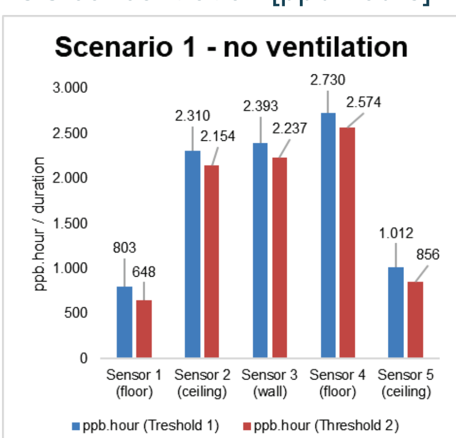


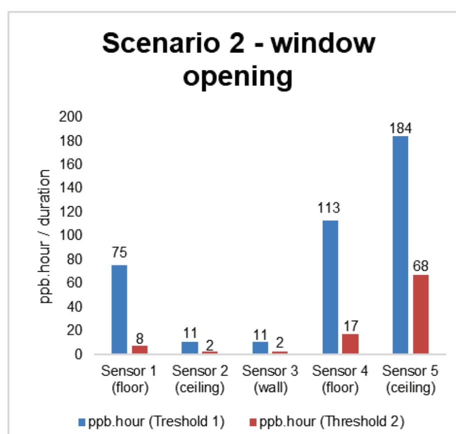


https://iiw.kuleuven.be/onderzoek/building-physics-and-sustainable-design/research/research-projects-map/cbci

Results

- TVOC concentration [ppb.hours]





Threshold 1: Guidance value= 66,7 ppb - Threshold 2: Intervention value= 222,2 ppb

Conclusion

- Importance of ventilation
- Impact of opening windows
- Limitations – experience using low-cost sensors
- Future work
- Questions?

References

- **Slide 2:**
- VOC Emission Test Chamber | ESPEC CORP. (z.d.). https://www.espec.co.jp/english/products/env-test/voc/
- Smart Sensor Solutions. (z.d.). Sensirion.com. https://sensirion.com/products/catalog/SGP30
- Circular bio-based construction industry. (z.d.-b). Building Physics and Sustainable Design. https://iiw.kuleuven.be/onderzoek/building-physics-and-sustainable-design/research/research-projects-map/cbci
- **Slide 3:**
- Interreg Programmes Portal: Find programmes, calls and jobs. (2023, 31 mei). Interreg.eu. https://interreg.eu/

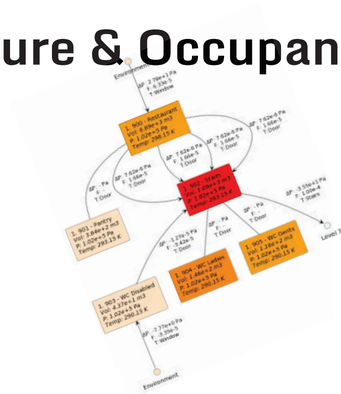
Smart & Predictive Air Quality Solution

Prometech

Dr.Ir. Paul Brasser – ***Scientific Software Developer***
paulb@prometech.eu

1

Protecting Critical Infrastructure & Occupants



Why:

Air quality monitoring to safeguard occupants from external and internal **hazards**

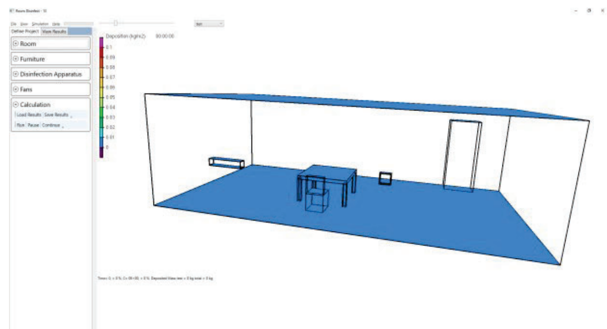
- Monitor and regulate indoor **air quality** to ensure safety of occupants
- Protect against external threats like pollutants and viruses
- Optimise HVAC systems layout & operation
- Improve **emergency** procedures & response and evacuation planning

2

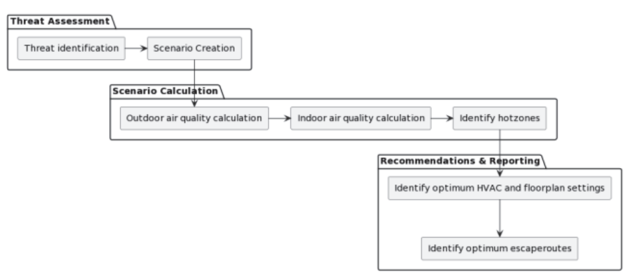
Predict Airflow and Hazard Dispersion

How:

- **Predict** indoor airflow and hazard dispersion
- Considers HVAC and **filtering** systems
- Estimates **effects** on occupants
- Automate smart **evacuation** routes

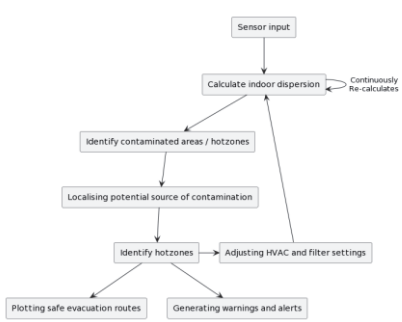


HAVAC Suite - Your Air Quality Guardian



When:

- **Design :** Optimize floorplans
- **Real-time** monitoring



What:

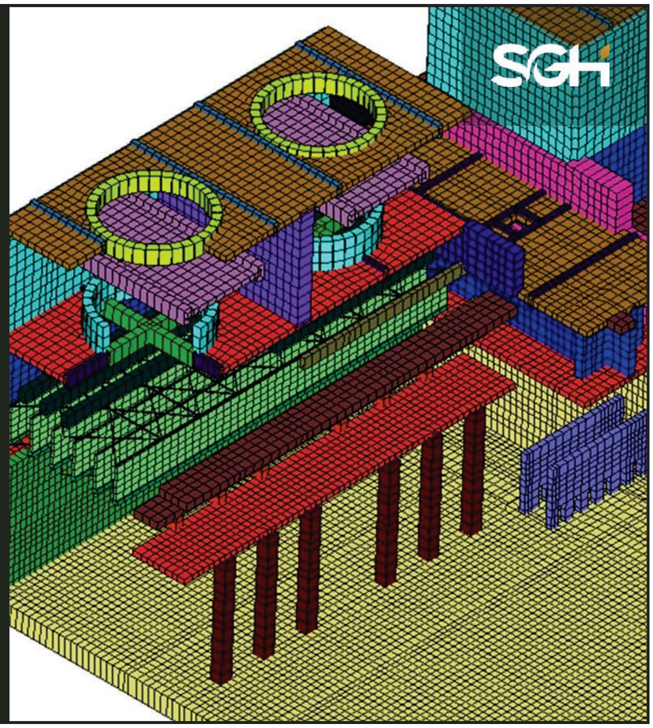
- HAVAC software suite utilises specialised **AI**
- Integrate **IAQ sensors** for predictive modelling
- Identify & predict rooms with **low air quality**
- Smart **alerting** and warning system

ENERGY IMPLICATIONS OF INCREASED VENTILATION IN COMMERCIAL BUILDINGS TO MITIGATE AIRBORNE PATHOGEN TRANSMISSION

Sean M. O'Brien, P.E.
Senior Principal, Simpson, Gumpertz & Heger Inc., New York, NY USA

David Artigas, P.E.
Senior Project Manager, Simpson, Gumpertz & Heger Inc., New York, NY USA

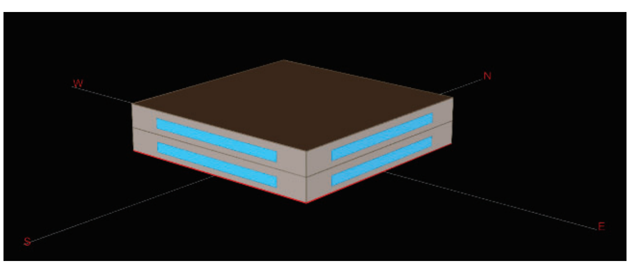
4 October 2023

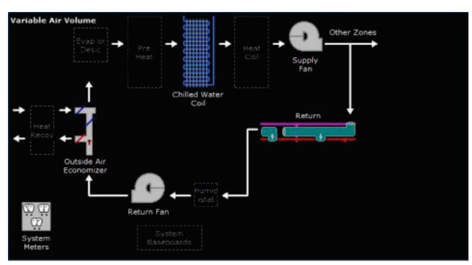


OBJECTIVE

Analyze the energy costs due to and feasibility of increased mechanical filtration and ventilation to mitigate airborne pathogen spread in commercial buildings

Locations	Cases (both locations)	Filtration (NYC 2-story Case)	Ventilation
New York, NY, USA	2-story Office Building	None	IECC minimum
Miami, FL, USA	22-story Office Building	MERV 9-12	20%, 50%, and 100% increase over IECC
		MERV 13-15	USA CDC Recommended 5 ACH





RESULTS

SGH

Filtration

Filtration Level	System Fan Power (kW)	Increase over Baseline	Building Source EUI	Increase over Baseline
None	3.1	-	174	-
MERV 9-12	5.3	71.0%	180	**4.0%**
MERV 13-15	5.8	87.1%	182	**4.7%**

Ventilation

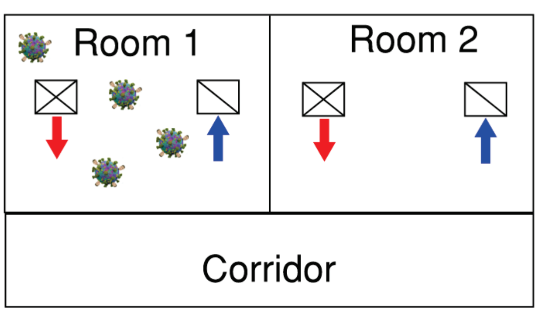
Ventilation L/s/Per	Heating Energy	Increase	Cooling Energy	Increase	Source EUI	Increase
Low Rise, New York						
2.38 (IECC)	48.5	-	32.2	-	181.7	-
4.72 (100% increase)	58.4	20.36%	35.3	9.64%	190.2	4.69%
39.3 (5 ACH)	**507.6**	**947%**	**146.9**	**356%**	**634.4**	**249%**
High Rise, New York						
2.38 (IECC)	305.7	-	379.5	-	178.2	-
4.72 (100% increase)	426.7	39.60%	411.8	8.49%	186.8	4.78%
Low Rise, Miami						
2.38 (IECC)	0	-	84.1	-	235.7	-
4.72 (100% increase)	0	-	96.3	14.53%	251.7	6.83%
High Rise, Miami						
2.38 (IECC)	0	-	853.4	-	225.9	-
4.72 (100% increase)	0	-	982.1	15.08%	241.0	6.70%

3

NEED TO REBALANCE

SGH

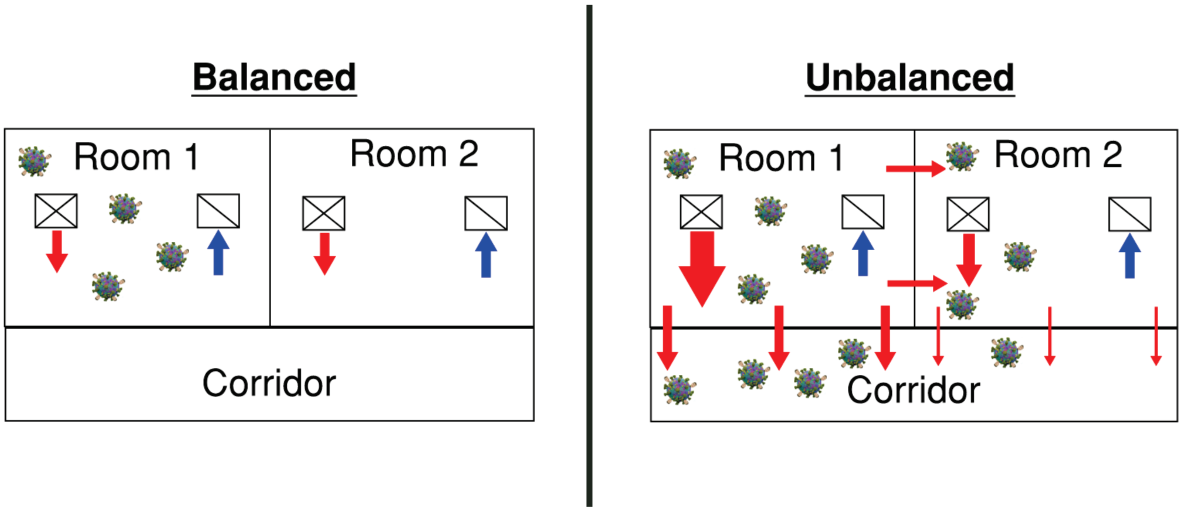
Balanced



4

NEED TO REBALANCE

SGH



5

QUESTIONS?

SGH

Sean M. Obrien, P.E.
Simpson Gumpertz & Heger Inc.
New York, NY USA
smobrien@sgh.com
+1-212-271-6933

David Artigas, P.E.
Simpson Gumpertz & Heger Inc.
New York, NY USA
djartigas@sgh.com
+1-212-271-6940

6

Reflections on alternative modelling approaches regarding occupants' window operation behaviour

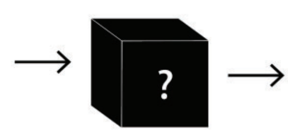
Christiane Berger
Department of Architecture, Design and Media Technology,
Aalborg University, Denmark

Ardeshir Mahdavi
Institute of Building Physics, Services, and Construction
Faculty of Civil Engineering Sciences, TU Graz, Austria

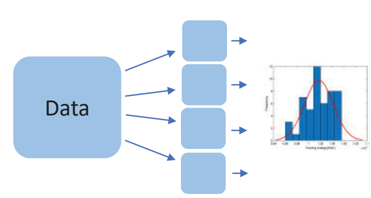
AIVC2023 – 3-5 October 2023 – Copenhagen, Denmark

Motivation

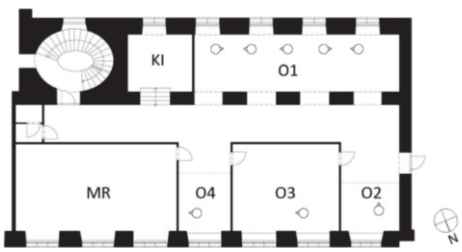
- Models derived from empirical data are typically of a black-box type



- Formulating and testing explicit hypotheses regarding factors that could influence occupants' operation of windows



Illustrative case study



Floor plan of open plan office area (Vienna, Austria)

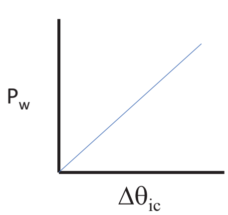
Collected data

- Indoor and outdoor temperatures
- Occupants’ presence
- Window operation actions

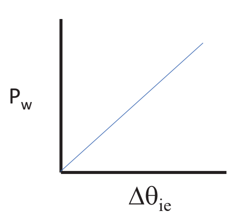
Methodology

- Focus on the probability of window operation actions upon occupants' arrival in the office
- Descriptive statistical analysis
- Formulation of 3 qualitative hypotheses:

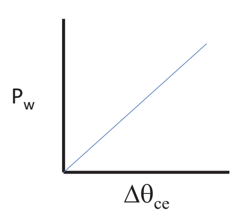
H_i

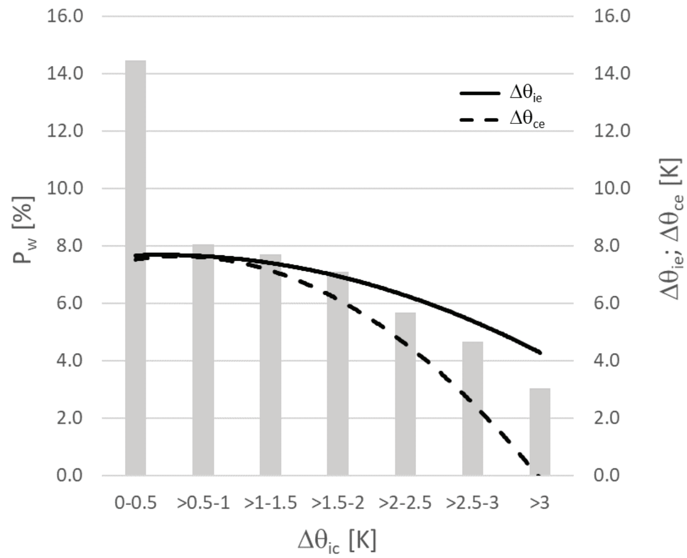


H_{ii}



H_{iii}





$\Delta\theta_{ie}$: difference between indoor temperature θ_i and outdoor temperature θ_e

$\Delta\theta_{ce}$: difference between comfort temperature θ_c and outdoor temperature θ_e

Conclusion

- H_i : The magnitude of perceived thermal discomfort upon arrival cannot, on its own, explain the observed window operation tendency

- H_{ii} and H_{iii} are not rejected: Both higher cooling potential of the outdoor air (H_{ii}) $\Delta\theta_{ie}$ and the pre-arrival experience of thermal discomfort (H_{iii}) $\Delta\theta_{ce}$ could have encouraged window opening behaviour immediately after entering the office space

Reflections on alternative modelling approaches regarding occupants' window operation behaviour

Christiane Berger
Department of Architecture, Design and Media Technology,
Aalborg University, Denmark
chbe@create.aau.dk

Ardeshir Mahdavi
Institute of Building Physics, Services, and Construction
Faculty of Civil Engineering Sciences, TU Graz, Austria

Thank you

for your

attention!

Please consult our paper for more detailed information!

AIVC Section4B

October 4th ,2023

Development of air supplied ceiling radiant air conditioning system using the Coanda effect

Satoshi Noguchi
The University of Kitakyushu

Yasuyuki Shiraishi
The University of Kitakyushu

Daishi Inoue
Nikken Sekkei

Hiroaki Tanaka
Nikken Sekkei

Research background and aim

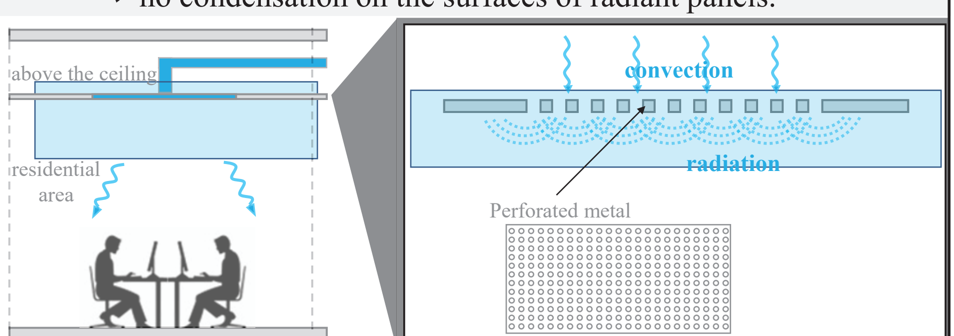
Recently…

ceiling radiant air conditioning systems are increasingly being adopted in office buildings.

In particular …

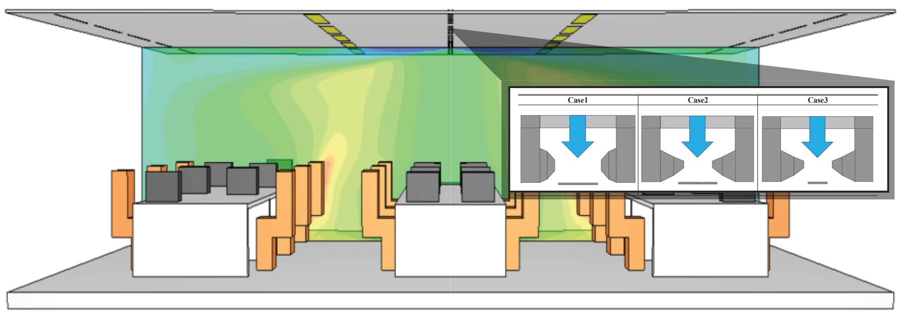
air-supplied ceiling radiant air conditioning systems are expected to become more widespread.

- ✓ no leakage from pipes
- ✓ no condensation on the surfaces of radiant panels.

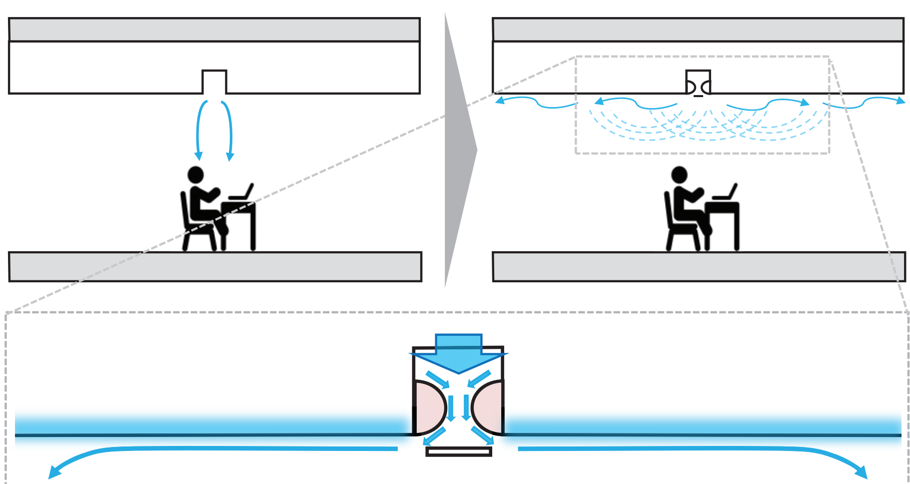


Research background and aim

this research aims to further improve **the comfort of and ease of installing and retrofitting** air-supplied ceiling radiant air-conditioning systems by developing **a line-type Coanda air-conditioning system** for installation in office spaces.

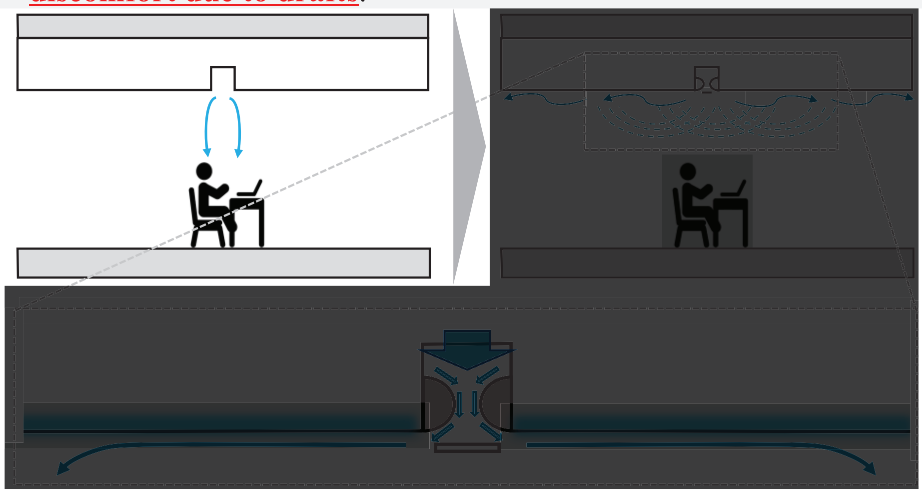


Line type Coanda air conditioning system



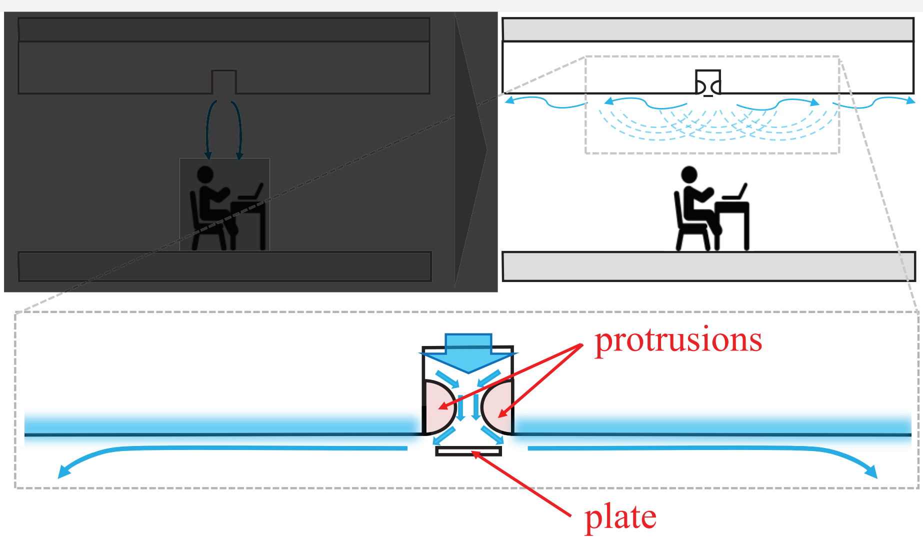
Line type Coanda air conditioning system

A typical air-conditioning system in an office space tends to cause **discomfort due to drafts**.



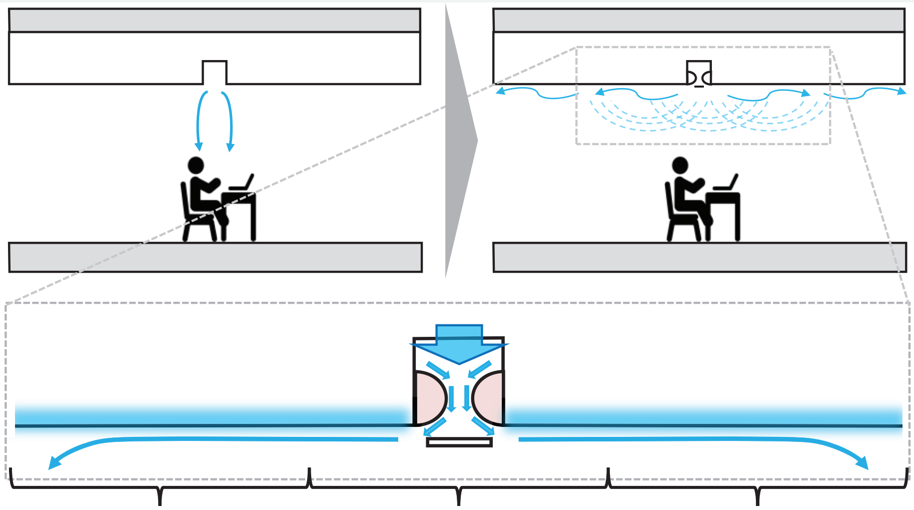
Line type Coanda air conditioning system

in this system, the airflow direction is changed by **installing protrusions** and **plates** at the air outlets and cooling the ceiling surface by the Coanda effect.



Line type Coanda air conditioning system

The coldness creates a **radiative air-conditioning area** near the air outlet and a **convection** one away from it, the aim being to improve the comfort of the entire space.

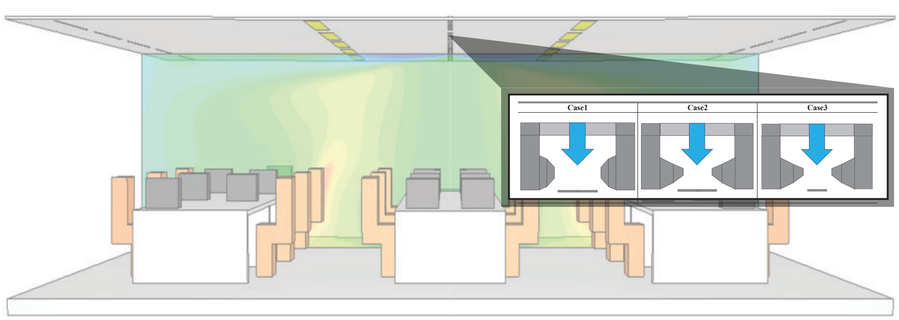


Overview of our research

this research…

① Optimization of outlet shape

» **determine the case that gives the largest separation distance**

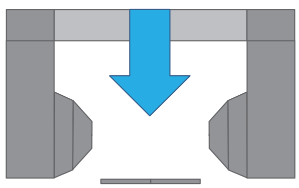
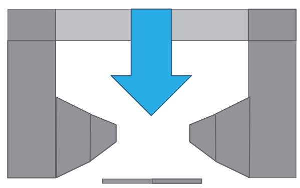
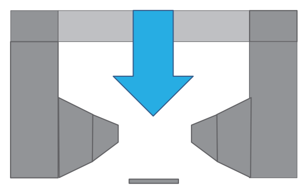


Overview of our research

this research…

① Optimization of outlet shape

» **determine the case that gives the largest separation distance**

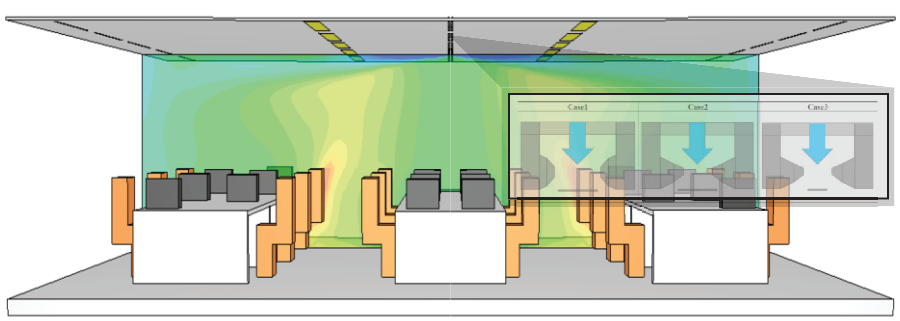
Case1	Case2	Case3
		
Basic Case	A model with extended central projection	A model with half the plate width of Case 2

Overview of our research

this research…

② Validation using model office

» **Demonstrating the effectiveness of a line-type Coanda air-conditioning system**



11

Contents

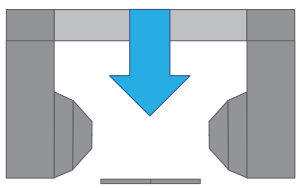
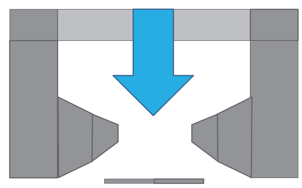
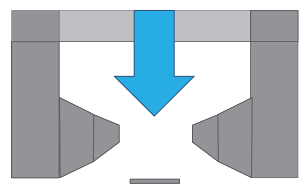
3. Optimization of outlet shape

the protrusion shape is optimised in a computational fluid dynamics (CFD) case study…

✓ determining the separation from the calculated **streamlines**

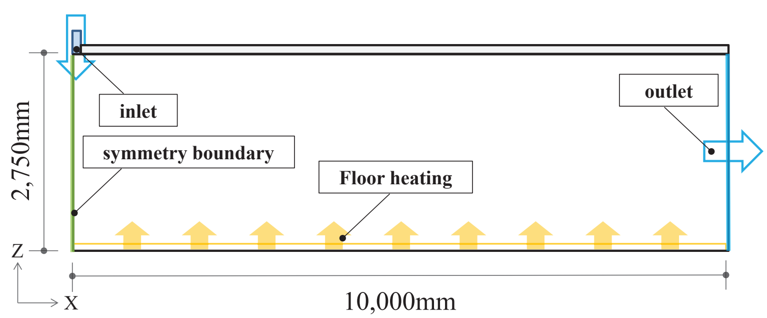
✓ the distance until the blown airflow separates from the ceiling is calculated from how the distribution of **wind velocity vectors varies along the z axis**

the shape that **gives the largest separation distance is considered the optimal shape.**

Case1	Case2	Case3
		
Basic Case	A model with extended central projection	A model with half the plate width of Case 2

3. Optimization of outlet shape

■ the analytical model

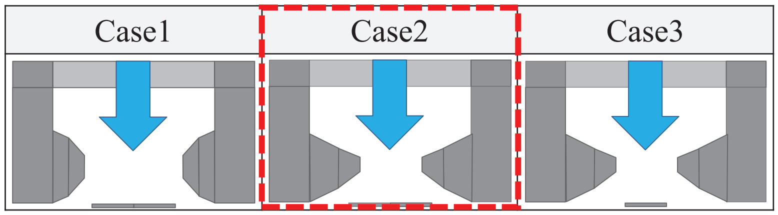


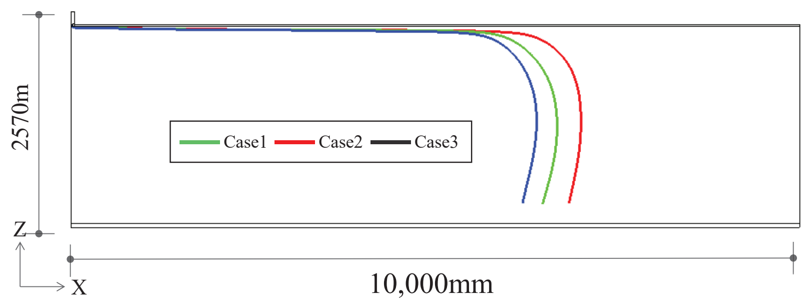
for improved calculation **accuracy** and **reduced calculation load**…

The analysis is performed on **a two-dimensional model**

3. Optimization of outlet shape

■ Results（the streamline analysis ）



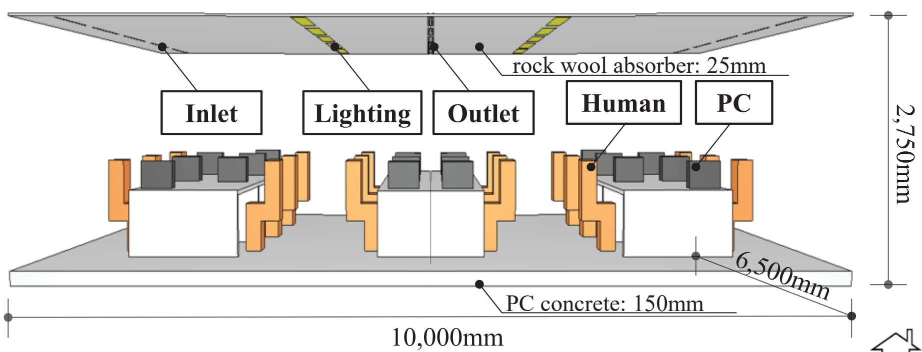


Contents

4.Validation using model office

the temperature, airflow, and radiation fields are analysed by means of steady-state CFD to assess whether the proposed system forms a comfortable thermal environment.

■ analytical model



4.Validation using model office

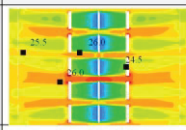
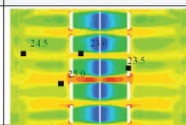
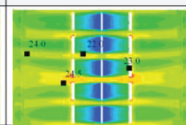
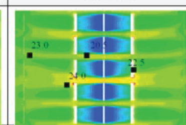
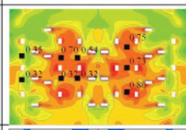
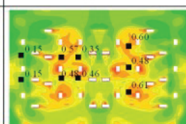
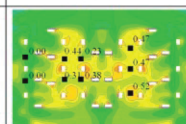
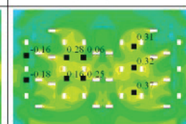
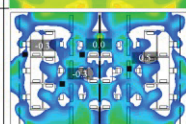
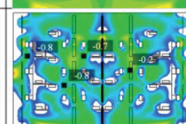
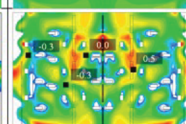
■ analysis cases

	flow rate[m^2/h]	blowoff temperatures[°C]
Case2-1	190	19.11
Case2-2		18.11
Case2-3		17.11
Case2-4		16.11

To derive the optimal operating conditions for the proposed system, the cases were set up with a fixed air flow rate and different air temperatures at each outlet.

4.Validation using model office

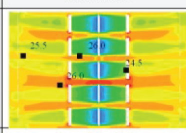
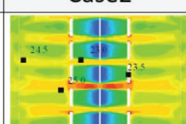
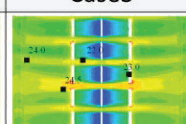
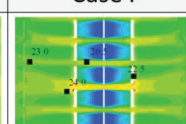
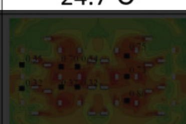
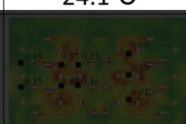
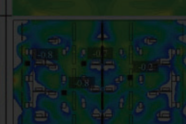
■ Results(Z=1.2)

	Case1	Case2	Case3	Case4
Ceiling surface temperature				
Average	24.7℃	24.1℃	23.4℃	22.8℃
PMV (Z=1.2m)				
EDT (Z=1.2m)				
ADPI	27.4%	70.2%	81.1%	84.7%

Temperature[℃] 20 – 28　PMV -1.0 – 1.0　EDT -1.7 – 1.1

4.Validation using model office

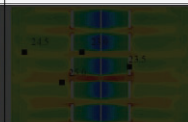
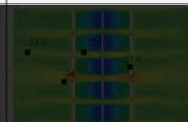
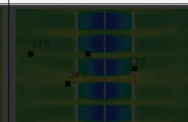
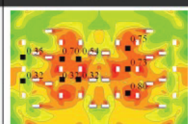
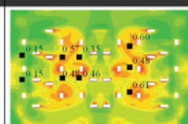
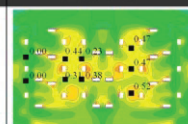
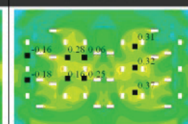
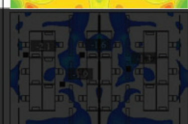
■ Results(Z=1.2)

	Case1	Case2	Case3	Case4
Ceiling surface temperature				
Average	24.7℃	24.1℃	23.4℃	22.8℃
PMV (Z=1.2m)				
EDT (Z=1.2m)				
ADPI	27.4%	70.2%	81.1%	84.7%

Temperature[℃] 20 – 28　PMV -1.0 – 1.0　EDT -1.7 – 1.1

4.Validation using model office

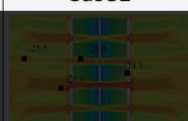
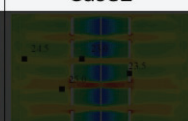
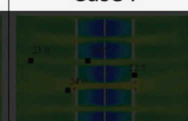
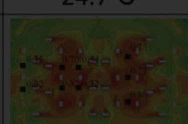
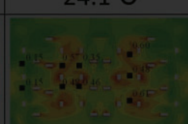
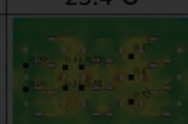
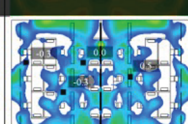
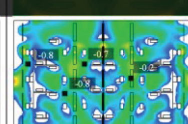
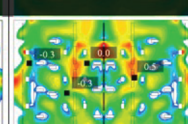
■ Results(Z=1.2)

	Case1	Case2	Case3	Case4
Ceiling surface temperature				
Average	24.7℃	24.1℃	23.4℃	22.8℃
PMV (Z=1.2m)				
EDT (Z=1.2m)				
ADPI	27.4%	70.2%	81.1%	84.7%

Temperature[℃] 20 – 28 PMV -1.0 – 1.0 EDT -1.7 – 1.1

4.Validation using model office

■ Results(Z=1.2)

	Case1	Case2	Case3	Case4
Ceiling surface temperature				
Average	24.7℃	24.1℃	23.4℃	22.8℃
PMV (Z=1.2m)				
EDT (Z=1.2m)				
ADPI	27.4%	70.2%	81.1%	84.7%

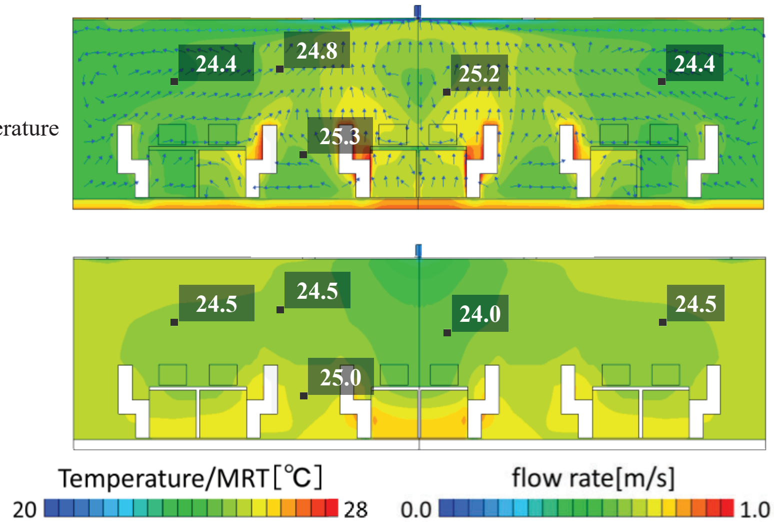
Temperature[℃] 20 – 28 PMV -1.0 – 1.0 EDT -1.7 – 1.1

4.Validation using model office

■ Results (temperature and MRT distributions Y=4.8m)

the temperature

MRT



Contents

1. Research background and aim
2. line type Coanda air conditioning system
3. Optimization of outlet shape
4. Validation using model office
5. Conclusion

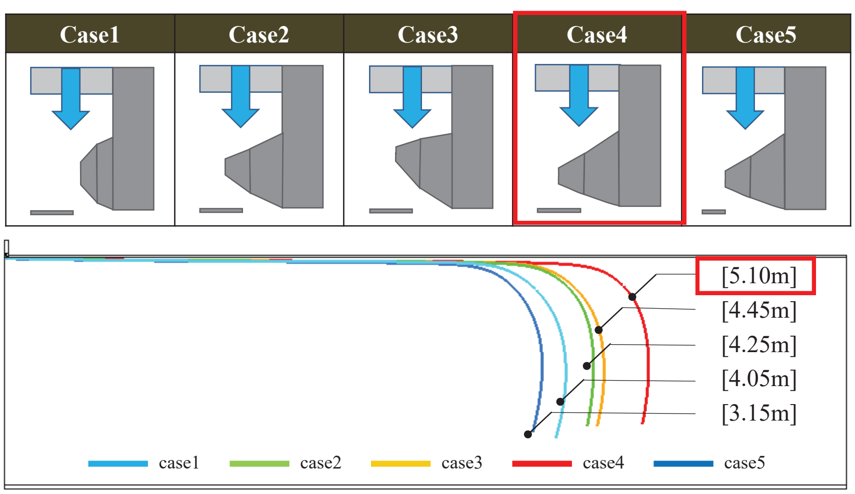
5. Conclusion

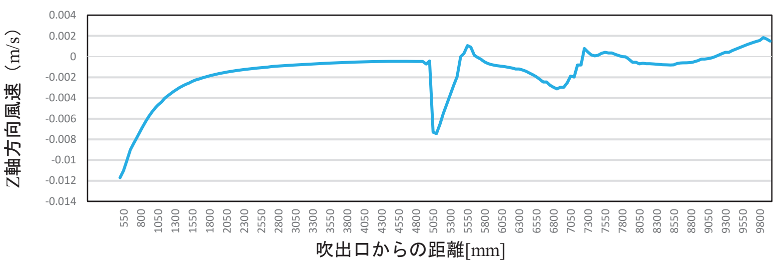
The followings are the findings of this study…

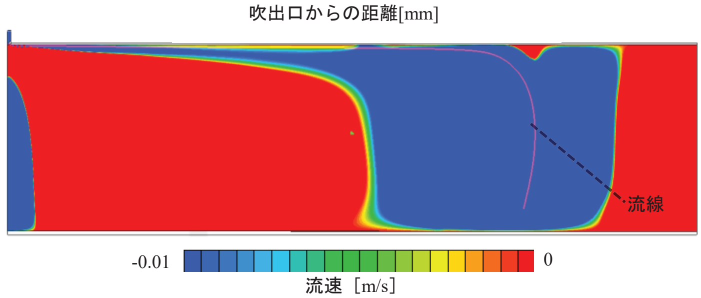
- ✓ We proposed an outlet shape that efficiently cools the ceiling surface.
- ✓ It was confirmed that installing a line-type Coanda air-conditioning system in the model office formed a radiative and a convection air-conditioning area and a comfortable thermal environment with little draft and uneven temperature.

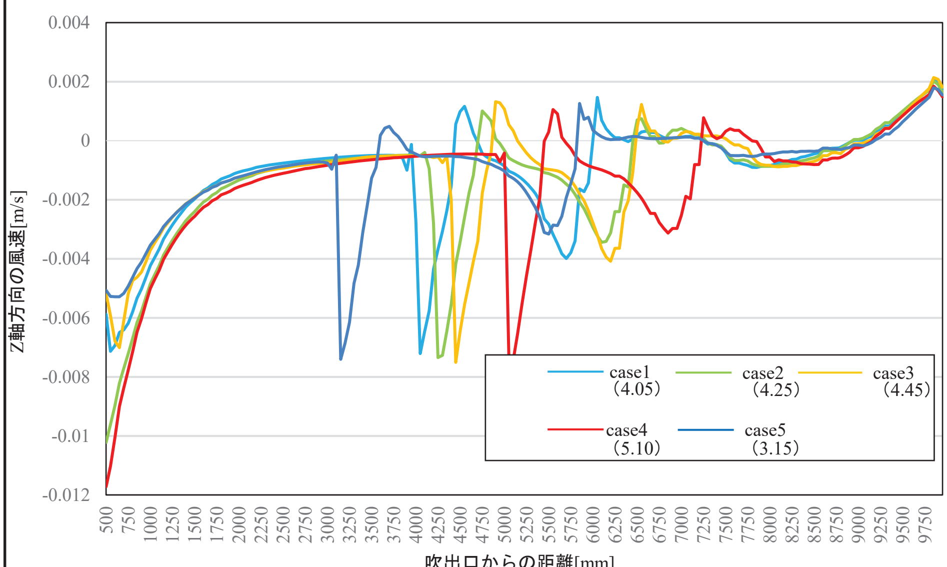
From now on…

- ✓ Comparison with general air-conditioning systems
- ✓ the proposal of design conditions using Archimedes number
- ✓ confirmation of ventilation performance using Age of air and other indices



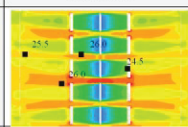
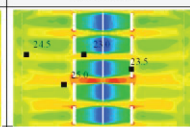
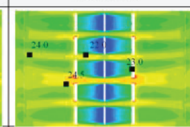
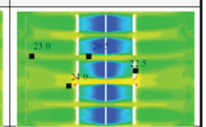
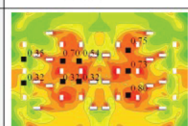
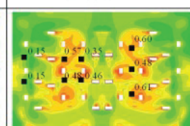
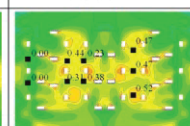
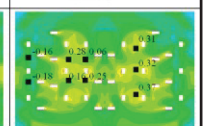
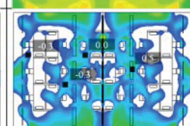
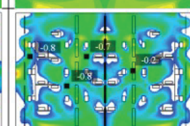
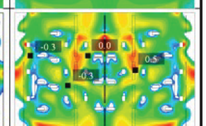

Z軸方向風速（m/s）
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
吹出口からの距離[mm]


流線
-0.01
0
流速［m/s］


Z軸方向の風速[m/s]
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
case1 (4.05)
case2 (4.25)
case3 (4.45)
case4 (5.10)
case5 (3.15)
吹出口からの距離[mm]

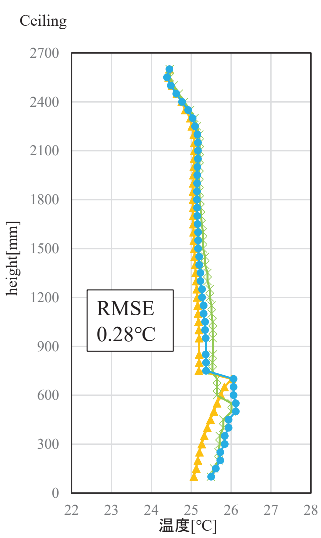
4.Validation using model office

■ Results(Z=1.2)

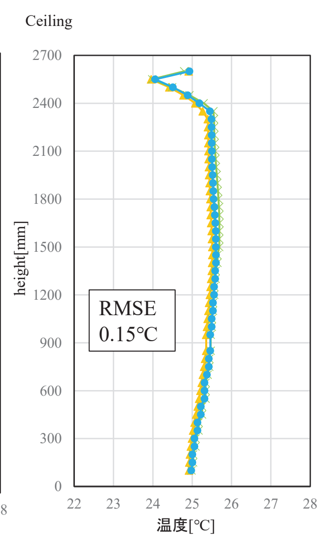
	Case1	Case2	Case3	Case4
Ceiling surface temperature				
Average	24.7℃	24.1℃	23.4℃	22.8℃
PMV (Z=1.2m)				
EDT (Z=1.2m)				
ADPI	27.4%	70.2%	81.1%	84.7%

Temperature[℃] 20 – 28 PMV -1.0 – 1.0 EDT -1.7 – 1.1

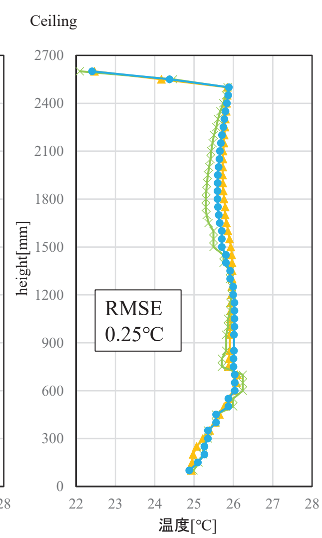
880,000grids 1,000,000grids 2,500,000grids



吹出口から2500mm地点



吹出口から1500mm地点



吹出口から500mm地点

■ EDT(Effective Draft Temperature)

Comfort index taking into account temperature differences and draughts in the room.

EDT=(TEMP-t_c)-7.66*(VECTV-0.15) [℃]

TEMP:室内の局所温度[℃], t_c:居住域平均温度[℃] , V_x:局所風速[m/s]

■ ADPI（Air Distribution Performance Index）

Percentage of EDTs in the comfort zone in the room.

ADPI＝n/n’ × 100 [%]

-1.7＜EDT＜1.1　かつ　気流速度＜0.35m/s ･･･(1)
を満たせば座っている在室者の大多数は満足する
n:(1)を満たすデータ数　n’:総データ数

大阪大学
OSAKA UNIVERSITY

Wind Tunnel Experiment of Wind-Induced Single-sided Ventilation under Generic Sheltered Urban Area

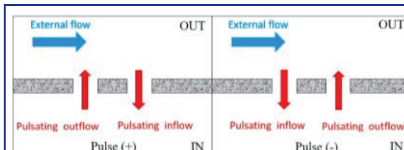
43rd AIVC 11th TightVent & 9th Venticool conference

Zitao JIANG (Osaka University, Japan)
Tomohiro KOBASHI (Osaka University, Japan)
Toshio YAMANAKA (Osaka University, Japan)
Mats Sandberg (Gavle University, Sweden)

1.Introduction

Natural ventilation is an effective strategy to improve indoor air quality without using energy.

Practical problems
The **urban morphology** influences the ventilation performance of **natural ventilation**.



$$Q = (\alpha A)_{eff} V \sqrt{\Delta C_P}$$

It is not accurate if ΔC_P is small.

$(\alpha A)_{eff}$:effective opening area [m²]
V :Reference velocity [m/s]
ΔC_P :Mean wind pressure coefficient difference[-]

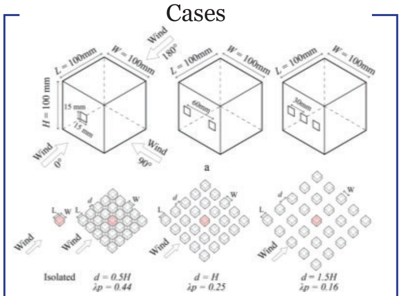
Theoretical problem
The Orifice equation, that uses the mean wind pressure coefficient difference, could not predict ventilation rate well when ΔC_P is small.

OSAKA UNIVERSITY

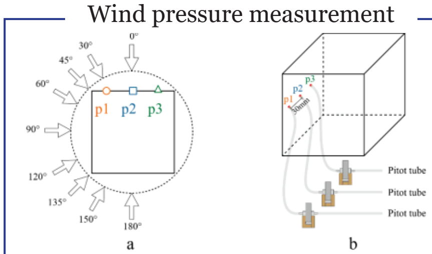
2.Methods

Investigated parameter: wind direction, building density, the number of openings.

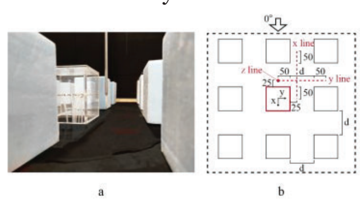
Cases



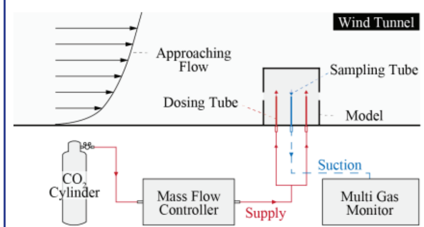
Wind pressure measurement



Wind velocity measurement



Ventilation rate measurement

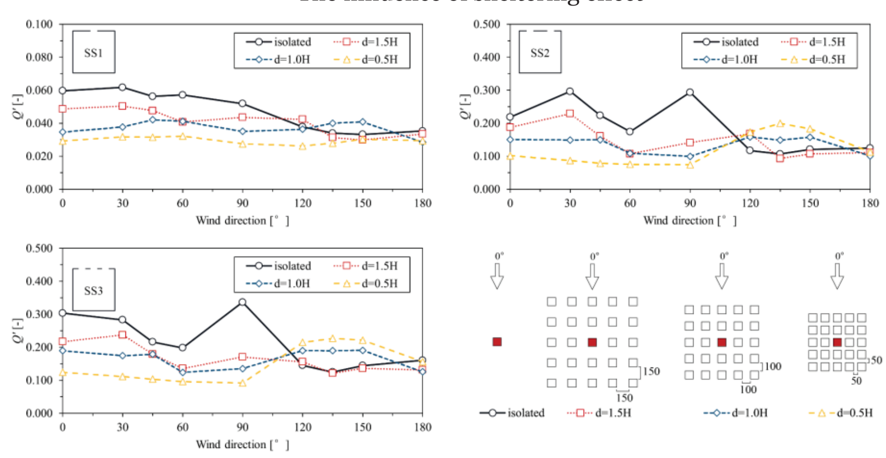


OSAKA UNIVERSITY

3

3.Results & Conclusions

The influence of sheltering effect



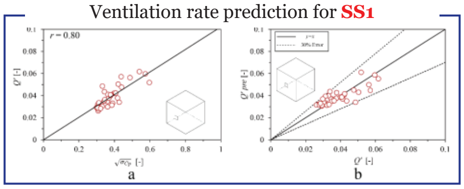
Windward openings: Higher building density **reduces** ventilation rate
Leeward opening: Higher building density **increases** ventilation rate

OSAKA UNIVERSITY

4

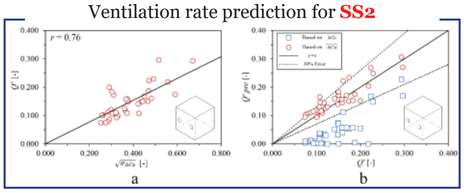
3.Results & Conclusions

Ventilation rate prediction for **SS1**



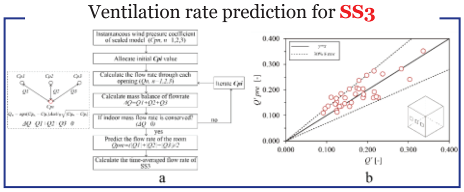
$$Q = CAU_{ref}\sqrt{\sigma_{Cp}}$$

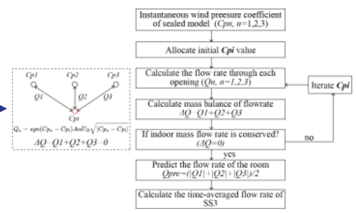
Ventilation rate prediction for **SS2**



$$Q = (C_dA)_{eff}U_{ref}\sqrt{|\Delta Cp|}$$

Ventilation rate prediction for **SS3**





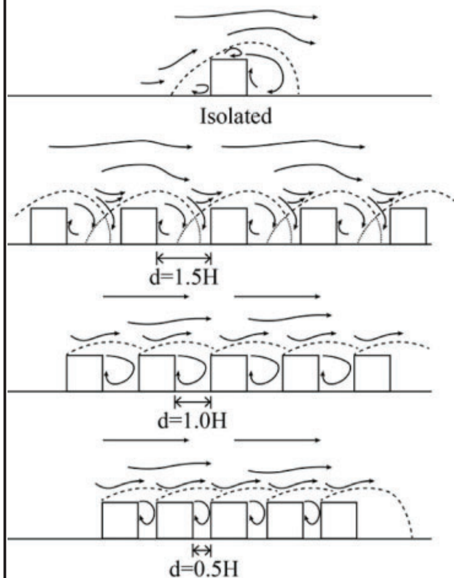
OSAKA UNIVERSITY

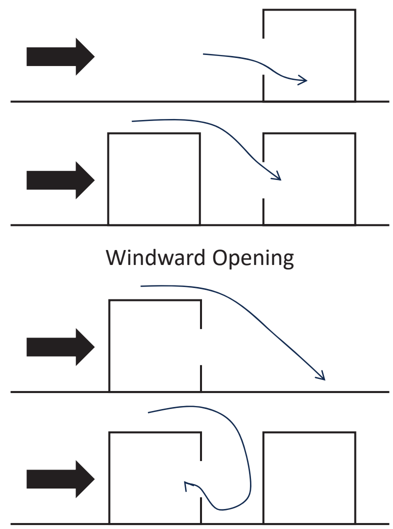
大阪大学
OSAKA UNIVERSITY

Thank you!

Wind tunnel experiment of wind-induced single-sided ventilation under generic sheltered urban area. Building and Environment, *242, 110615. Jiang, Z., Kobayashi, T., Yamanaka, T., Sandberg, M., Choi, N., Kobayashi, N., ... & Toyosawa, K. (2023).*

Why high building density can sometimes increase ventilation rate?





OSAKA UNIVERSITY

10/4/2023 AIVC 2023 Conference

think for future

ミサワホーム総合研究所

A study on desiccant system regenerated by waste heat from home-use solid oxide fuel cell cogeneration system

Keita Mizuno

Isamu Ohta

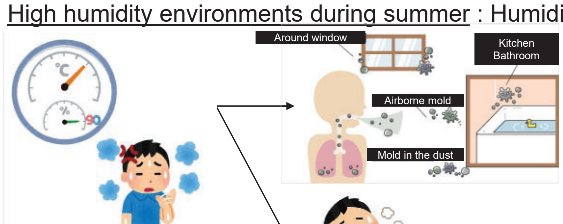
Misawa Homes Institute of Research and Development Co., Ltd.

E-mail:mizuno.k52@home.misawa.co.jp

Research background

①The need for indoor humidity control

・High humidity environments during summer : Humidity environment above 60%



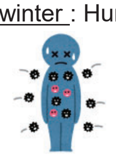
High humidity environment

Mold growth on buildings and equipment, and poor air quality.
⇒Adverse effects on the human health.

・Promote sweating
・Amplifies the feeling of physical fatigue.

・In a low-humidity environment such as winter : Humidity environment below 40%

Viruses easily suspend



The immune system gets weaker.

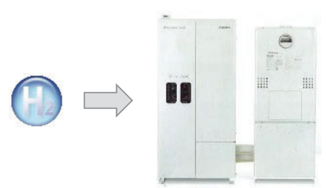
It is necessary to control indoor humidity appropriately with a desiccant system throughout the year in order to realize an indoor environment that takes human health into consideration.

Research background

②The need to achieve carbon neutral by 2050 (COP21,COP27)

- Hydrogen utilization is attracting attention as a way to achieve carbon neutral.
- Building facilities are required to achieve significant energy savings.
- A home-use solid oxide fuel cell cogeneration system is an equipment that uses hydrogen in a home.

Power generation capacity	700W
Waste heat utilization capacity	430W
Waste heat recovery temperature	65℃



Home-use solid oxide fuel cell cogeneration system(Hear after EF)

Electricity

Waste heat ⇒Hot water supply in kitchens and for for showers.

- In summer and in hot and humid regions, the demand for hot water supply is low and unused waste heat is generated.
- If exhaust heat is not utilized and accumulates, EF will shut down.

By using waste heat for dehumidification and humidification, unused waste heat is reduced. In addition to improving overall efficiency of the EF, it also increases the operating hours and high-load operation(efficient operation) of EF.

Research purpose

By identifying methods to maximize the use of limited waste heat, the goal is to achieve an indoor environment that contributes to energy conservation while also being considerate of human health.

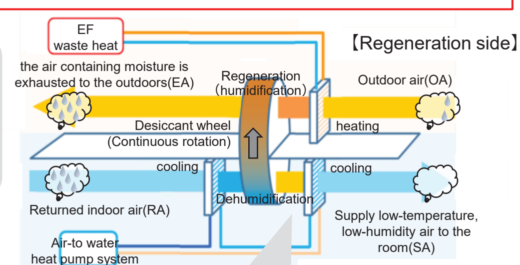


Figure: Internal configuration of desiccant unit

Subject①
The EF waste heat usage by sending water(about 65℃).
⇒Clarified the flow rate that maximizes the amount of the waste heat usage.

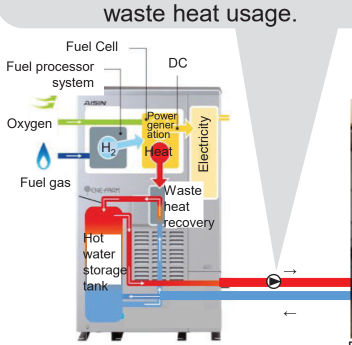


Figure: Home-use solid oxide fuel cell cogeneration system(EF)

Figure: Desiccant unit

Subject②
The balance of air volume（OA and RA） that maximizes the amount of dehumidification was clarified.

Research results

Subject①

Clarified the flow rate that maximizes the amount of the waste heat usage.

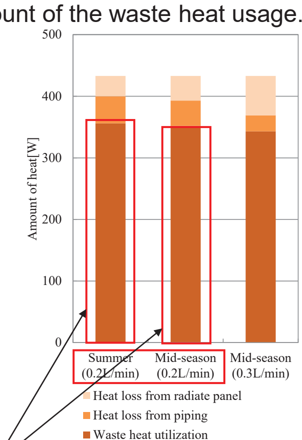
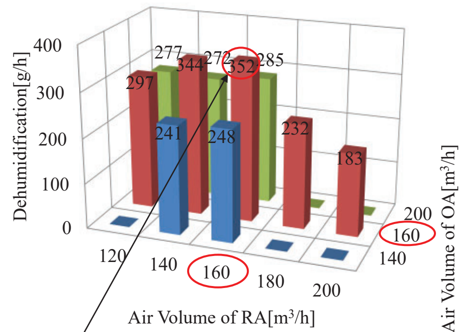


Figure: Breakdown of waste heat

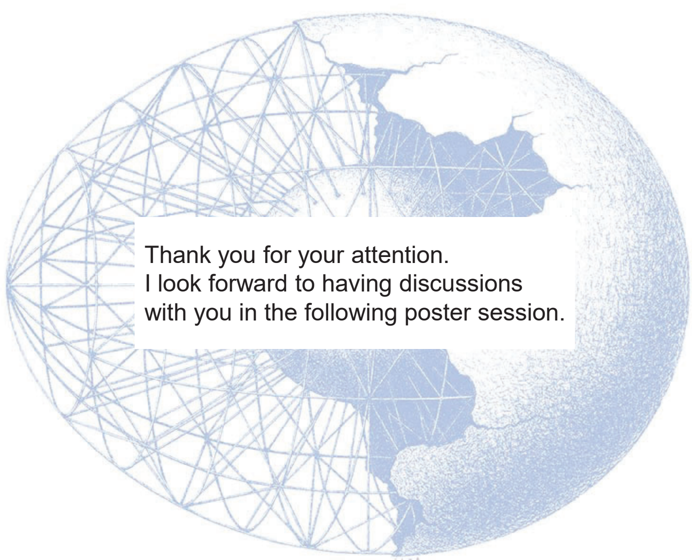
With a flow rate of 0.2L/min, about 80% of the heat emitted from the EF was utilized in the desiccant unit in both the mid-season and summer seasons.

Subject②

The balance of air volume(OA and RA) that maximizes the amount of dehumidification was clarified.



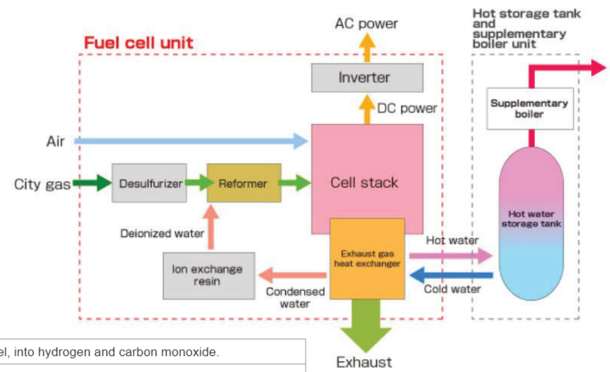
The peak dehumidification amount was at 160 m3/h for both air volumes, with a maximum dehumidification rate of 352 g/h.



Thank you for your attention.
I look forward to having discussions with you in the following poster session.

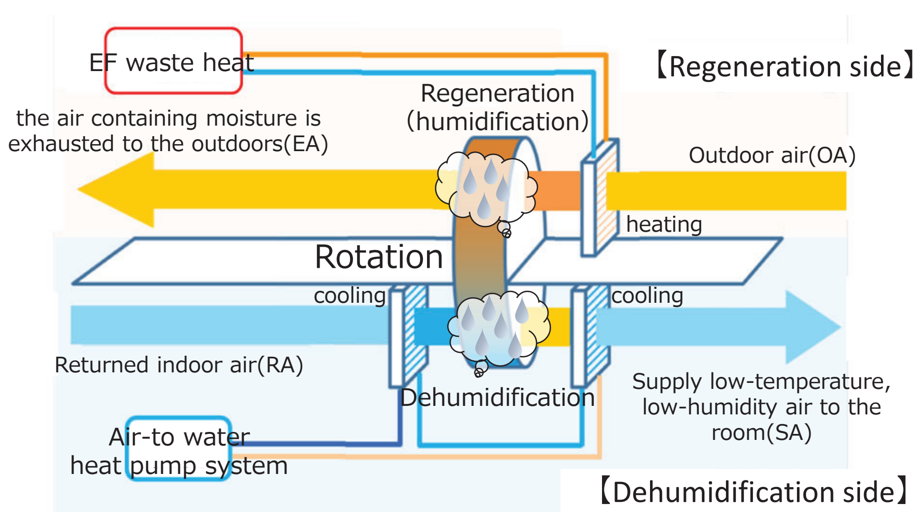
Supplementary materials

SOFC consists of two parts, a ‘fuel cell unit’ and a ‘hot storage tank and supplementary boiler unit’. The fuel cell unit generates electricity and simultaneously recovers the exhaust heat as hot water. The hot storage tank and supplementary boiler unit stores the recovered hot water to supply hot water.



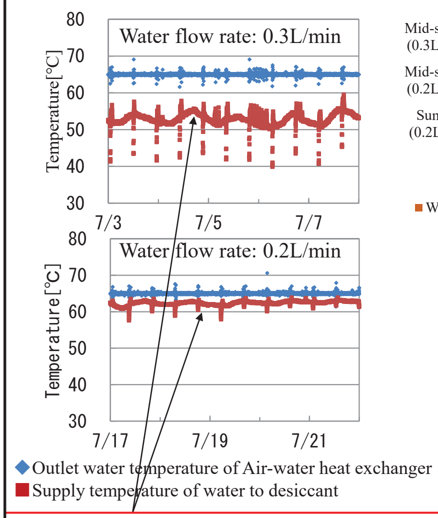
1.Reformer	Converts city gas, fuel, into hydrogen and carbon monoxide.
2.Cell stack	Generates power using oxygen in the air and city gas(reformed to hydrogen and carbon monoxide.)
3.Inverter	Converts power generated in the cell stack into alternating current and supplies it to homes.
4.Exhaust gas heat exchanger	Recovers the heat generated during power generation as hot water.
5.Hot-water storage tank	Tank for storing hot water recovered by the exhaust gas heat exchanger.
6.Supplementary boiler	When there is not enough hot water in the hot water storage tank, the supplemantary boiler is used to supply hot water.

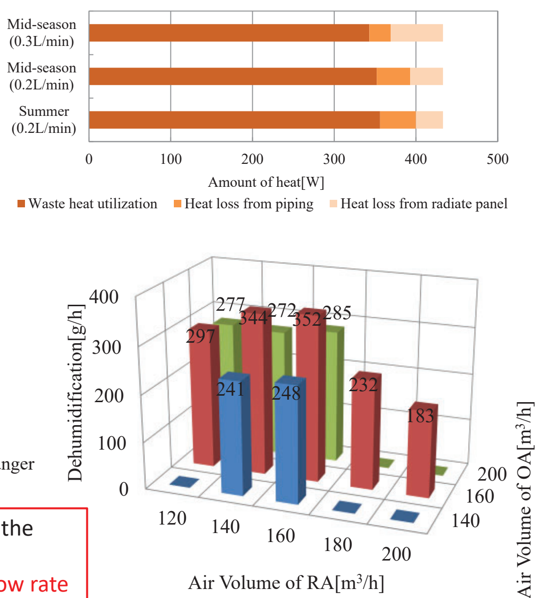
Supplementary materials-Desiccant unit-



The balance of air volume that maximizes the amount of dehumidification was clarified.

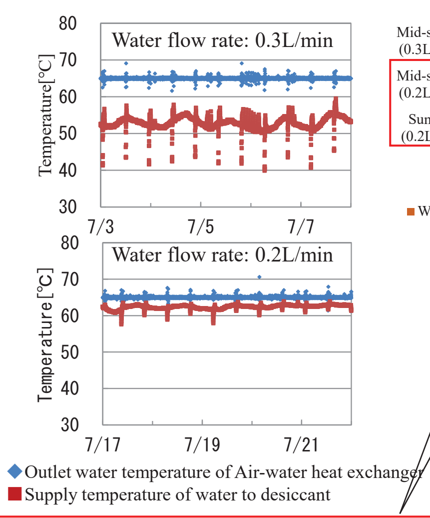
Supplementary materials

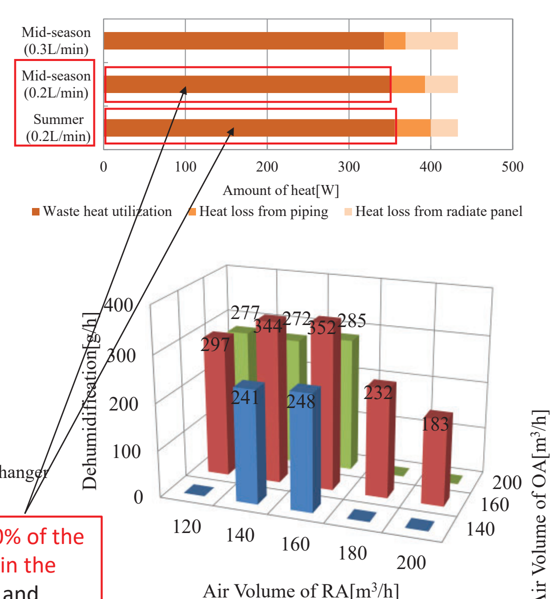




The hot water temperature supplied to the desiccant unit was stable at 62-63°C, approximately 10°C higher when the flow rate was 0.2 L/min.

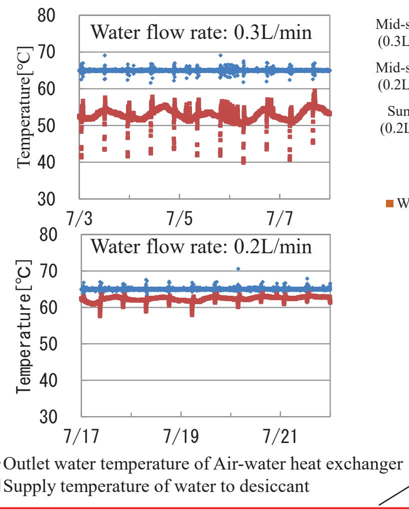
Supplementary materials

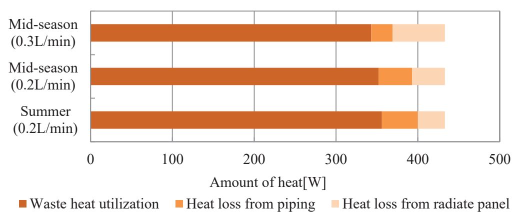


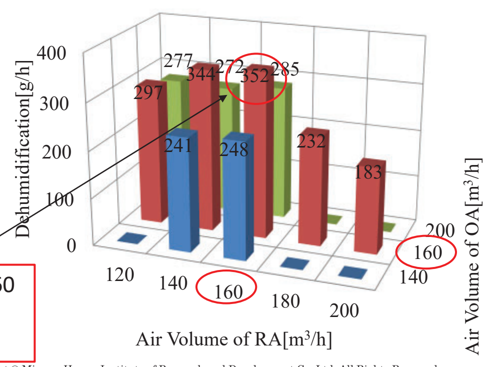


With a flow rate of 0.2L/min, about 80% of the heat emitted from the EF was utilized in the desiccant unit in both the mid-season and summer seasons.

Supplementary materials







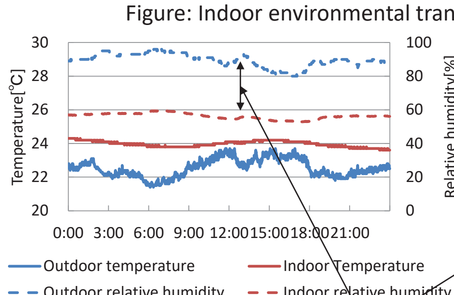
The peak dehumidification amount was at 160 m3/h for both air volumes, with a maximum dehumidification rate of 352 g/h.

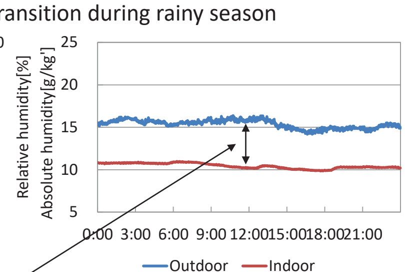
 4

Supplementary materials

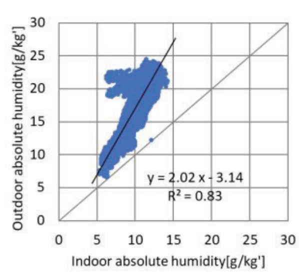
Okinawa has the harshest humidity environment in Japan.

Figure: Indoor environmental transition during rainy season





By installing this system, the indoor relative humidity can be dehumidified to less than 60% even on days when the outdoor relative humidity exceeds 80%. The indoor absolute humidity was about 10 g/kg', which is about 5 g/kg' lower than the outdoor.

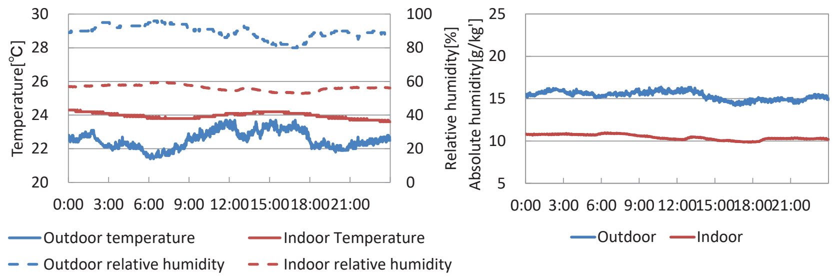


 5

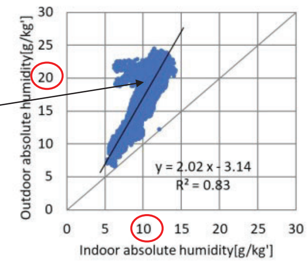
Supplementary materials

Okinawa has the harshest humidity environment in Japan.

Figure: Indoor environmental transition during rainy season

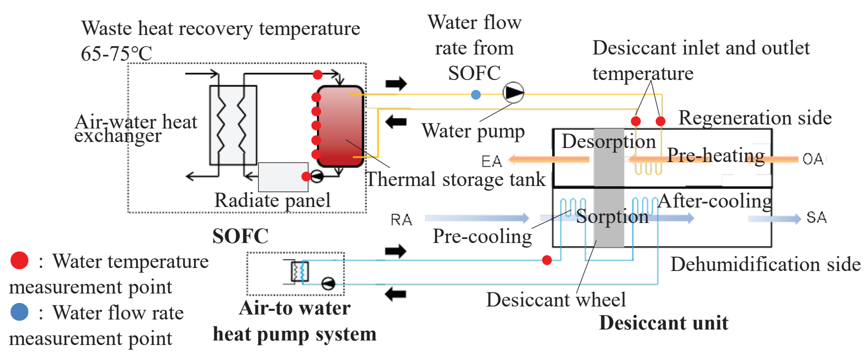


Under the high humidity environment exceeding 20 g/kg', the indoor environment was able to achieve 5 to 10 g/kg' lower than the outdoor air. It can be said that this system has realized a humidity environment favourable to the building and human body throughout the year.



 5

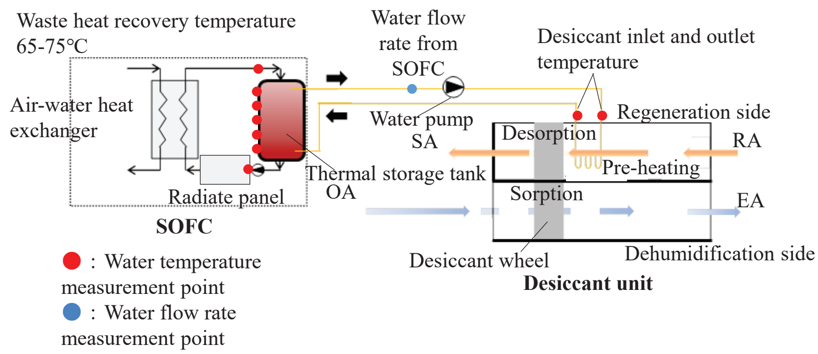
Supplementary materials



①The waste heat from the EF is recovered by the air-water heat exchanger and stored in the hot water storage tank.

 13

Supplementary materials



 14

14

Supplementary materials

EFデシカントシステムの特徴

 15

15

Supplementary materials

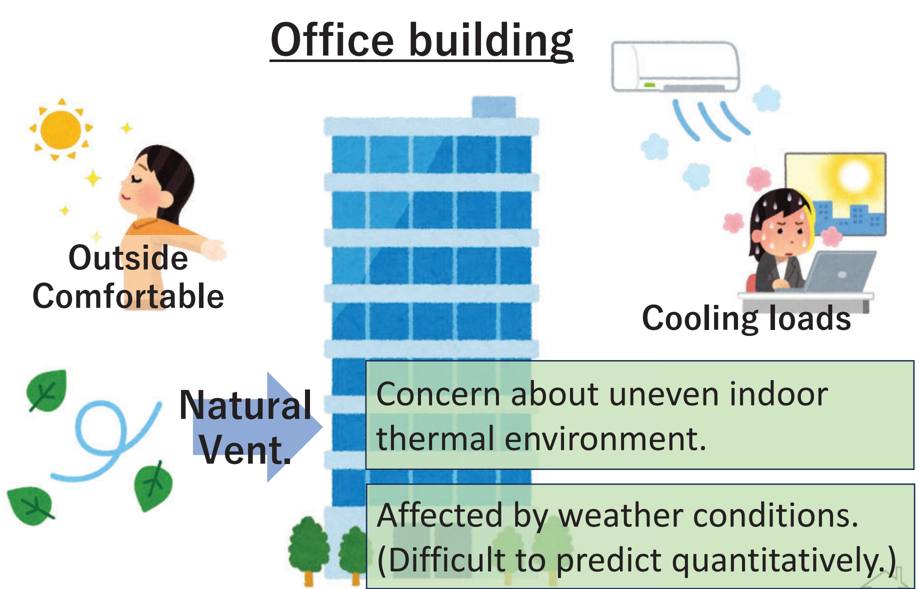
高分子収着剤が低温再生でき、エネ
ファームの排熱が利用できる説明

Method for Evaluating an Air-Conditioning System with Natural Ventilation by Coupled Analysis of a Building Energy Simulation Tool and Computational Fluid Dynamics

YASUNAGA Ryuichi SHIRAISHI Yasuyuki
The University of Kitakyushu

1

BACKGROUND



Concern about uneven indoor thermal environment.

Affected by weather conditions. (Difficult to predict quantitatively.)

2

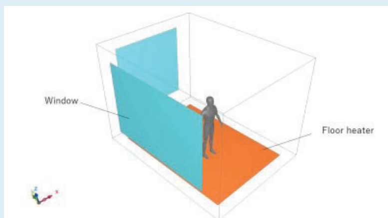
BACKGROUND

BES(Building Energy Simulation) tool

Comprehensive analysis tool for evaluating the performance of buildings.

→ Represents the physical quantity of the room as a SINGLE NODE

CFD(Computational Fluid Dynamics)



calculate 3D matrix.

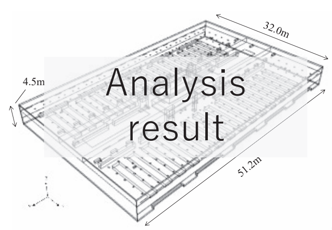
BACKGROUND

Propose a method

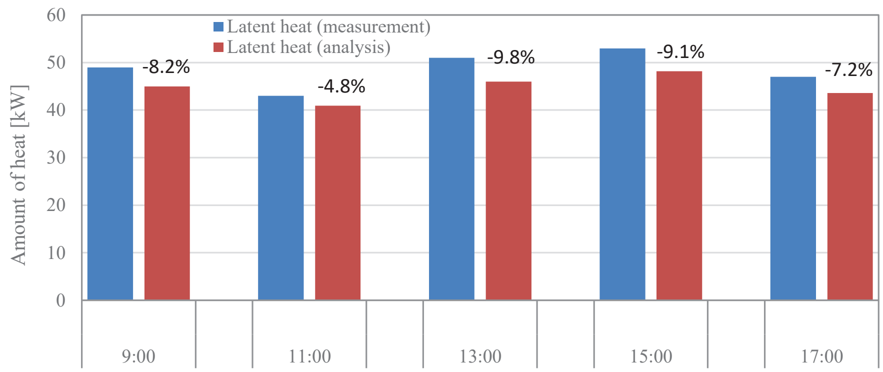
BES tool ⇄ Coupled Analysis ⇄ CFD

Verify accuracy

⇔ Compare



RESULT – Heat removed by natural vent. -



- Maximum error was under 10 %
- This model has sufficient predictive accuracy

CONCLUSION

Proposed a method for evaluating an A/C system by coupling a BES tool and CFD.

Verified the prediction accuracy of the model by comparing the simulation results with measurements

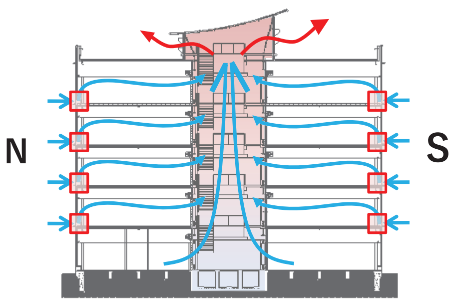
Future

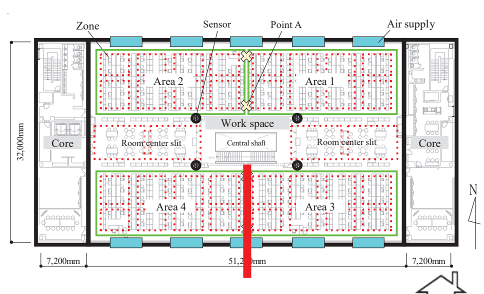
- Verification of this analysis model under unsteady conditions
- Verify the performance of this building as a case study of the method.

OFFICE BUILDING

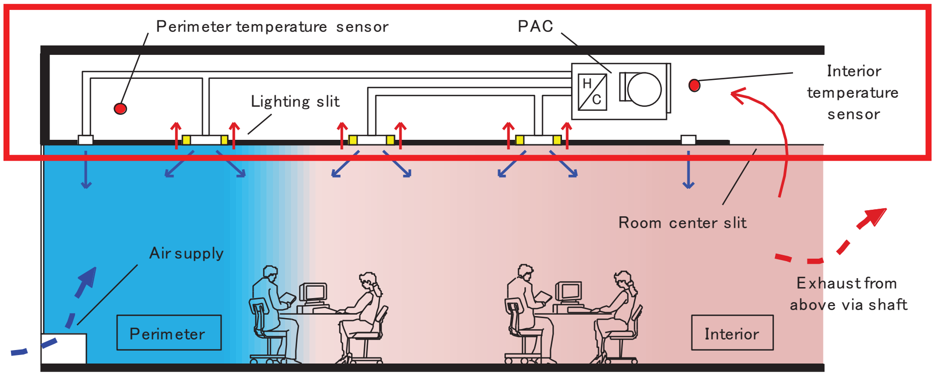
INFORMATION

- Japan
- 5 floors
- BEMS(building energy management system)





OFFICE BUILDING



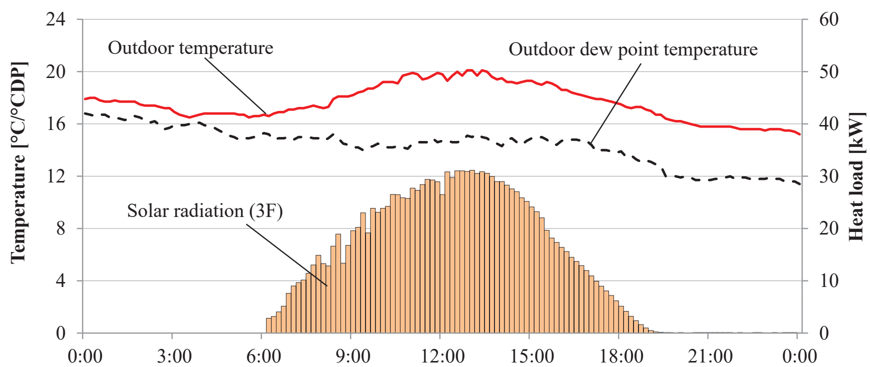
9 The University of Kitakyushu YASUNAGA Ryuichi

MEASUREMENTS

- Measured for May 1st to 31st
- Select May 10th as a representative day

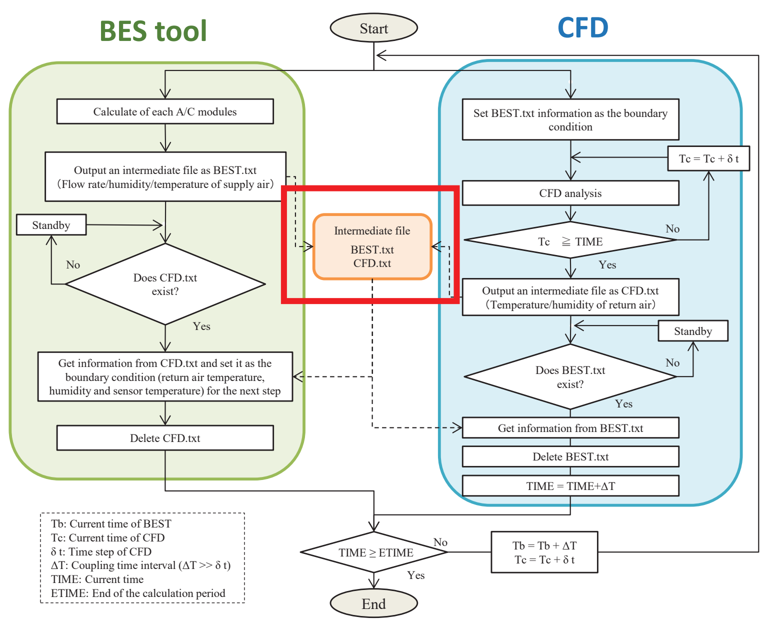
10 The University of Kitakyushu YASUNAGA Ryuichi

MEASUREMENTS

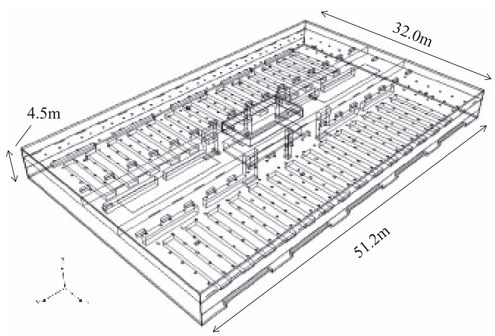


Representative day (May 10)

ANALYSIS

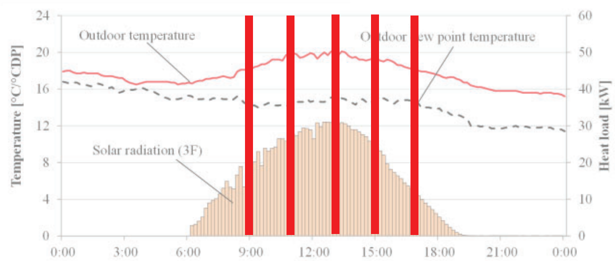


ANALYSIS

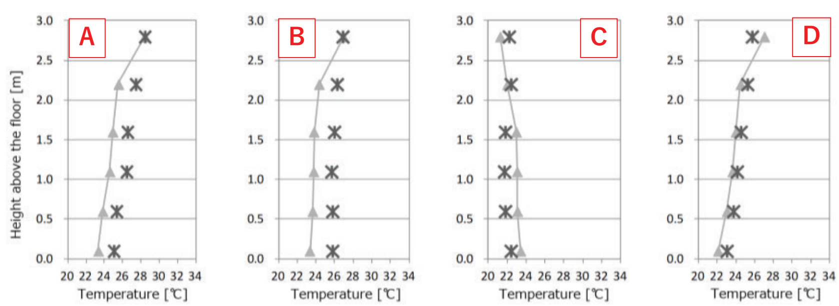


Analysis conditions

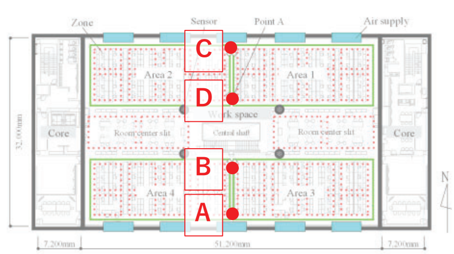
- 3rd floor office room
- Steady-state analyses
- Five times of the representative day



RESULT – Vertical temperature -

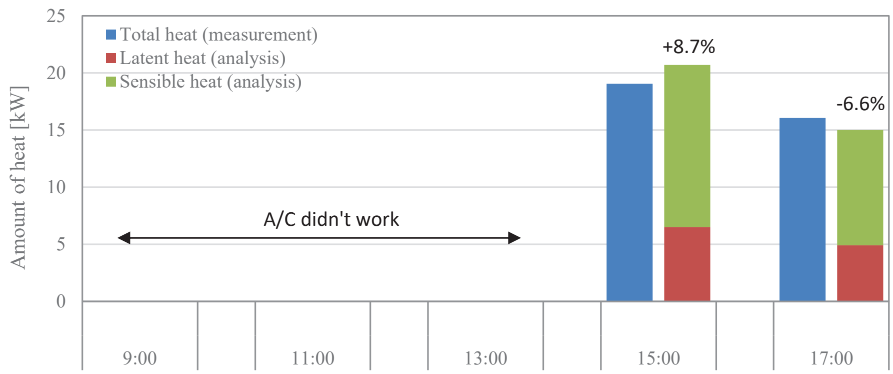


3 p.m.



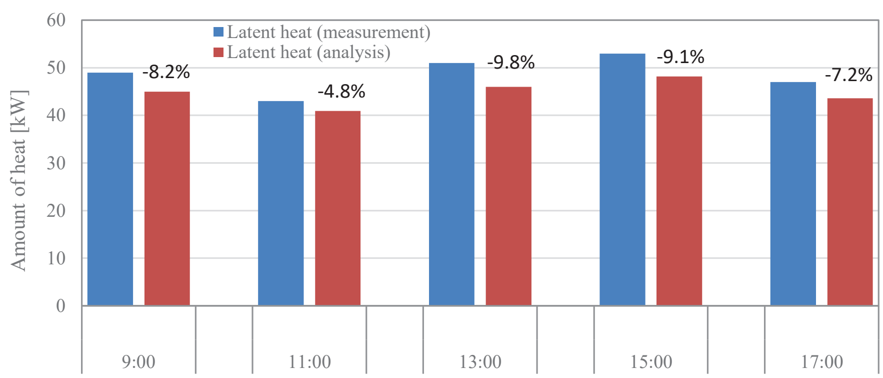
Time	9:00	11:00	13:00	15:00	17:00
RMSE [°C]	0.45	0.66	0.98	0.75	0.97

RESULT – A/C heat load -



- Maximum error was 8.7 %

RESULT – Heat removed by natural vent. -



- Maximum error was under 10 %
- This model has sufficient predictive accuracy

CONCLUSION

Proposed a method for evaluating an A/C system by coupling a BES tool and CFD.

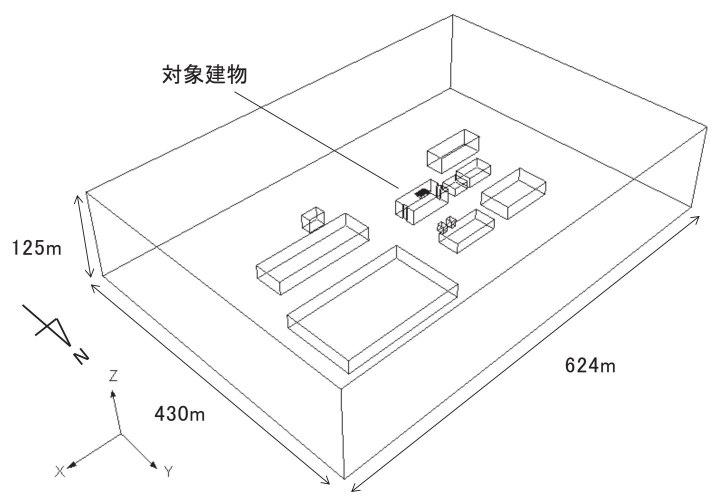
Verified the prediction accuracy of the method by comparing the simulation results with measurements

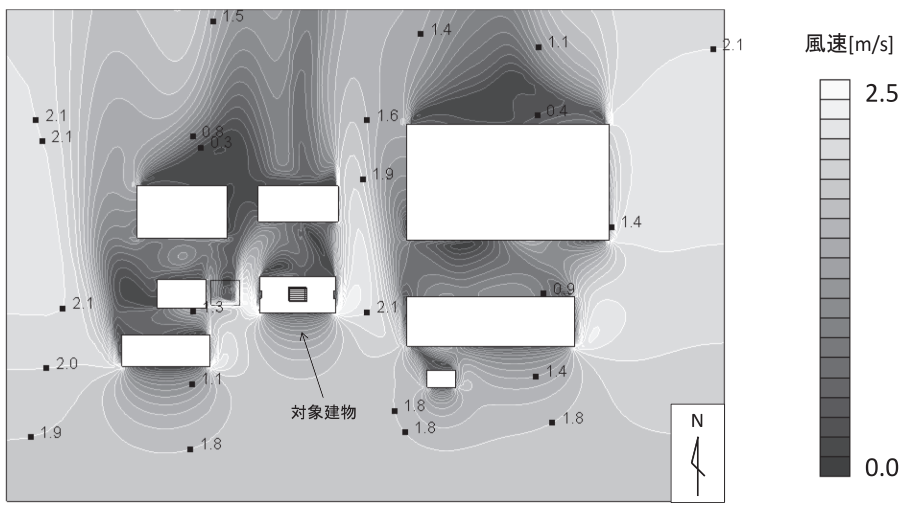
- Verification of this analysis model under unsteady conditions
- Verify the performance of this building as a case study of the method.

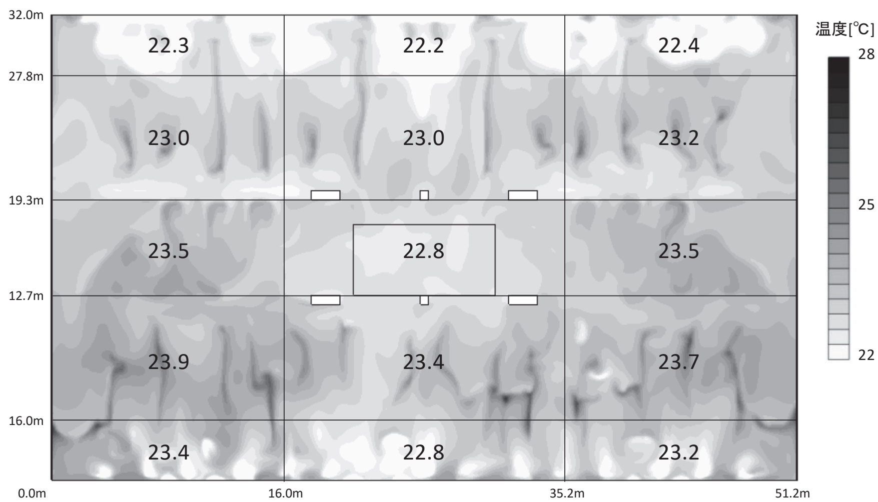
CFD conditions

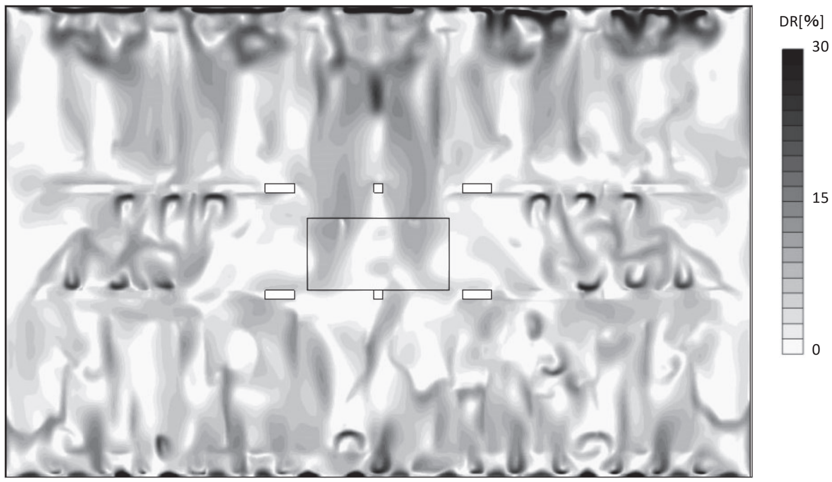
Domain	32.0m(x)×51.2m(y)×4.45m(z)	
Mesh	452(x)×283(y)×39(z) = 4,988,724	
Mesh for radiation	7,291	
Turbulence model	Standard k-ε model	
Inflow conditions	A/C	Temperature: Proportional control Flow rate: 17.5 m^3/min per unit $k_{in}=(U_{in}/10)^2$, $\varepsilon_{in}=C_u^{3/4}k_{in}^{3/2}/\ell_{in}$
	Natural ventilation	Temperature: Outdoor temperature of the BEMS data Flow rate: BEMS data $k_{in}=3/2(U_{in}\times 0.05)^2$, $\varepsilon_{in}=C_u^{3/4}k_{in}^{3/2}/\ell_{in}$
Outflow conditions	A/C	Fixed flow
	Natural ventilation	Fixed static pressure
Wall boundary conditions	Temperature: Fixed convection heat transfer coefficient 4.5 W/m^2K Speed: Generalized logarithmic law	
Outside boundary conditions	South/North: Sol-air temperature, Fixed heat transfer coefficient 23W/m^2K East/West: insulation	
Heating conditions	Lighting/Office equipment/Human/Solar radiation: Measured value	

U_{in}: supply wind speed [m/s]; k_{in}: turbulence energy [m^2/s^2]; ε_{in}: dissipation rate of k_{in}[m^2/s^3]; C_μ: model constant (= 0.09); ℓ_{in}: inlet length



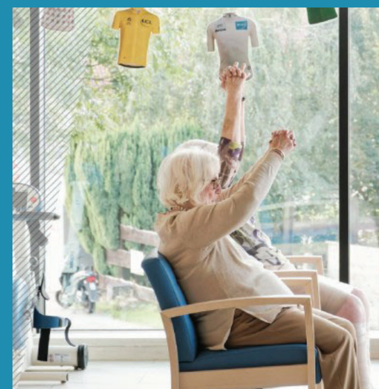

1.5
1.4
1.1
2.1
風速[m/s]
2.5
2.1
2.1
0.8
0.3
1.6
0.4
1.9
1.4
2.1
1.3
2.1
0.9
2.0
1.1
1.4
対象建物
1.8
1.8
1.8
1.9
1.8
N
0.0


32.0m
27.8m
19.3m
12.7m
16.0m
0.0m
16.0m
35.2m
51.2m
22.3
22.2
22.4
23.0
23.0
23.2
23.5
22.8
23.5
23.9
23.4
23.7
23.4
22.8
23.2
温度[℃]
28
25
22


DR[%]
30
15
0

KU LEUVEN

Performance comparison of different ventilation strategies in elderly care homes in Belgium



Douaa Al-Assaad, Quinten Carton, Abantika Sengupta, **Hilde Breesch**
Building Physics & Sustainable Design

Context and aim

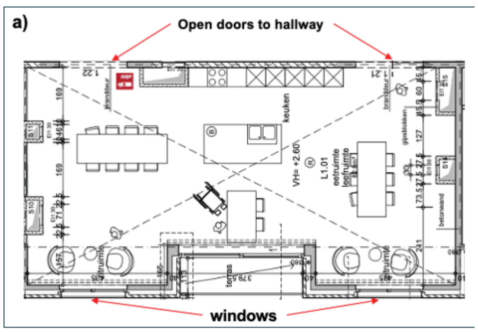
- Elderly care homes
  - EU field studies
    - Poor IAQ and ventilation
    - Exposure to high levels indoor pollution -> decreased health
  - During pandemic: advise to maximize window opening -> increased energy use & decreased thermal comfort
- Aim
  - Determine window opening strategies to ensure good IAQ throughout year
  - Common room in elderly care home

Quality handbook
“Ventilation in elderly care homes”

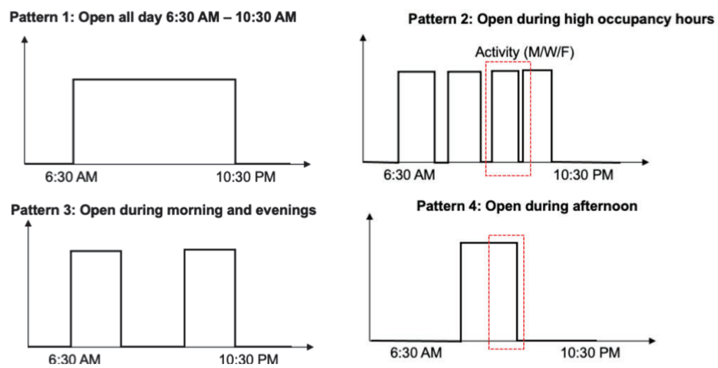
2 https://www.zorg-en-gezondheid.be/kwaliteitshandboek-ventilatie-in-woonzorgcentra KU LEUVEN

Case study

- Typical common room
  - 13.3 x 6.8 x 2.7 m³
  - 5 to 15 pers

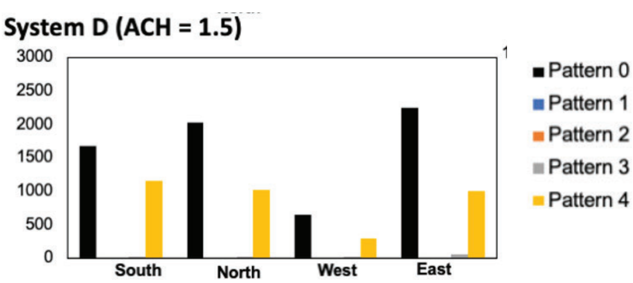


- Ventilation strategies
  - Natural supply & extract (A)
  - Mechanical extract (C) (ACH = 1.5, IDA3)
  - Balanced mechanical (D) (ACH = 1.5, IDA3)
- Window opening patterns



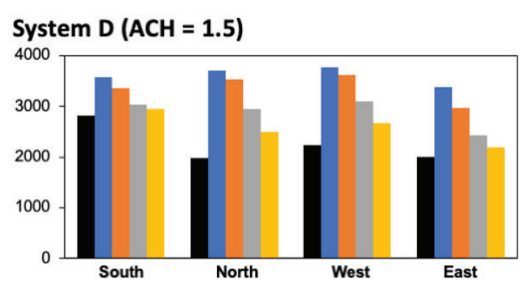
Results

- IAQ heating season (ppm.hours CO_2 > 1000 ppm)



- NL: max 30.000 ppm.hours/a

- Energy use heating season (kWh)



Conclusions

- Guidelines for window opening strategy in common room in elderly care homes

System type	Season	Window opening strategy	Pattern N°
Natural ventilation	Heating	Open during afternoon	4
	Cooling	Open all day during occupied periods	1
Mechanical extract ventilation (ACH = 1.5)	Heating	Open during morning and evening (south, west, north) Open during high occupancy periods (east)	3 2
	Cooling	Open all day during occupied periods	1
Balanced mechanical ventilation (ACH = 1.5)	Heating	Windows can be kept closed	0
	Cooling	Windows can be kept closed	0

KU LEUVEN

Sea Water Air Conditioning (SWAC):
A Resilient and Sustainable Cooling Solution for hot and humid climates Energy Performance and Numerical Modeling

Kanhan Sanjivy, Olivier Marc, Franck Lucas

SANJIVY Kanhan – PhD Student - ADEME

Sea Water Air Conditioning (SWAC) process

- Sea Water Air Conditioning (SWAC) uses Deep Ocean Water (DOW) as a cold source to supply a District Cooling (DC):
  - SWAC process efficiency is not limited by Carnot efficiency
  - Seawater temperatures constant throughout the year
  - SWAC doesn't use any refrigerants
- Requirements:
  - High cooling needs close to the sea
  - Great depths near the coast

- SWAC system is divided in three parts:

Primary loop (Seawater)

Drawn around -960 m at 5/6 °C

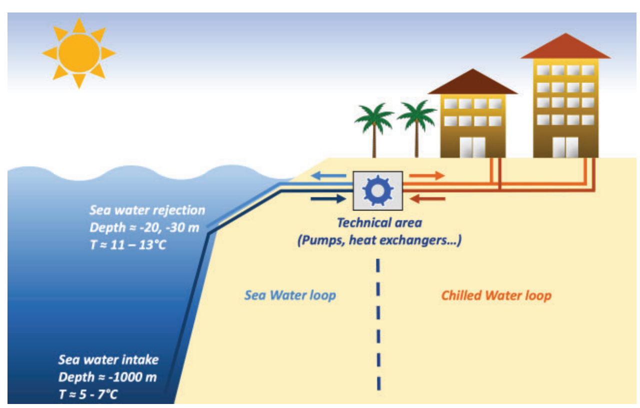
Discharged around -30 m at 10/11 °C

Technical area

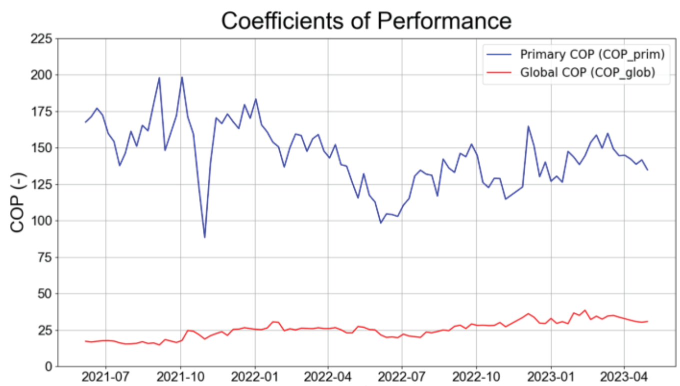
Pumps on both loops with heat exchangers linking them

Secondary loop (Chilled water)

Temperature regime : 7/12 °C



Energy Performance on operation data



- Performance indicators

Primary COP : District Cooling excluded

Compared to other centralized systems

Global COP : District Cooling included

Compared to unitary systems

SCOP : Averaged global COP

Consider seasonal variations of performance

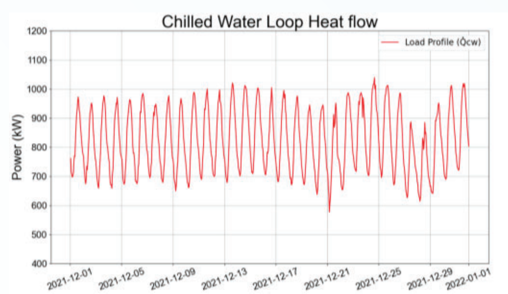
$$COP_{prim} = \frac{Q_{cw}}{W_{sw}}$$

$$COP_{glob} = \frac{Q_{cw}}{W_{sw}+W_{cw}}$$

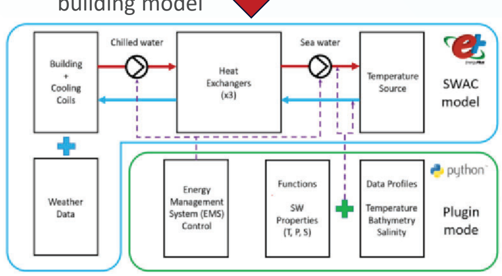
$$SCOP = \frac{1}{T}\int_0^T COP_{glob} \text{ with } T \geq 1 \text{ year}$$

- **SWAC process: SCOP = 25,44**
- **Conventional AC: SCOP = 4**

Numerical Modeling



Input replacing building model



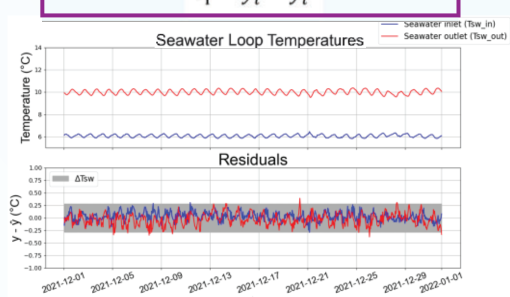
Validation method

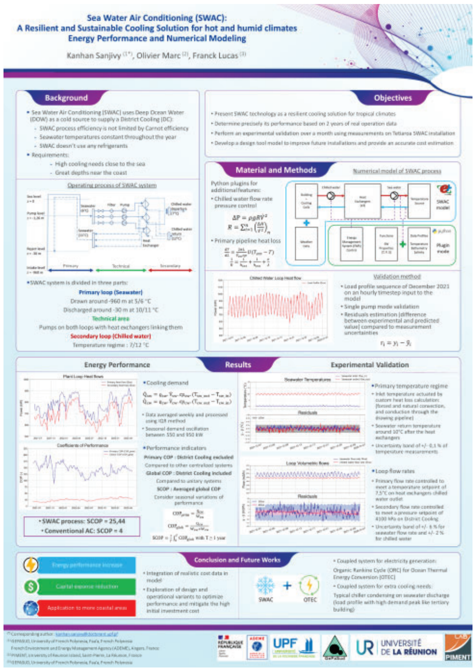
- Load profile sequence of December 2021 on an hourly timestep input to the model

- Residuals estimation (difference between experimental and predicted value) compared to measurement uncertainties

$$r_i = y_i - \hat{y}_i$$

Model Measurements comparison





Thank you for your attention !

building health & comfort
binnenmilieu

The Effects of Lowering Temperature Setpoints on Perceived Thermal Comfort

An experimental case study in office buildings

Beatriz Coutinho
bc-bba@binnenmilieu.nl
Mechanical Engineer Master's project

1

Methodology

Introduction
Methodology
Results
Conclusion

121
Thermal comfort surveys

Thermal comfort
Adaptation mechanisms
Controls
Motivation
Evaluation of the execution of the **energy-saving campaign**.

Office workers
3 office buildings

2

2

Results

Occupants feeling disregarded

Complains and lack of motivation

Occupants will be less willing to accept lower temperatures

You can not simply turn the switch

Create resistance toward the application of energy saving measures

Dissatisfied and unproductive employees

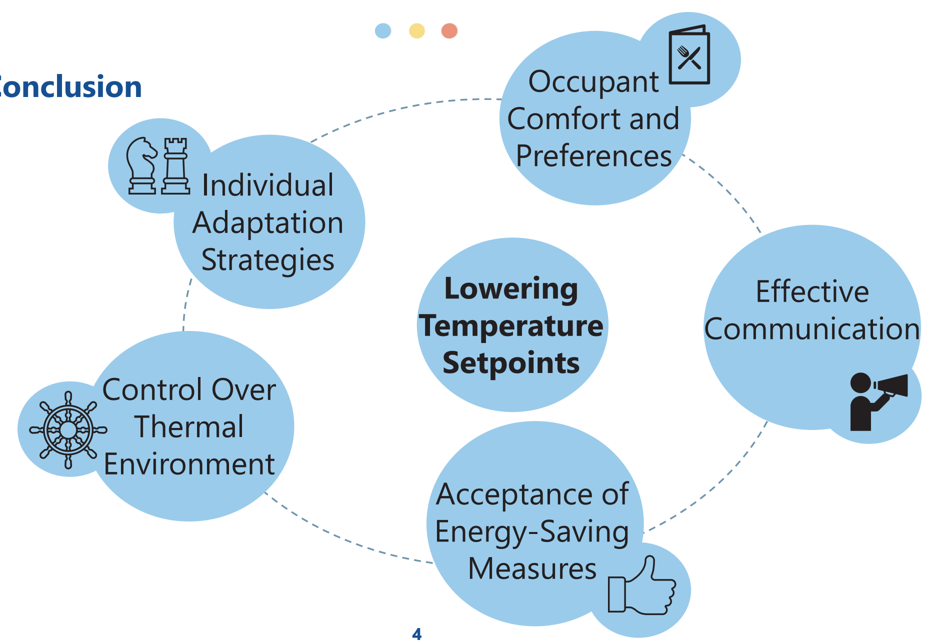
Lower motivation levels when energy saving camapaign is not well executed

Introduction
Methodology
Results
Conclusion

3

3

Conclusion



Introduction
Methodology
Results
Conclusion

4

4

43rd AIVC - 11th TightVent & 9th venticool Conference

October 4-5, 2023

Aalborg University, Copenhagen, Denmark

UNIVERSIDAD Đ CÓRDOBA

Long-term energy performance of dew-point indirect evaporative cooler under the climate change world scenario

María Jesús Romero-Lara[1*], Francisco Comino[2] and Manuel Ruiz de Adana[1]

[1]Departamento de Química-Física y Termodinámica Aplicada, Escuela Politécnica Superior, Universidad de Córdoba, Campus de Rabanales, Antigua Carretera Nacional IV, km 396, 14071 Córdoba, Spain

[2]Departamento de Mecánica, Escuela Politécnica Superior, Universidad de Córdoba, Campus de Rabanales, Antigua Carretera Nacional IV, km 396, 14071 Córdoba, Spain

[*]p42rolam@uco.es; francisco.comino@uco.es; manuel.ruiz@uco.es

Objective

UNIVERSIDAD Đ CÓRDOBA

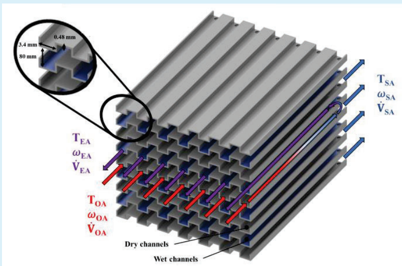
What is the feasibility of using dew-point indirect evaporative coolers under the climate change scenario?

Methodology

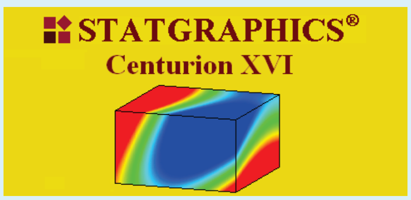
UNIVERSIDAD DE CÓRDOBA

Experimental

1) Tests in DIEC based on DOE statistical technique



2) Empirical model of DIEC



3) Selection of climatic zones

Simulation

4) Climate change scenario (years 1995, 2020, 2050 and 2080)

5) Annual energy simulations

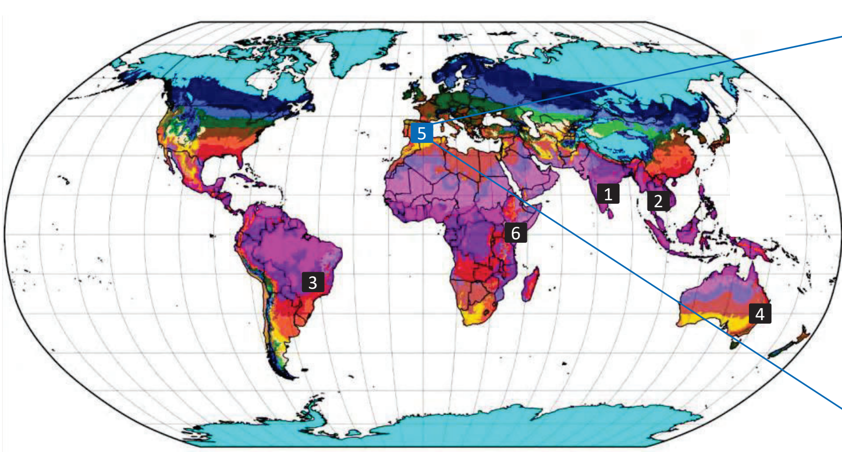
$$SEER = \frac{\sum \dot{Q}_{cooling}}{\sum \dot{W}} = \frac{Q_{cooling}}{W}$$

6) Analysis of **SEER** results

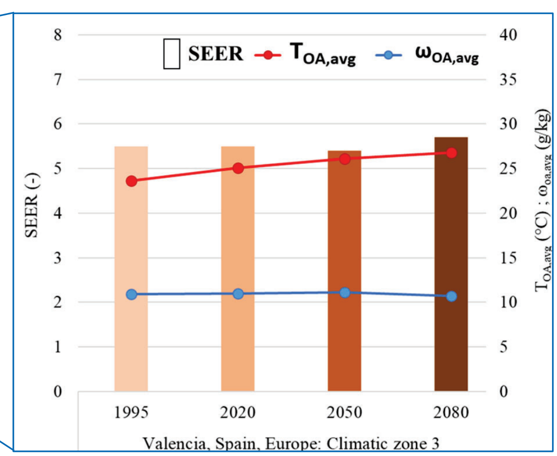
Results and analysis

UNIVERSIDAD DE CÓRDOBA

- Progressive increase in outdoor air temperature (**T_{OA}**) in the climate change scenario



ANSI/ASHRAE 169–2020 world climate zones map



- High SEER values for DIEC for all cities studied → **above 4.7**
- Outdoor humidity is maintained + outdoor temperature increases → **SEER value increases**

Conclusions

UNIVERSIDAD DE CÓRDOBA

- **High SEER values for DIEC** were obtained for all cities studied under the climate change scenario, between 4.7 and 6.3.
- DIEC showed higher SEER values for **hot-dry climatic conditions** than for hot-humid climatic conditions.
- The use of **DIEC is feasible** under the climate change world scenario given its **increasing SEER value**.

Acknowledgments

European Commission

W.E. DISTRICT

The authors acknowledge the financial support received by
European Union's Horizon 2020 research and innovation programme,
through the research project WEDISTRICT **H2020-WIDESPREAD2018-03-857801**

Thanks for your attention!

AIVC TightVent Europe venticool

On the assessment of the pressure coefficient on the mixed ventilation modeling

Pontifical Catholic University of Paraná (Brazil)
&
University of Savoie Mont-Blanc (France)

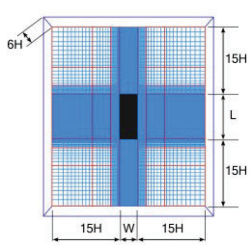
Marcos Batistella
Gaëlle Guyot
Nathan Mendes

October 4 2023, Copenhagen

1

Validation Study

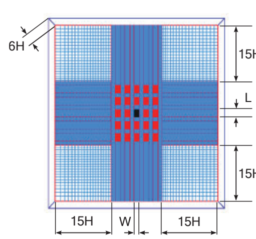
Isolated



H = 4m
W = 16m
L = 40m

94×146x46 nodes

Non-Isolated

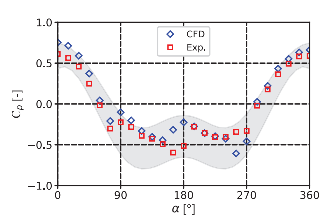


H = 12m
W = 16m
L = 40m
AR = 1.0
166×200x30 nodes

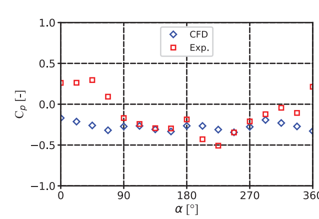
CFD

Length scale 1:100
$U_H = 7$ m/s

Isolated



Non-Isolated

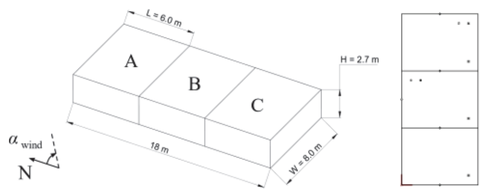


Exp. data from TPU Aerodynamic Database (2023)

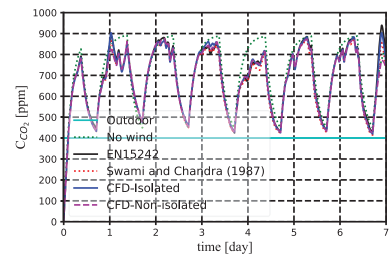
2

Test Study

Modified BESTEST MZ320



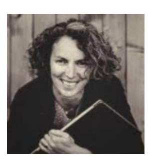
Zone B



Case	ACH	Er_{ACH}	$\bar{C}_{CO_2}^{Zone\ A}$	$Er_{\bar{C}_{CO_2}}^{Zone\ A}$	$\bar{C}_{CO_2}^{Zone\ B}$	$Er_{\bar{C}_{CO_2}}^{Zone\ B}$	$\bar{C}_{CO_2}^{Zone\ C}$	$Er_{\bar{C}_{CO_2}}^{Zone\ C}$
No wind	0.334	-	59	-	754	-	497	-
EN15242	0.354	+6%	411	+599%	713	-6%	480	-3%
Swami and Chandra (1987)	0.360	+8%	409	+596%	703	-7%	476	-4%
CFD-Isolated	0.357	+7%	412	+602%	708	-6%	478	-4%
CFD-Non-isolated	0.354	+6%	411	+599%	708	-6%	482	-3%

Thank you

Nathan Mendes
nathan.mendes@pucpr.br



Gaëlle Guyot
Gaelle.Guyot@cerema.fr

Questions?

Marcos Batistella Lopes
batistella.marcos@pucpr.br

Construction of operational control rules for an earth-to-air heat exchanger through transfer reinforcement learning

〇 Yuki ADACHI Yasuyuki SHIRAISHI

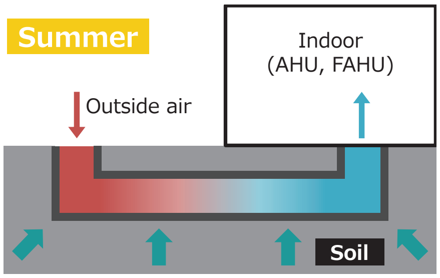
The University of Kitakyusyu

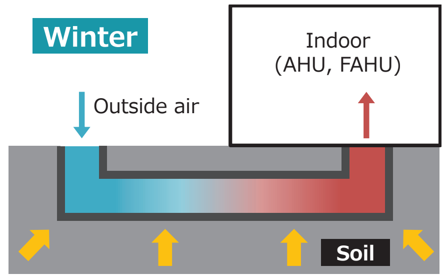
INTRODUCTION

Overview of EAHE

Features of EAHE（Earth-to-air heat exchanger）：

- The EAHE utilizes the enormous heat capacity of soil to pre-cool and pre-heat the OA
- The EAHE can reduce the heat load of OA for an AHU or a FAHU by introducing the pre-heated or pre-cooled OA via this system



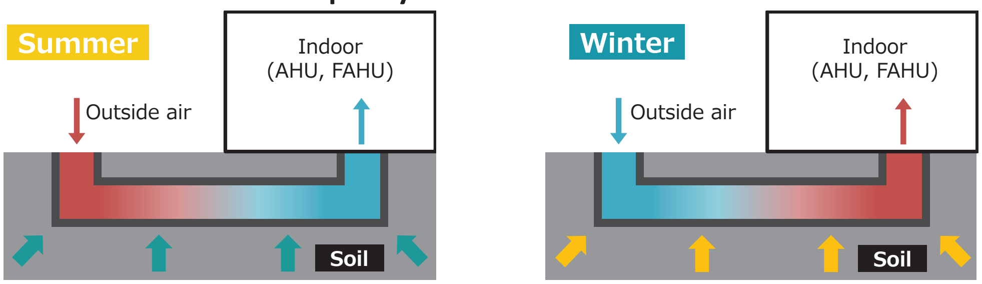


INTRODUCTION — Issues in operation

Common problems for EAHE：

- Risk of air quality contamination of introduced outdoor air
- Dew condensation due to introduction of humid outside air
  - Air quality pollution due to growth of mold

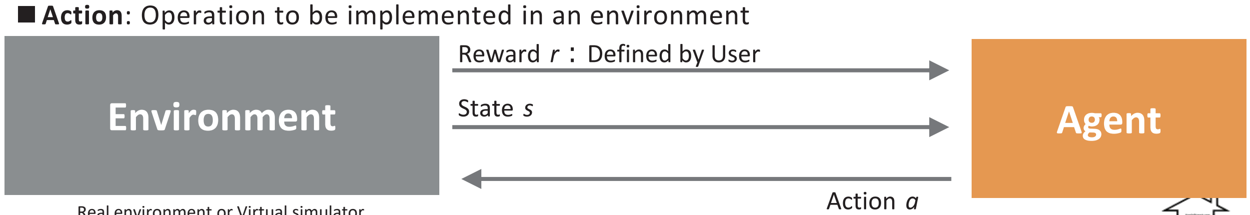
It is necessary to establish an optimal operation method that ensures the energy-saving effect of the earth-to-air heat exchange system and the air quality of the introduced outdoor air.



INTRODUCTION — Reinforcement learning

Machine Learning		
	Supervised learning	・Regression ・Classification
	Unsupervised learning	・Clustering
	Reinforcement learning (RL)	

- **RL**: Sequential decision-making Goal: Select actions to maximize total future reward
- **Reward**: Indicate how well the Agent's output is doing
- **State**: Information of an environment used to determine next action
- **Action**: Operation to be implemented in an environment



INTRODUCTION — Transfer Learning

Reinforcement Learning Issues

Huge number of trials required for learning convergence

CFD as an environment for reinforcement learning → Each analysis takes several hours

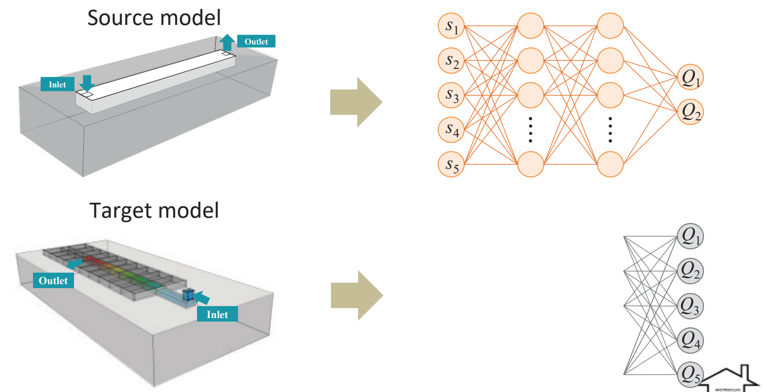
» Simplify the model and reduce the number of meshes → Supports a huge number of trials

Approach methods for reducing learning time in Reinforcement Learning

Transfer Learning

The transferring agent has Learned knowledge

Transfer agents reuse



INTRODUCTION — Transfer Learning

Reinforcement Learning Issues

Huge number of trials required for learning convergence

CFD as an environment for reinforcement learning → Each analysis takes several hours

Simplify the model and reduce the number of meshes → Supports a huge number of trials

Approach methods for reducing learning time in Reinforcement Learning

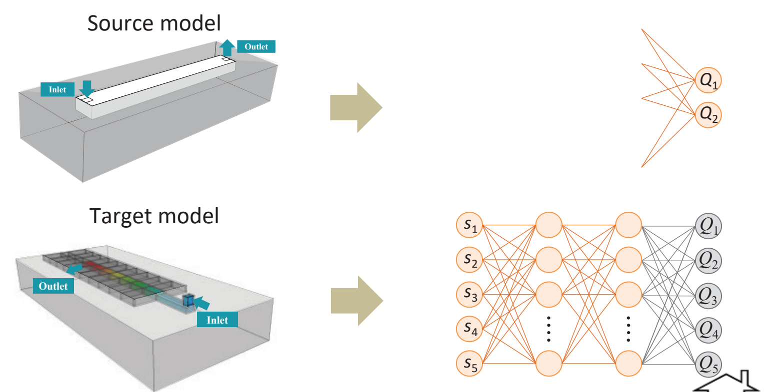
Transfer Learning

Advantage

① Can be trained with less data

② Reduced learning time

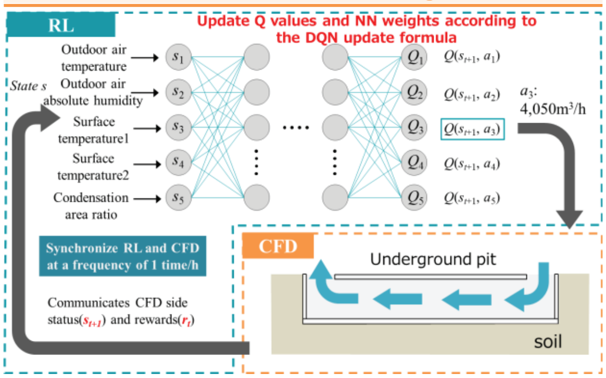
③ Improved learning performance



INTRODUCTION

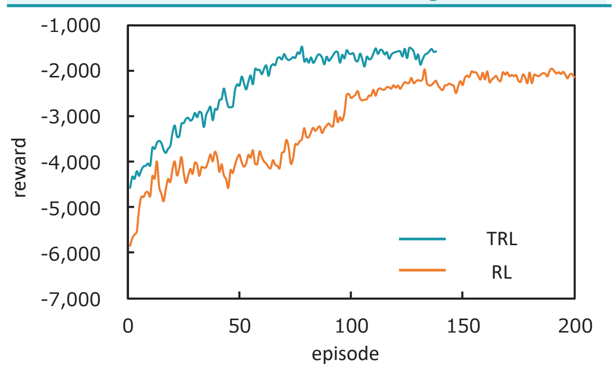
As a study of learning speed-up and learning performance improvement of reinforcement learning

Construction of control laws by reinforcement learning



Coupled Reinforcement Learning and CFD

Combination of transfer learning and reinforcement learning



Learning Progress

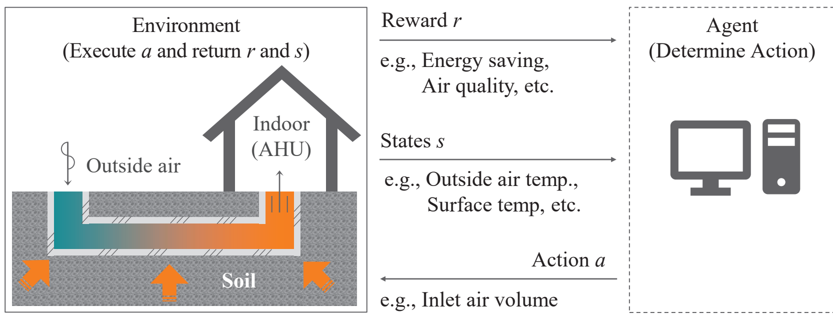
Construction of Efficient Operational Control Laws for EAHE Systems Using Reinforcement Learning

Purpose of this study：

As a study of learning speed-up and learning performance improvement of RL

- Construction of control laws by RL
- Combination of TL and RL

Construction of efficient operational control laws for EAHE systems using RL



Expected Results in Transfer Reinforcement Learning

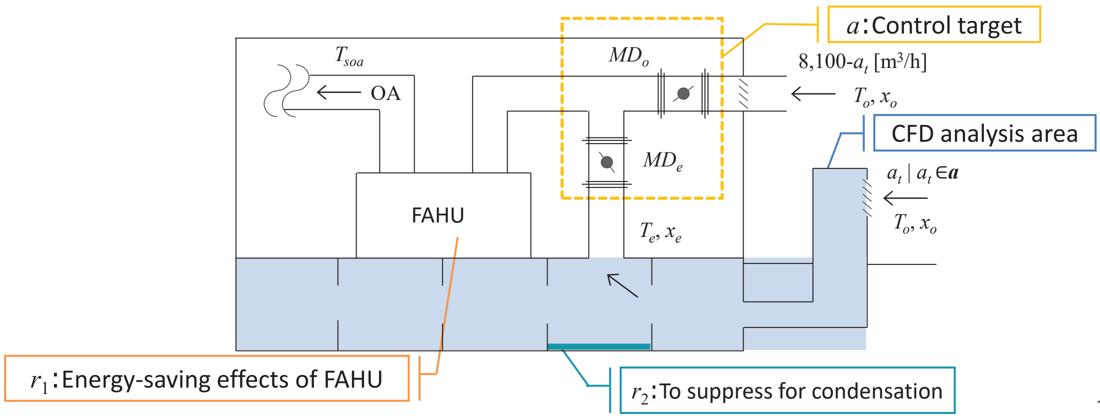
① Once the control side of the soil heat exchange system is built by reinforcement learning, control models can be built for various targets in a short time.

② Direct reuse of control laws, i.e., sufficient control performance may be obtained for practical use without new learning.

③ Accelerate learning while improving learning performance

Reinforcement learning control –Method-

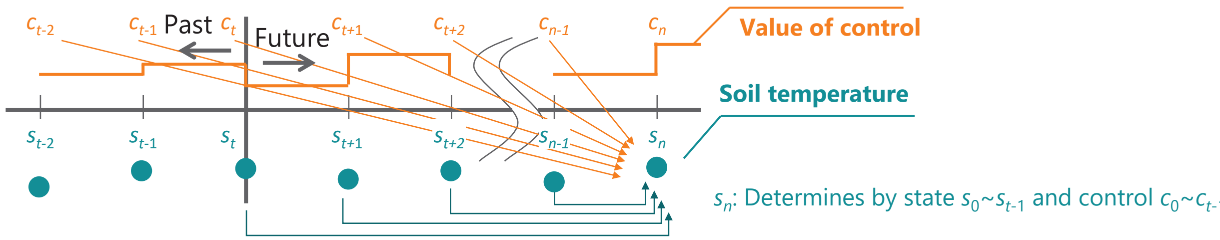
- State s : Outside air temperature・absolute humidity , Surface temperature in pit (two points), Condensation area
- Action a : MD_o / Md_e OA damper opening → **Amount of outside air introduced through the system**(5types)
- Reward r : **r_1 :Energy-saving effects of FAHU , r_2 :To suppress for condensation**



CASE	Source	Target	Subject of transfer
1	2	5	Action
2-1	Straight	L	Shape
2-2	Straight	Corridor	
2-3	Straight	Meandering	
2-4	Straight	Actual tunnel	
3-1	Kitakyusyu	Fukuoka	Weather
3-2	Kitakyusyu	Akita	

Application of conventional control：

- EAHE uses enormous heat capacity of soil
  - \> Sequential operations are affected over a period of days to months
- We need to consider the situation a few months ahead
  - \> Real-time prediction of the future is complex in terms of accuracy and calculation time



Not suitable for EAHE control algorithm

AIVC 2023
11th TightVent & 9th Venticool Conference
Copenhagen, Denmark
October 4-5, 2023

Ventilation and Thermal Performance Examination of Slot Line Diffuser for Perimeter Usage by CFD Simulation

〇Shaoyu Sheng Specially Appointed Researcher
Toshio Yamanaka Professor
Tomohiro Kobayashi Associate professor
@Osaka University, Japan

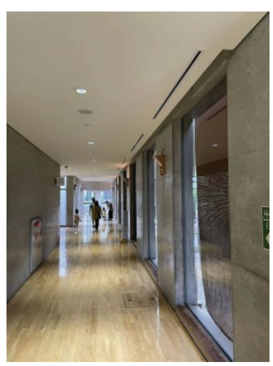
大阪大学
OSAKA UNIVERSITY

◆ Background

The slot line (linear slot) diffuser

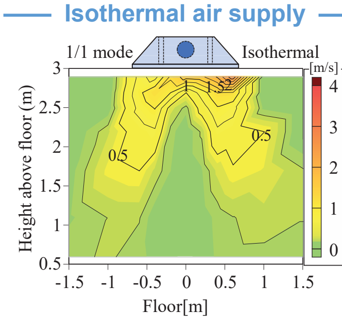

@Office


@Ferry boat

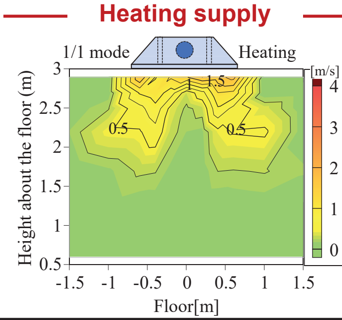

@Hotel

- An air terminal wildly used in Japan for near-window application
- Slim outlet area (always 1~2m in long side) and supply air vertically downward
- Can effectively block the heat flow during the summer
- Insufficient throw distance in winter due to buoyancy impact

Isothermal air supply



Heating supply

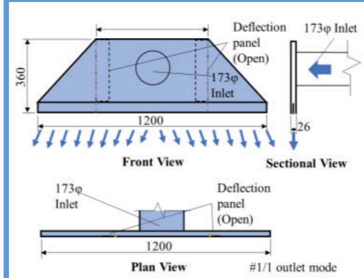


◆ Purpose and Method

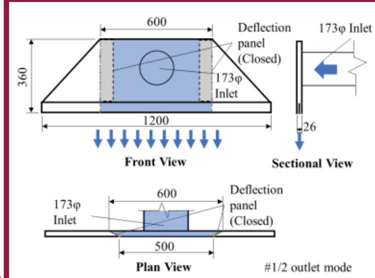
A Novel Slot Line with Adaptive Outlet Area

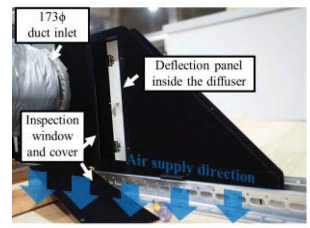
- Previous studies always emphasized the **slot number** or the **nozzle shape**'s impact
- The **velocity distribution** along the **long side** of the slot line is often **disregarded**
- Deflection panels are putting in the diffuser's chamber to adjust the outlet area in the **longitudinal direction**.
- These panels serve both to **enhance outlet velocity** and **modify airflow** distribution.
- The outlet area can be **adapted** based on either the **supply temperature** or **room temperature**

Before adjusting (1/1 Outlet Mode)



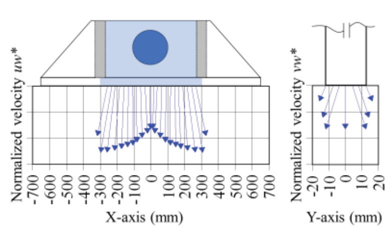
After adjusting (1/2 Outlet Mode)



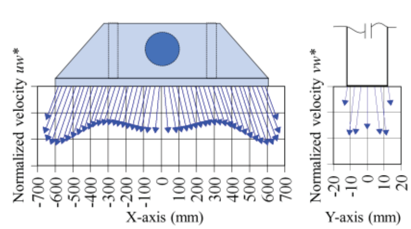


◆ Evaluation by CFD

Full-scale experiment in the free field: Proposing and validating a detailed modeling method for replicating outlet airflow

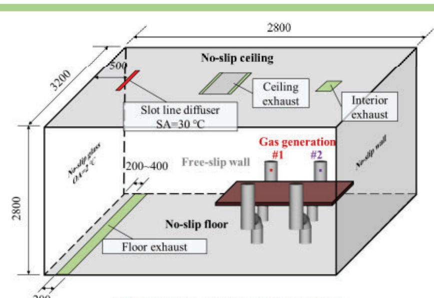


Velocity distribution under 1/2 outlet mode

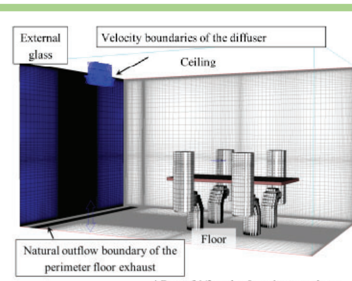


Velocity distribution under 1/1 outlet mode

Numerical study by CFD: Evaluating Heating and Ventilation Performance in an Office Space with Large-Area Glazing



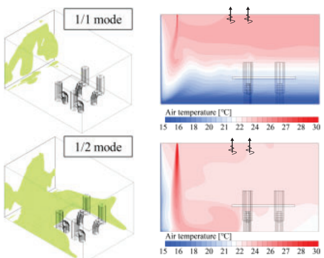
Dimensions of the analysis space



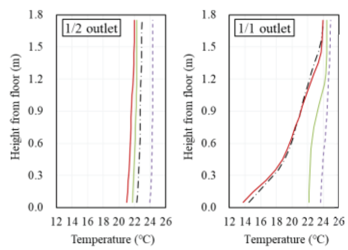
3D model and griding for CFD

◆ Results

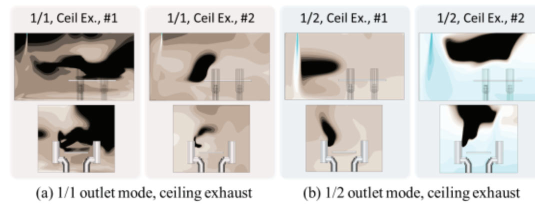
1/2 outlet mode improved the heating and ventilation performance



Velocity and temperature distribution



Velocity and temperature vertical distribution



Normalized concentration distribution in the vertical section

- The impact of exhaust location has also been examined
- Recommend to use a floor exhaust for extra heating efficiency
- Compared the mean normalized concentration and age of air
- Ceiling displacement ventilation tends to be achieved by combine the 1/2 slot line with a ceiling exhaust

Please refer to our:

- Poster
- Conference paper
- Related research papers

for more details and further examinations

Quantifying the Potential Health Impacts of Unvented Combustion in Homes

Jacob Bueno de Mesquita, PhD
Núria Casquero-Modrego, PhD
Iain Walker, PhD

Lawrence Berkeley National Lab. (LBNL)

10/9/2023

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

Combustion-Related Contaminants

- **$PM_{2.5}$** (and **PM_{10}**/ultrafine) ► Generally, the most important contaminant of concern for health impacts
- **NO_2** ► is an irritant to the respiratory tract
- **VOCs** ► health impact minimal compared with $PM_{2.5}$ and NO_2
- **Water vapor and odours** – not directly health-related and not the subject of this paper

<u>This Study</u>:
- **Combustion of Gas** – not oil / wood / propane, etc.
- **NO_2 only** – to disambiguate between gas and electric cooking, PM common to all cooking

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

What is “Unvented”

Most combustion equipment has a vent to outside:

- Boilers
- Furnaces
- Water heaters

This study is about unvented combustion:

- Cooking with gas
- Room heaters

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

3

Methodology: Meta-Analysis

- Review of publications since the year 2000.
- Literature related to:
  - Interventions where gas combustion appliances were replaced.
  - Effective engineering controls were implemented.
  - Measured NO_2 was taken as the main exposure variable.
  - Meta-analysis focused on gas stove effects on cough and wheeze.

Studies that used epidemiologic methods:

►Associations between health outcomes and the presence or use of unvented gas combustion appliances and/or measured NO_2 with results presented as effect estimates with confidence intervals.

4

Summary of relevant articles

TOTAL 29 Studies

- 10 meta-analyses
- 12 observational studies
- 7 RCTs or quasi-experimental studies

TOTAL ► 184 effect estimates

5

Types of Studies

- Primarily Acute exposures – monitoring over several years
- RCT and observational studies isolated exposure from unvented appliances
  - Does not include exposure to contaminants from vented sources that enter a building from outdoors.
  - Studies compared home with indoor unvented combustion to homes without, for the same outdoor conditions
- Meta-analyses based on overall NO_2 concentrations and presence of unvented appliances

6

Health Outcomes: 12 categories

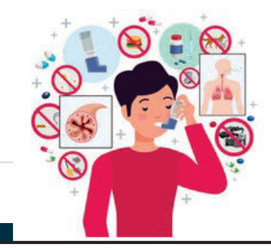
1. **Mortality**
2. **Hospital visits**
3. **Health symptoms**
4. **Others**

- All-cause mortality.
- Cardiovascular mortality.
- Respiratory mortality.

- Healthcare visits or emergency room visits or changes to asthma management.
- Hospitalization or emergency room visits

- Asthma symptoms including wheeze, cough, shortness of breath, chest tightness, respiratory symptoms, nasal symptoms, and difficulty breathing.
- Asthma symptom scores including ordinal scores 0-3 (3 as the most severe and 0 as no symptom)
- Systemic symptoms including poor/fair health, diarrhea, vomiting, ear infection stomach ache, eczema, sensitization, allergies, night-time waking, and steroid use.

- Medication use including asthma preventer and reliever use.
- Nonpharmaceutical interventions including limiting activity.
- Neurological disease development including schizophrenia.
- Absences from school.



ENERGY TECHNOLOGIES AREA
BERKELEY LAB

Combining results from different studies

- Convert effect estimates into continuous, independent variables.
  - ► e.g., effect per 20 ppb increase in NO_2.
- Convert intervention studies to consider control groups as the numerator in effect estimate ratios.
- Use effect estimates adjusted for confounders: (e.g., age, season, mold exposure, etc.)
- Stratified pooled estimates by:
  - Health outcome
  - Categorical or continuous exposure.
  - Effect estimate type:
    - Odds ratios (OR)
    - Risk ratios (RR)
    - Incident rate ratios (IRR)

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

Geographical Distribution

Gas Cooking
- The Netherlands

Gas Stove
- USA: New York
- Global

Room Heater
- Australia: Adelaide; New South Wales
- New Zealand
- USA: Connecticut; Massachusetts

Indoor
- USA: Connecticut; Massachusetts; Maryland
- Japan

Ambient (exterior)
- Australia: Adelaide
- Denmark
- USA: Maryland; Massachusetts

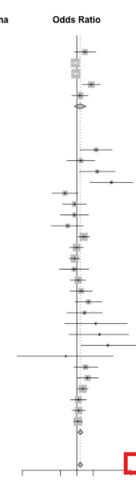
ENERGY TECHNOLOGIES AREA
BERKELEY LAB

Results

Odds ratios for combustion cooking and/or heating on asthma symptoms

► Overall…. **Gas vs Electric Appliances (both vented AND unvented)**
Associated with 1.16 times the odds of reporting asthma symptoms (95% CI 1.06-1.28)

Study	Follow-up length	Combustion	Outcome	Age	Subgroup	N participants	% with asthma	OR	95%-CI	Weight
design_type = RCT										
howden-chapman_2008	52 weeks	heat	wheezeing attack	6-12	.	349	100	1.41	[0.90; 2.22]	3.0%
marks_2010	6 weeks	heat	morning wheeze or cough	8-12	.	400	15	0.94	[0.80; 1.10]	7.2%
marks_2010	6 weeks	heat	evening wheeze or cough	8-12	.	400	15	0.96	[0.85; 1.09]	7.8%
marks_2010	6 weeks	heat	morning wheeze or cough	8-12	atopy	152	15	1.85	[1.26; 2.72]	3.7%
marks_2010	6 weeks	heat	evening wheeze or cough	8-12	atopy	152	15	1.14	[0.81; 1.61]	4.2%
Random effects model								1.16	[0.91; 1.47]	25.9%
Heterogeneity: $I^2 = 70\%$, $\tau^2 = 0.0534$, $p < 0.01$										
design_type = observational										
belanger_2006	2 weeks	stove	wheeze	0-12	multifamily	242	100	2.27	[1.15; 4.47]	1.7%
belanger_2006	2 weeks	stove	persistent cough	0-12	multifamily	242	100	1.19	[0.66; 2.16]	2.0%
belanger_2006	2 weeks	stove	shortness of breath	0-12	multifamily	242	100	2.38	[1.12; 5.06]	1.4%
belanger_2006	2 weeks	stove	chest tightness	0-12	multifamily	242	100	4.34	[1.76; 10.69]	1.0%
belanger_2006	2 weeks	stove	wheeze	0-12	singlefamily	486	100	0.61	[0.35; 1.05]	2.3%
belanger_2006	2 weeks	stove	persistent cough	0-12	singlefamily	486	100	0.92	[0.55; 1.51]	2.6%
belanger_2006	2 weeks	stove	shortness of breath	0-12	singlefamily	486	100	0.91	[0.50; 1.64]	2.0%
belanger_2006	2 weeks	stove	chest tightness	0-12	singlefamily	486	100	0.68	[0.34; 1.32]	1.7%
willers_2006	8 years	stove	nasal symptoms	0-8	.	3148	4	1.34	[1.06; 1.71]	5.8%
willers_2006	8 years	stove	wheeze	0-8	.	3148	4	0.99	[0.74; 1.32]	5.0%
willers_2006	8 years	stove	transient early wheeze	0-8	.	3148	4	0.91	[0.73; 1.14]	6.1%
willers_2006	8 years	stove	late onset wheeze	0-8	.	3148	4	0.89	[0.48; 1.67]	1.9%
willers_2006	8 years	stove	persistent wheeze	0-8	.	3148	4	1.06	[0.76; 1.47]	4.4%
rice_2020	28 months	both	wheeze or cough	0-16	bpd	244	.	1.21	[0.76; 1.92]	2.9%
rice_2020	28 months	both	nighttime respiratory symptoms	0-16	bpd	244	.	1.64	[0.93; 2.89]	2.2%
rice_2020	28 months	both	wheeze or cough	0-16	bpd with resp support	114	.	1.39	[0.66; 2.94]	1.4%
rice_2020	28 months	both	nighttime respiratory symptoms	0-16	bpd with resp support	114	.	2.24	[0.60; 8.45]	0.5%
lu_2018	0 weeks	heat	asthma-like symptoms	6-11	.	231	.	2.62	[0.72; 8.93]	0.6%
lu_2018	0 weeks	both	flulike symptoms	6-11	.	242	.	3.73	[1.20; 14.95]	0.6%
paulin_2017	0 weeks	both	daytime asthma symptoms	5-12	.	30	100	0.63	[0.08; 4.72]	0.2%
boulic_2012	0 weeks	heat	asthma symptoms current	6-12	gas vs electric heat	3874	.	1.45	[0.89; 2.43]	2.6%
boulic_2012	0 weeks	heat	asthma symptoms current	6-12	kerosene vs electric heat	3874	.	1.58	[1.03; 2.49]	3.1%
boulic_2012	0 weeks	heat	asthma symptoms current	6-12	unflue vs flue combustion heat	3874	.	1.29	[1.02; 1.63]	5.9%
boulic_2012	0 weeks	heat	asthma symptoms ever	6-12	gas vs electric heat	3874	.	1.07	[0.77; 1.49]	4.4%
boulic_2012	0 weeks	heat	asthma symptoms ever	6-12	kerosene vs electric heat	3874	.	1.08	[0.82; 1.44]	5.1%
boulic_2012	0 weeks	heat	asthma symptoms ever	6-12	unflue vs flue combustion heat	3874	.	1.05	[0.88; 1.26]	6.8%
Random effects model								1.17	[1.05; 1.29]	74.1%
Heterogeneity: $I^2 = 45\%$, $\tau^2 = 0.0179$, $p < 0.01$										
Random effects model								**1.16**	**[1.06; 1.28]**	**100.0%**
Heterogeneity: $I^2 = 52\%$, $\tau^2 = 0.0271$, $p < 0.01$										
Test for subgroup differences: $\chi^2_1 = 0.00$, df = 1 ($p = 0.96$)										



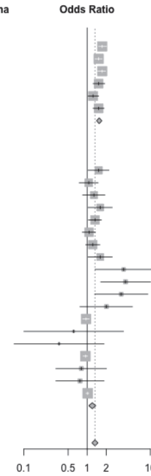
ENERGY TEC
BERKELEY LAB

Results – Asthma Symptoms

20 ppb increase in NO_2 = It is an increase in the odds of asthma symptoms by 33%

Asthma Symptoms and Symptom Scores

Study	Follow-up length	Combustion	Outcome	Age	Subgroup	N participants	% with asthma	OR	95%-CI	Weight
design_type = RCT										
gillespie-bennet_2011	4 months	heat	nighttime cough	6-13	.	344	100	1.73	[1.52; 2.03]	6.4%
gillespie-bennet_2011	4 months	heat	daytime cough	6-13	.	358	100	1.52	[1.33; 1.73]	6.5%
gillespie-bennet_2011	4 months	heat	cough with waking	6-13	.	344	100	1.73	[1.47; 1.96]	6.4%
gillespie-bennet_2011	4 months	heat	nighttime wheeze	6-13	.	343	100	1.52	[1.24; 1.90]	5.7%
gillespie-bennet_2011	4 months	heat	daytime wheeze	6-13	.	365	100	1.24	[1.04; 1.52]	5.9%
gillespie-bennet_2011	4 months	heat	wheeze with waking	6-13	.	343	100	1.52	[1.24; 1.85]	5.8%
Random effects model								1.55	[1.41; 1.71]	36.7%
Heterogeneity: $I^2 = 49\%$, $\tau^2 = 0.0070$, $p = 0.08$										
design_type = observational										
belanger_2006	2 weeks	stove	wheeze	0-12	multifamily	242	100	1.52	[1.04; 2.21]	4.0%
belanger_2006	2 weeks	stove	persistent cough	0-12	multifamily	242	100	1.06	[0.75; 1.49]	4.3%
belanger_2006	2 weeks	stove	shortness of breath	0-12	multifamily	242	100	1.28	[0.85; 1.91]	3.7%
belanger_2006	2 weeks	stove	chest tightness	0-12	multifamily	242	100	1.61	[1.04; 2.49]	3.4%
belanger_2006	2 weeks	stove	wheeze	0-12	singlefamily	486	100	1.33	[1.05; 1.68]	5.4%
belanger_2006	2 weeks	stove	persistent cough	0-12	singlefamily	486	100	1.07	[0.84; 1.35]	5.4%
belanger_2006	2 weeks	stove	shortness of breath	0-12	singlefamily	486	100	1.23	[0.95; 1.59]	5.2%
belanger_2006	2 weeks	stove	chest tightness	0-12	singlefamily	486	100	1.61	[1.04; 2.49]	3.4%
belanger_2013	4 months	stove	wheeze	5-10	.	1342	100	3.78	[1.33; 10.59]	1.0%
belanger_2013	4 months	stove	nighttime asthma symptoms	5-10	.	1342	100	4.04	[1.64; 10.08]	1.3%
permaul_2020	5 years	both	days of asthma symptoms	4-13	obese	97	100	3.46	[1.32; 9.12]	1.1%
permaul_2020	5 years	both	wheeze, cough, or chest tightness	4-13	obese	97	100	2.02	[0.77; 5.20]	1.2%
permaul_2020	5 years	both	nighttime asthma symptoms	4-13	obese	97	100	0.96	[0.85; 1.08]	6.6%
permaul_2020	5 years	both	days of asthma symptoms	4-13	overweight	41	100	0.61	[0.10; 3.76]	0.4%
permaul_2020	5 years	both	wheeze, cough, or chest tightness	4-13	overweight	41	100	0.36	[0.07; 1.85]	0.4%
permaul_2020	5 years	both	nighttime asthma symptoms	4-13	overweight	41	100	0.94	[0.86; 1.02]	6.9%
permaul_2020	5 years	both	days of asthma symptoms	4-13	normalweight	133	100	0.81	[0.32; 2.02]	1.2%
permaul_2020	5 years	both	wheeze, cough, or chest tightness	4-13	normalweight	133	100	0.77	[0.32; 1.85]	1.3%
permaul_2020	5 years	both	nighttime asthma symptoms	4-13	normalweight	133	100	1.02	[0.96; 1.06]	7.1%
Random effects model								1.21	[1.06; 1.37]	63.3%
Heterogeneity: $I^2 = 65\%$, $\tau^2 = 0.0354$, $p < 0.01$										
Random effects model								**1.33**	**[1.19; 1.49]**	**100.0%**
Heterogeneity: $I^2 = 86\%$, $\tau^2 = 0.0457$, $p < 0.01$										
Test for subgroup differences: $\chi^2_1 = 9.42$, df = 1 ($p < 0.01$)										



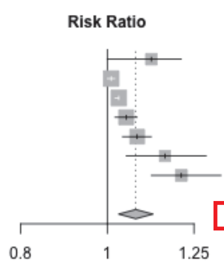
ENERGY TECHNOLOGIES AREA
BERKELEY LAB

Odds ratios for a 20 ppb increase in average <u>NO_2 exposure</u> linked with <u>combustion cooking and/or unvented heating</u>

Results - Death

- Meta-analyses mostly used a continuous NO_2 exposure variable to evaluate risk of mortality, asthma incidence, emergency room visits, and hospitalizations.

Study	Subgroup	N Effect Sizes	RR	95%-CI	Weight
huangfu_2020		15	1.12	[1.00; 1.21]	10.0%
orellano_2020	1-hr max	10	1.01	[1.00; 1.02]	18.3%
orellano_2020	24-hr avg	54	1.03	[1.02; 1.03]	18.4%
orellano_2020	O3 adj	6	1.05	[1.02; 1.08]	17.1%
atkinson_2018		48	1.08	[1.04; 1.12]	16.4%
faustini_2014		10	1.16	[1.05; 1.29]	9.3%
hoek_2013		13	1.21	[1.12; 1.34]	10.5%
Random effects model			**1.08**	**[1.03; 1.12]**	**100.0%**
Heterogeneity: $I^2 = 86\%$, $\tau^2 = 0.0028$, $p < 0.01$					



20 ppb increase in NO_2 = 8% increase of DEATH overall

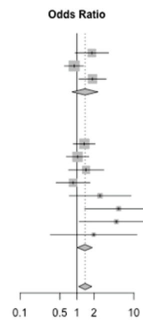
ENERGY TECHNOLOGIES AREA
BERKELEY LAB

Pooled meta-analysis all-cause mortality risk ratios for 20 ppb increases in indoor NO_2

Summary

- We found an increased likelihood of using asthma medication across both randomized controlled trials (RCTs) and observational studies, with a combined confidence interval showing 7-81% higher odds when gas appliances were present.

Study	Follow-up length	Combustion	Outcome	Age	Subgroup	N participants	% with asthma	OR	95%-CI	Weight
design_type = RCT										
howden-chapman_2008	52 weeks	heat	reliever use at night	6-12	.	349	100	1.82	[0.93; 3.57]	9.8%
marks_2010	6 weeks	heat	reliever use	8-12	.	400	15	0.89	[0.60; 1.30]	17.0%
marks_2010	6 weeks	heat	reliever use	8-12	atopy	152	15	1.87	[1.08; 3.25]	12.4%
Random effects model								1.38	[0.82; 2.32]	39.1%
Heterogeneity: $I^2 = 68\%$, $\tau^2 = 0.1369$, $p = 0.04$										
design_type = observational										
rice_2020	2 months	both	systemic steroid use	0-16	bpd	244	.	1.34	[0.86; 2.07]	15.4%
rice_2020	2 months	both	reliever use	0-16	bpd	244	.	1.02	[0.65; 1.61]	15.0%
rice_2020	2 months	both	systemic steroid use	0-16	bpd with resp support	114	.	1.44	[0.71; 2.95]	9.1%
rice_2020	2 months	both	reliever use	0-16	bpd with resp support	114	.	0.85	[0.43; 1.69]	9.6%
schachter_2020	2 weeks	stove	summertime asthma medication puffs per day	6-14	.	36	100	2.53	[0.73; 8.86]	3.8%
schachter_2020	2 weeks	stove	wintertime asthma medication puffs per day	6-14	.	36	100	5.39	[1.36; 21.28]	3.2%
paulin_2017	0 weeks	both	reliever use at night	5-12	.	30	100	4.90	[1.09; 22.00]	2.8%
paulin_2017	0 weeks	both	reliever use at day	5-12	.	30	100	1.96	[0.34; 11.29]	2.1%
Random effects model								1.37	[1.02; 1.85]	60.9%
Heterogeneity: $I^2 = 37\%$, $\tau^2 = 0.0330$, $p = 0.14$										
Random effects model								**1.39**	**[1.07; 1.81]**	**100.0%**
Heterogeneity: $I^2 = 42\%$, $\tau^2 = 0.0673$, $p = 0.07$										
Test for subgroup differences: $\chi^2_1 = 0.00$, df = 1 ($p = 0.98$)										



ENERGY TECHNOLOGIES AREA
BERKELEY LAB

Summary

- **Findings** ► Foundation for extrapolating the potential health advantages of broad-scale initiatives aimed at mitigating the effects of unvented combustion.

- **Initiatives** ► Enhancing ventilation and source control, transitioning to vented appliances, improving regulations governing device emissions, and quantifying the advantages of electrifying various end-uses.

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

QUESTIONS…?

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

FRENCH PERFORMANCE BASED REGULATION

Valérie Leprince

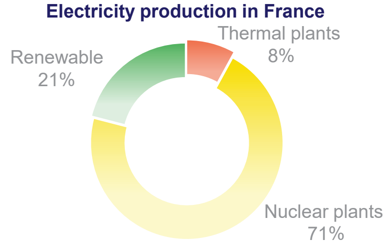
AIVC conference, October 4th and 5th, 2023

1

PERFORMANCE BASED REGULATION AND DECARBONATION

- New buildings : Electrically heated
  - Ventilation around 20% of the need
  - **Low impact of ventilation saving on decarbonisation**
- **Existing buildings**
  - More than 50% fossil energy for heating
  - Prescriptive regulation difficult to apply in refurbishment
  - Need for alternative performance-based regulation
- **Embodied energy in ventilation system**
  - Taken into account in new RE2020
  - Performance base regulation promote/allow innovation
    - Just-tech systems

Electricity production in France



Performance-based approaches

Required ***IAQ performance*** *indicators to be achieved by the ventilation systems instead of* ***ventilation rates.***

RÉPUBLIQUE FRANÇAISE
Cerema
CLIMAT & TERRITOIRES DE DEMAIN

2

Prescriptive French regulation

Arrêté de 1982

RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN

FRENCH PERFORMANCE BASED REGULATION

ARRÊTÉ DE 1982

Art. 1: The air renewal in dwelling is general and permanent at least during the heating season.

Art2: The air renewal system shall include natural or mechanical inlet in main rooms and outlet in utility rooms. The air shall circulate between main and utility rooms

Art 3: The ventilation system shall be able to reach, simultaneously or not the following values:

Number of main rooms in the dwelling	Extract flowrate in m³/h				
	Kitchen	Bathroom	Other room with water source	Toilet	
				Only one	Multiple ones
1	75	15	15	15	15
2	90	15	15	15	15
3	105	30	15	15	15
4	120	30	15	30	15
5 or more	135	30	15	30	15

Additional requirements are set for fire safety and interaction with combustion appliance.

Art. 4: The total extract flowrate can be reduced as follow :

	Number of main rooms						
	1	2	3	4	5	6	7
Total minimal flowrate in m³/h	35	60	75	90	105	120	135
Minimal flowrate in the kitchen m³/h	20	30	45	45	45	45	45

If the ventilation system **automatically control flowrate** to maintain an indoor air quality that is not dangerous for occupant and avoid condensation (except temporarily) the flowrate can be reduced. Provided that the **system has been validated by the ministry** in charge of construction and health. In any case the total extracted flowrate shall at least be:

	Number of main rooms						
	1	2	3	4	5	6	7
Total minimal flowrate in m³/h	10	10	15	20	25	30	35

Art.5: air inlet shall be designed to reach extracted flowrates defined at article 3.

RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN

FRENCH PERFORMANCE BASED REGULATION

Objective of the new performance base regulation

NEW REGULATION

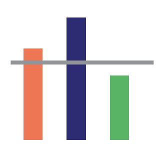
The new construction code states that :
*"Air renewal, shall be such as, in normal condition of use, the **indoor air pollution does not endanger health** and **security of occupants** and that **condensation is avoided,** except temporarily".*

This is respected if the system:

Respects

Arrete de 82
requirements
Art.1 ____
Art.2 ____
Art.3 ____
Art.4 ____
Art.5 ____

Or



Fulfills
Key Performance Indicators levels*

*(named Résultats minimaux – Minimal results) as defined in a Regulatory text to be published by January 2025.

*Ambitious because **defining KPI for ventilation** with minimum **is still a matter of research**, this is worked on in IEA-EBC Annex 86*

WHAT IS THE PURPOSE OF VENTILATION?

Ventilation is air renewal by purpose-provided means which replaces the air with air coming directly from outdoors. The objective of a ventilation system can be to:

Maintain healthy indoor air
limit indoor-produced pollutant concentration, and/or limit outdoor-produced pollutant concentration,
Ensure olfactive comfort
and avoid stuffiness feeling

Improve summer comfort

Regulate humidity level to mitigate the risk of condensation and mold development (building lasting quality),

Etc…

*Additionally, the ventilation system should **not compromise acoustic comfort and significantly increase energy consumption**.*

In France the regulation in 1982 has been made to:

- First, **humidity:** avoid condensation,
- Second, **health:** limit indoor produced pollutant concentration and their transfer from utility rooms to main rooms
- Three, **comfort:** limit stuffiness feeling and avoid olfactive discomfort due to the transfer of odors from utility rooms (ex. Kitchen to main rooms)

KPI follow this logic

Foreseen new requirements

PRELIMINARY DECISIONS

Before starting the work on indicators, it has been decided that:

The validation of systems shall be done building's **project by building's project**

The agreement is **valid only for a given ventilation** system **in a defined architecture and climate**.

As some parameters of local climate is difficult to anticipate (such as wind) and may change over the years, parametric study will be done on those parameters

› and **not for a ventilation system.**

Today system that **fulfill Arrêté de 82** (modified in 83) regulation shall **have performance** in-line with **required levels for indicators** but **not necessarily** systematically comply **for all kind of dwelling/location etc…**

A performance-based regulation shall be more "safe-sided" than a prescriptive one.

The performance **will be evaluated on :**

- **the 3 French climate zones**
- **multiple size and configuration**
- **every existing systems**

› **to help the definition of the required level for key performance indicators**

RÉPUBLIQUE FRANÇAISE — Cerema CLIMAT & TERRITOIRES DE DEMAIN

FRENCH PERFORMANCE BASED REGULATION

9

PRELIMINARY DECISIONS

Before starting the work on indicators, it has been decided that:

› **The ability of a system** in a project **to fulfill performance indicators level** will be

validated through preliminary simulations

not through on-site measurements

Nevertheless, the ability of indicators to be compared to on-site measurement is a criterion to define them

› **Some prescriptive requirements** will be **kept as a safeguard** as everything cannot be planed. **The following prescriptive requirements** shall be **kept:**

- **A general and permanent minimum flowrate** (every rooms shall be ventilated) *The foreseen flowrate is twice the second table of Article 4*
- **A non-closable outlet** *in each utility rooms*
- **A non-closable inlet** *(or outlet) in each main room*
- Existing **requirements on fire-safety** *The system shall not compromise the well-functioning of combustion appliance if any in the dwelling*
- **Maintenance requirements**

RÉPUBLIQUE FRANÇAISE — Cerema CLIMAT & TERRITOIRES DE DEMAIN

FRENCH PERFORMANCE BASED REGULATION

10

PRELIMINARY DECISIONS

Before starting the work on indicators, it has been decided that:

- **The validation** of a project will be **done by an independent body** with a process to be defined
- **A system includes a maintenance process** and the description of its inspection **protocol to check and maintain its performances.**

DEFINITION OF KPI

The following questions needs to be answered to define performance indicators

On which criteria shall the system be evaluated to determine whether he fulfill the regulation

- Indoor air parameters – which ones?
- CO_2, humidity, $PM_{2.5}$, Radon, fictive polluants, etc.
- Energy parameters

Which indicators for each criterion?

- Criteria on rooms or occupant's exposition
- Cumulated exposure
- Maximum exposure
- A multi-criteria aggregation, in this case the impact of the weight distribution needs to be clearly explored in order to propose distribution adapted to the IAQ
- Else?

Which level of requirements on indicators

- Absolut acceptable threshold
- Relative performance regarding a reference system ? (theoretical or ideal system)
- Else?

- **In the context of the French** regulation on ventilation **it has been decided not to evaluate performances according the energy performance** as it is already included in the energy performance calculation.
- In France, **to fulfill the objective of ventilation** defined in the introduction **the chosen criteria regarding indoor quality are the following :**

Humidity — CO_2

A fictive pollutant P1 emitted continuously in every rooms with an emission rate proportional to the area

A fictive pollutant P2 emitted in the kitchen during cooking events at mid-day and in the evening.

FORESEEN KPI IN FRANCE

For CO_2

- For each room, **the CO_2 concentration (in ppm) below which it remains 67% of occupied time**

> **This indicator reflects the mean operating conditions**

An indicator in ppm is more easily readable than a cumulative exposure in ppm.h

- For each room, **the CO_2 concentration (in ppm) below which it remains 95% of the occupied time**

> **This Indicator reflets pic conditions**

For Humidity

- For every room, **a maximum percentage of time over 75% of relative humidity during the heating period**. The maximum value will depend on the type of room (as surface finishing standards depend on it)
- Number of hour when at least one leak is overpresssured and the humidity level is above 75% (for every rooms)

For the fictive pollutant P1 -> permanent emission

- The **mean exposure** (for the most exposed person)
- The **maximum exposure over one hour** (moving average, for the most exposed person).

For the fictive pollutants P2 -> Emitted during cooking periods

- The **maximum exposure over one hour** (or half an hour) (moving average, in the kitchen).
- The mean concentration of pollutant P2 for each bedroom (to avoid transfer)
- For each room but kitchen, the P2 concentration (in ppm) below which it remains 99% of time

13

CONCLUSION

> **France is about to have an alternative to its prescriptive regulation on ventilation developing a performance-based regulation that :**

- **Open the market to**
  - Smart ventilation
- **And systems that will**
  - Maintain or improve the indoor air quality
  - Limit the energy use and their embodied energy

> **This new regulation should help decarbonize the full building stock for two reasons :**

- **It will give a framework and guidelines for refurbishment and for existing building**
- **The reduction of the energy use but also on the reduction of buildings' materials impact**

Natural, hybrid, low-pressure systems etc…

The objective is to define KPI **by the end of 2023** and to publish the regulation **by 2025**

*This regulation should allow the development **of low-tech ventilation systems** with **less impact on embodied energy** which is now considered in the French energy performance regulation RE2020.*

14

RÉPUBLIQUE FRANÇAISE

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

FRENCH PERFORMANCE BASED
Titre présentation
REGULATION

15

INPUT PARAMETERS FOR SIMULATION

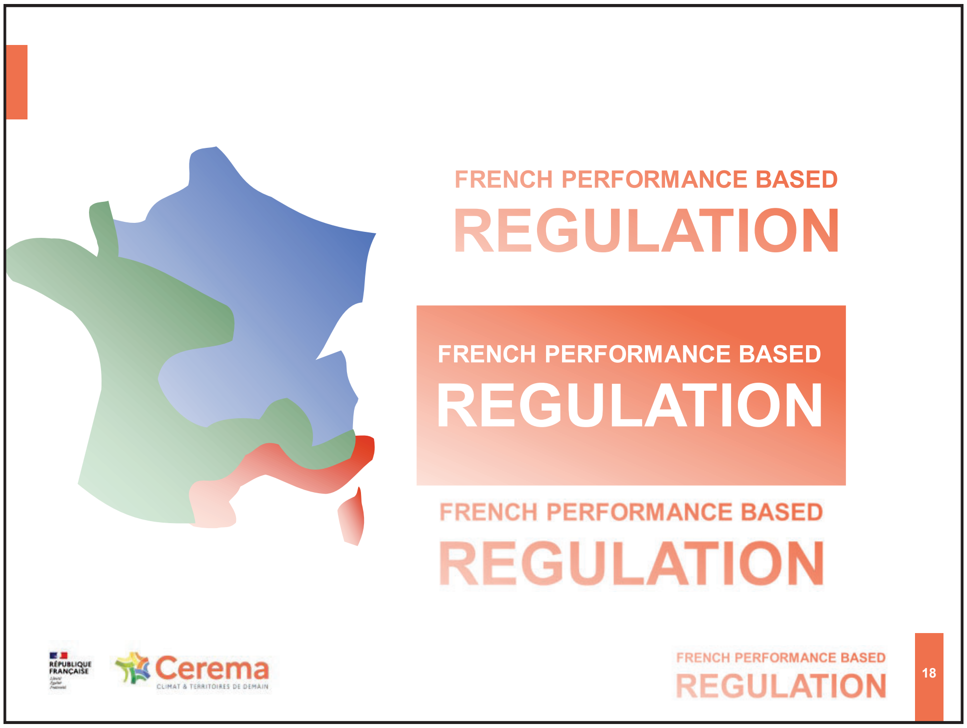
RÉPUBLIQUE FRANÇAISE

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

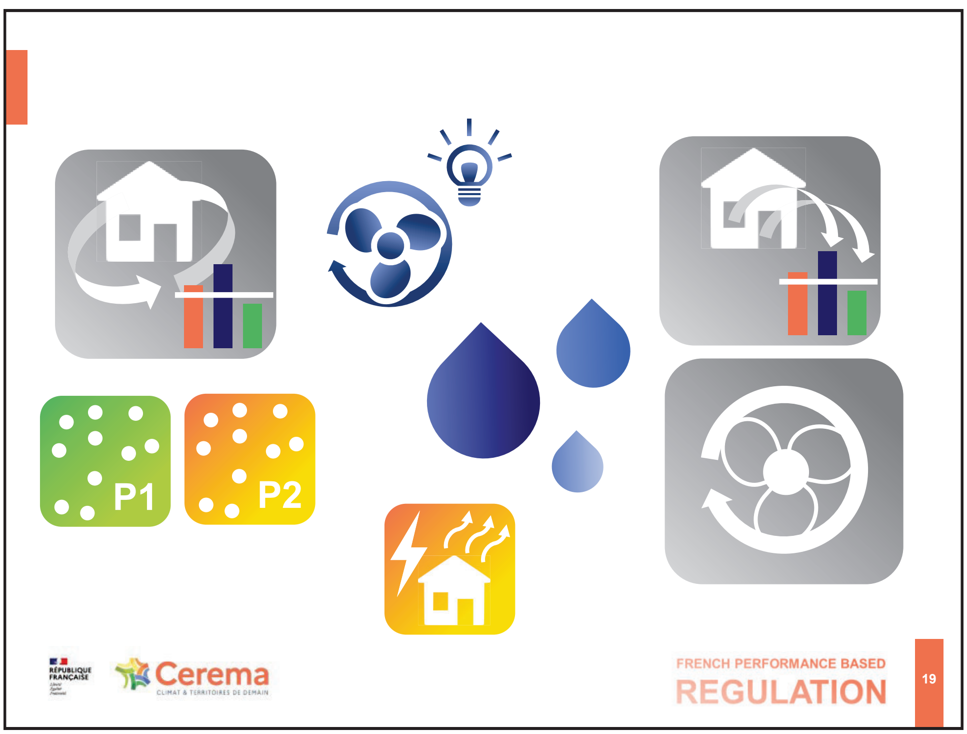
FRENCH PERFORMANCE BASED
REGULATION

16

16


FRENCH PERFORMANCE BASED
REGULATION
FRENCH PERFORMANCE BASED
REGULATION
FRENCH PERFORMANCE BASED
REGULATION
RÉPUBLIQUE FRANÇAISE
Cerema
CLIMAT & TERRITOIRES DE DEMAIN
FRENCH PERFORMANCE BASED
REGULATION
18

18


P1
P2
RÉPUBLIQUE FRANÇAISE
Cerema
CLIMAT & TERRITOIRES DE DEMAIN
FRENCH PERFORMANCE BASED
REGULATION
19

19

Comparative Analysis Between Indoor Temperatures of Dwellings at Urban Scale During a Typical and Extreme Summers in a Temperate Climate

Ainhoa Arriazu-Ramos, Germán Ramos Ruiz, Juan José Pons Izquierdo, Ana Sánchez-Ostiz Gutiérrez and Aurora Monge-Barrio

Ainhoa Arriazu-Ramos
aarriazu@unav.es
School of architecture- University of Navarra
Spain

43rd AIVC
11th TightVent & 9th venticool Conference

1

INTRODUCTION | OBJECTIVES | METHODS | RESULTS | CONCLUSIONS

GLOBAL WARMING

DUE TO CLIMATE CHANGE

PREDICTIONS…

IPCC→ temperature 1.1 °C above 1850-1900 in 2011-2020

Extreme warm temperatures=North Africa

Mega-heatwaves will increase by a factor of 5-10 in the next 40 years

ALREADY HAPPENING…

August 2003 → 50,000 excess deaths

2022 →110,000 excess deaths (and around 4,500 in Spain)

3

RESEARCH OBJECTIVES

This research is focused on…

Quantifying and comparing indoor operative temperatures (IOT) of dwellings in relation to their **building parameters**

The assessment was conducted in **two neighbourhoods of Pamplona** (a city in the north Spain) during a

typical summer (climate series 1980-2010) / **2003** extreme warm summer and **2022** extreme warm summer with heatwaves

Considering the **effect of microclimate**

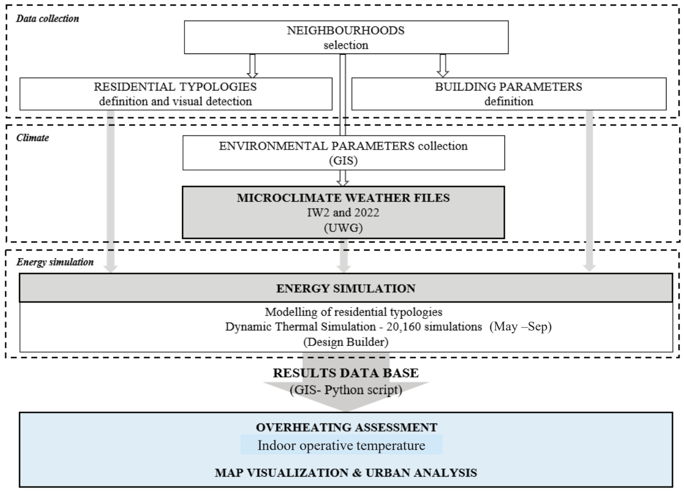
Specific research aims are the following:

1. To quantify the **influence of microclimate** on indoor operative temperatures in dwellings.
2. To compare how **indoor operative temperatures of dwellings are intendified in extreme warm summers** in relation to a typical climate series.
3. To **analyse the influence of different building parameters** (built period, floor level, main orientation, area of windows and number of orientations) on indoor operative temperatures.

RESEARCH NOVELTY

- **Simulation with real data of 2003 and 2022 extreme summers with heatwaves**
- **Assess the effect of microclimate on indoor temperatures**
- **The neighbourhood-scale**
- **The simulation results per dwelling**

METHODOLOGY SUMMARY

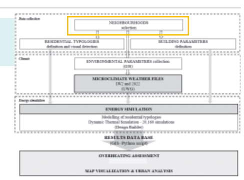


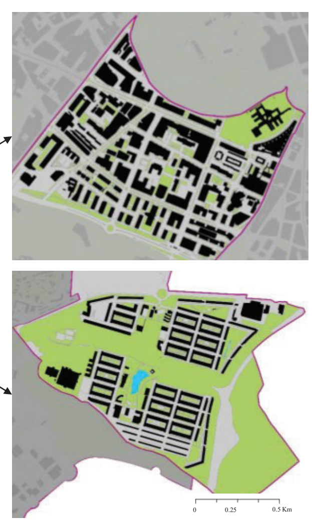
Urban Weather Generator 4.1
urban heat island effect modeling software

ArcGIS Pro

DesignBuilder

URBAN CONTEXT

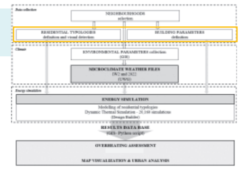




(1960-1980) 9,242 dwellings

(1990-2006) 5,634 dwellings

ENERGY PARAMETERS



Energy parameters → built period → energy regulation

- **N1** was built before 1979 (no energy regulation) when **there weren't any energy regulations for buildings**.
- **N2** was built between 1980-2006 (CT-79 period) with the first standard energy regulation in Spain **NBE CT-79** which appears after the 1970s energy crisis as in other countries.

Infiltration rates were not regulated in Spain until 2019 (with the Spanish Building Code regulation) so the used values are based on previous studies.

There weren't any IAQ regulations in any of the periods and

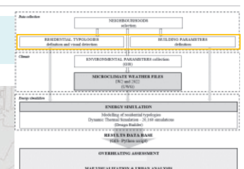
All dwellings are naturally ventilated.

Used parameters and values for energy simulations

	Built period / Energy regulation	Ufaçade / Uroof (W/m²K)	Uglass / Uframe (W/m²K)	Infiltrations (50Pa)	Solar shading system	Ventilation
ENVELOPE 1	*N1* *No energy regulation*	1.39[a] / 2.9	5.7 / 8.5	7	Blinds with low reflectivity slats[b]	Calculated natural ventilation: Windows free aperture = 15% 1AM- 8AM: 4 ach/h 9AM- 12PM: 0 ach/h Cracks: medium
ENVELOPE 2	*N2* *CT-79*	0.73[a] / 0.65	3.5 / 8.5	7	Blinds with medium reflectivity slats[b]	

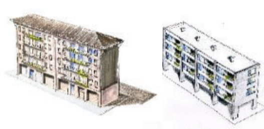
[a] *This value considers the influence of thermal bridges, which worsen the façade transmittance (U) it by 30%.*
[b] *They are considered to be in use (completely down) when solar radiation >150 w/m2*

BUILDING TYPOLOGIES



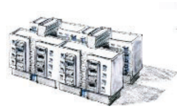
Typologies 11, 12, 13, 14 and 15

→multi-family buildings grouped in **linear blocks**



Typologies 21 and 22

→multi-family buildings grouped in **H-blocks**



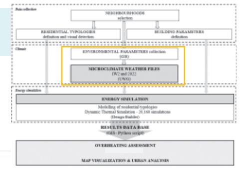
Typologies 31, 32 and 34

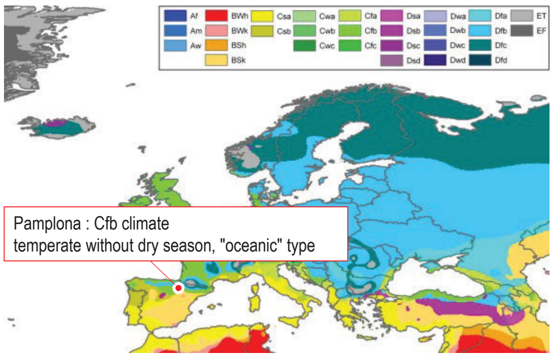
→ dwellings in **tower**

Typologies 51

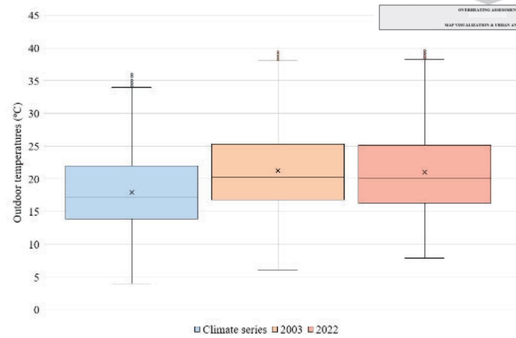
→ single-family dwellings: **attached**

CLIMATE AND MICROCLIMATE





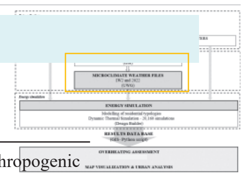
Koppen-Geiger classification



Three weather files were used for energy simulations:

- Climate series (IWEC2-based in climate series 1980-2010 of ASHRAE)
- Two extreme warm summers
  - 2003 → 20 days of heatwave
  - 2022 →41 days of heatwave

CLIMATE AND MICROCLIMATE

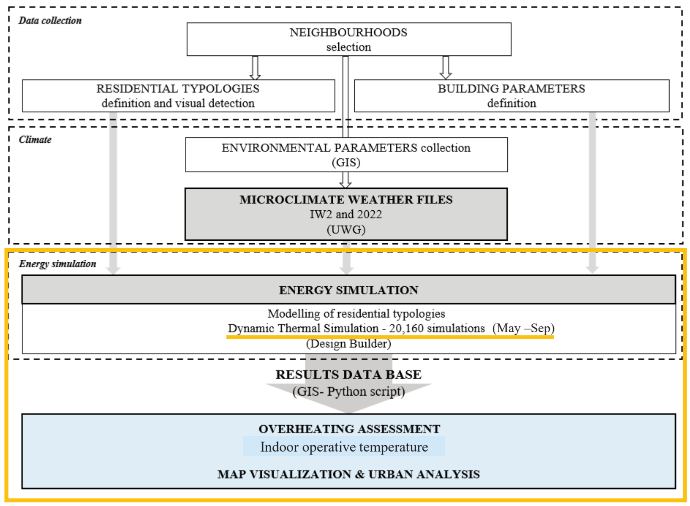


Urban Weather Generator (UWG)

	Site coverage ratio	Facade to site ratio	Road albedo/ Roof albedo/ Wall albedo	Average building height	Urban ground covered in grass/ Urban ground covered in trees	Vegetation albedo	Anthropogenic heat generation (traffic)
	(0-1)	(0-1)	(0-1)	(m)	(0-1)	(0-1)	(w/m^2)
N1	0.34	0.57	0.20/ 0.45/ 0.60	25.45	0.25/ 0.05	0.4	25
N2	0.17	0.18	0.20/ 0.29/ 0.63	10.32	0.47/ 0.02	0.4	25

GIS and Cadastre

METHODOLOGY SUMMARY



RESEARCH OBJECTIVE 1

<u>To quantify the influence of microclimate on indoor operative temperatures in dwellings</u>

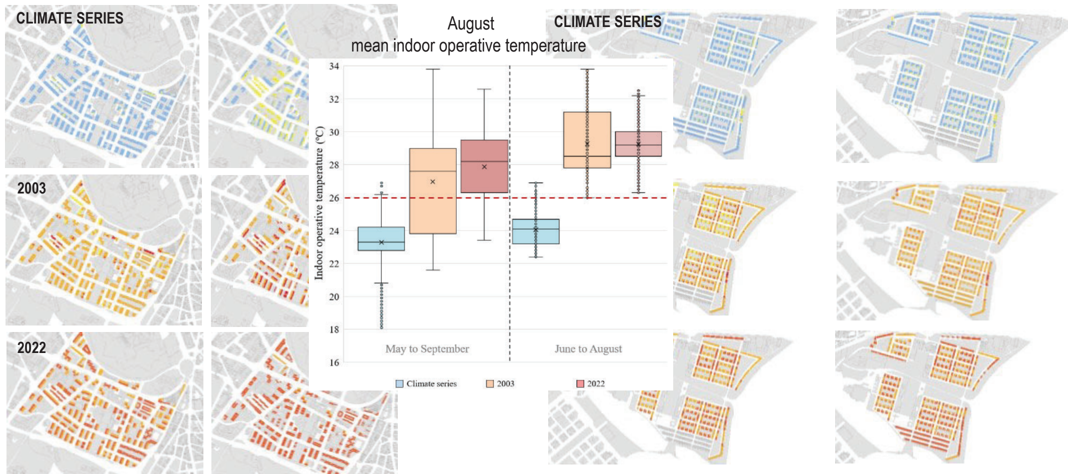
Differences between mean indoor operative temperatures (ºC) considering microclimate or not considering it.

Group	Climate series	2003	2022
N1. base	23.08 (SD. 1.61)	26.01 (SD. 2.82)	26.64 (SD. 2.00)
N1. microclimate	23.22 (SD. 1.45)	26.95 (SD. 3.23)	27.94 (SD. 2.00)
N1. Diff.	**0.13 (0.15-0.11) p<0,001**	**0.93 (0.97-0.89) p<0,001**	**1.30 (1.32-1.27) p<0,001**
N2. base	23.07 (SD. 1.59)	25.90 (SD. 2.73)	26.47 (SD. 1.96)
N2. microclimate	23.40 (SD. 1.26)	26.96 (SD. 3.17)	27.74 (SD. 1.96)
N2. Diff.	**0.32 (0.35-0.30) p<0,001**	**1.06 (1.11-1.01) p<0,001**	**1.30 (1.33-1.26) p<0,001**

Ttest

RESEARCH OBJECTIVE 2

To compare how indoor operative temperatures of dwellings are intensified in extreme warm summers in relation to a typical climate series



RESEARCH OBJECTIVE 3

To analyse the influence of different building parameters on indoor operative temperatures

	Climate series		2003		2022		
Parameters**	**Beta Coef.**	**[95% Conf. Interval]**	**Beta Coef.**	**[95% Conf. Interval]**	**Beta Coef.**	**[95% Conf. Interval]**	**p value**
Built period							
No regulation (N1)	0 (Ref.)		0 (Ref.)		0 (Ref.)		
CT-79 (N2)	+0.20	(+0.18 to +0.21)	-0.17	(-0.19 to -0.16)	-0.37	(-0.38 to -0.35)	<0.001
Floor level							
Top floor	0 (Ref.)		0 (Ref.)		0 (Ref.)		
Intermediate floor	+0.31	(+0.29 to +0.32)	-0.20	(-0.22 to -0.18)	-0.40	(-0.42 to -0.37)	<0.001
Orientation							
N/ NE / NW	0 (Ref.)		0 (Ref.)		0 (Ref.)		
S / SW / W	+0.20	(+0.19 to +0.21)	+0.38	(+0.37 to +0.40)	+0.44	(+0.42 to +0.46)	<0.001
E / SE	+0.13	(+0.11 to +0.14)	+0.06	(+0.05 to +0.08)	+0.03	(+0.00 to +0.05)	<0.001
Window area							
≤ 4m²	0 (Ref.)		0 (Ref.)		0 (Ref.)		
>4m²	+0.16	(+0.15 to +0.17)	+0.39	(+0.37 to +0.40)	+0.31	(+0.29 to +0.32)	<0.001
Nº orientations							
1 orientation	0 (Ref.)						
> 1 orientation	-0.40	(-0.41 to -0.37)	-0.33	(-0.35 to -0.30)	-0.83	(-0.04 to -0.12)	<0.001

multilevel mixed-effects linear regression

Quantifying and comparing **indoor operative temperatures (IOT) of dwellings** in relation to their **building parameters** in **different climate scenarios** and at **urban scale**

1. Microclimate effect on indoor operative temperatures in dwellings
   - Statistically significant ($p<0.05$)
   - Higher when the summer was warmer → reaching a difference between means of 1.3ºC in 2022.

2. Indoor operative temperatures of dwellings are intensified in extreme warm summers in relation to a typical climate series
   - 2003 and 2022 showed higher indoor operative temperatures → difference of 4.1ºC on average
   - 2003 and 2002 → most dwellings are over 26ºC

3. Influence of built period, floor level, orientation, window area and number of orientations on indoor operative temperatures
   - Statistically significant ($p<0.05$)
   - Worst parameters→ built before any energy regulation / top floors / S and W façade / single orientation dwelling / windows area > 4m2
   - Intensified in old neighbourhood and in 2003 and 2022

Quantifying and comparing **indoor operative temperatures (IOT) of dwellings** in relation to their **building parameters** in **different climate scenarios** and at **urban scale**

In temperate climates

- Assess temperatures through a summer with heatwaves
- Considering microclimate
- Identify the key building parameters → to adapt dwellings to warming conditions and prevent the risk of overheating within cities

Thank you for your attention!

Project behind: "*ClimaReady -Adaptation Assessment of Spanish residential buildings*" (2020-2023)

School of architecture - University of Navarra (Spain)

aarriazu@unav.es

AIVC TightVent Europe venticool

2023

DECARBONIZATION AND IAQ IN SPAIN: A ROADMAP

Marta Sorribes Gil msorribes@ietcc.csic.es
Rafael Villar Burke pachi@ietcc.csic.es
Daniel Jiménez González danielj@ietcc.csic.es

Construction Quality Technical Department (UCC)
Eduardo Torroja Institute for Construction Sciences (IETCC-CSIC)

1

INDEX

DECARBONIZATION AND IAQ IN SPAIN: A ROADMAP

1. INTRODUCTION — EUROPEAN STRATEGY
2. DECARBONIZATION IN SPANISH REGULATION — DECARBONIZATION AND IAQ
3. CONCLUSIONS

2

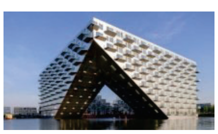
1 INTRODUCTION

THIS IS A CURRENT OVERVIEW OF THE DECARBONIZATION PROCESS UP TO 2050 IN THE EUROPEAN FRAMEWORK, AND ITS TRANSPOSITION INTO SPANISH ENERGY POLICY AND REGULATIONS, WITH A SPECIAL FOCUS ON THOSE ASPECTS RELATED TO BUILDING VENTILATION AND INDOOR AIR QUALITY

3

1 EUROPEAN STRATEGY

DECARBONIZATION OF THE EUROPEAN BUILDING STOCK:



NEW BUILDINGS:
ZERO-EMISSION BUILDINGS
BY **2030**

EXISTING BUILDINGS:
ZERO-EMISSION BUILDINGS
BY **2050**

EPBD Article 2:

*A **zero-emission building** is a building with a very high energy efficiency (determined in accordance with Annex 1, which states that it shall be expressed by an indicator of primary energy consumption per unit area per year [kWh/m^2]) <u>in which the small amount of energy that is still needed is fully covered by energy from renewable sources</u> generated on-site, from a renewable energy community or from a district heating and cooling system in accordance with the requirements of Annex III*

4

2 DECARBONIZATION IN SPANISH REGULATION

CURRENT REGULATION:

- **DB-HE** (Basic Document on Energy Saving)
  - $C_{ep,nren}$ CLIMATE ZONE DEPENDING VALUES
  - $C_{ep,tot}$ CLIMATE ZONE DEPENDING VALUES
- **EPC** (Energy Performance Certification)
  - CO_2 emissions in USE PHASE
  - $C_{ep,nren}$ CLIMATE ZONE DEPENDING VALUE
- **ERESEE** (Long Term Strategy for Energy Rehabilitation of the building sector in Spain)

NEXT REGULATION:

- **DB-HE** (Basic Document on Energy Saving)
  - $C_{ep,nren}$ ≈ 0
  - $C_{ep,tot}$ <<<<<
- **EPC** (Energy Performance Certification)
  - CO_2 emissions in LIFE CYCLE ASSESMENT
  - $C_{ep,tot}$
- **PNRE** (National Plan for Building Rehabilitation)
- RECHARGING OF ELECTRIC VEHICLES
- FOSSIL FUELS BAN BY 2030
- ELECTRIFICATION OF EPB USES AND DECARBONIZATION OF SUPPLY NETWORKS

$k_{exp} = 1$

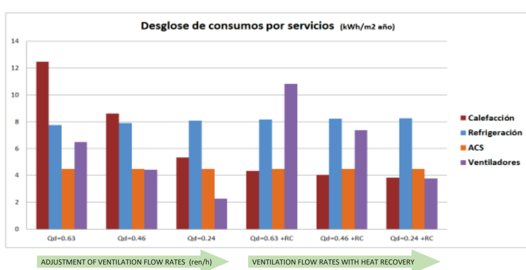
CSIC

5

2 DECARBONIZATION AND IAQ

VENTILATION AND ENERGY IMPACT

Growing impact of the air exchange with the outside on the building energy performance



FUTURE EVOLUTION

1. ADJUSTMENT OF VENTILATION FLOW RATES
2. IMPROVING THE AIRTIGHTNESS TREATMENT AND THE USE OF HEAT RECOVERY SYSTEMS

CSIC

6

2

DECARBONIZATION AND IAQ

1 **ADJUSTMENT OF VENTILATION FLOW RATES**

- DISCREPANCIES IN THE CALCULATION OF VENTILATION FLOW RATES BETWEEN THE ENERGY MODEL AND THE AIR QUALITY MODEL:
  - ➢ DIFFERENCES BETWEEN THE VOLUME OF LIVING QUARTERS CONSIDERED
  - ➢ USE SCENARIOS:
    - FOR AIR QUALITY: MAXIMUM RATE
    - FOR ENERGY CALCULATION: AVERAGE RATE

- DEMAND-CONTROLLED VENTILATION SYSTEMS:
  THEIR USE CAN BE EXPECTED TO PLAY AN IMPORTANT ROLE IN REDUCING ENERGY REQUIREMENTS IN BUILDINGS AND THERE IS A NEED TO CLARIFY HOW THEY SHOULD BE CONSIDERED FOR ENERGY CALCULATION PURPOSES, ESPECIALLY IN LESS COMPLEX BUILDINGS AND WITH SIMPLIFIED TOOLS

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

7

2

DECARBONIZATION AND IAQ

2 **IMPROVING THE AIRTIGHTNESS TREATMENT AND THE USE OF HEAT RECOVERY SYSTEMS**

- IS AIRTIGHTNESS OF THERMAL ENVELOPE AN ENERGY REGULATORY STRATEGY IN SPAIN?
  - NOT GENERALLY (MILD CLIMATES)
  - NEED FOR IMPROVEMENT IN SOME CONFLICT POINTS

- FORTHCOMING INCORPORATION IN THE REGULATIONS OF THE NEED TO ADJUST THE PERMEABILITY OF THE BUILDING WHEN USING HEAT RECOVERY UNITS

- OTHER VENTILATION-BASED ENERGY EFFICIENCY STRATEGIES (FREE-COOLING / THERMAL BYPASS) NEED TO IMPROVE THEIR KNOWLEDGE IN TECHNICIANS AND ENERGY CALCULATION TOOLS

- VENTILATION AND BUILDING RENOVATION:
  - REPLACEMENT OF WINDOWS WITH LOWER AIR PERMEABILITY NEED TO INCREASE AWARNESS OF BEST PRACTICES

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

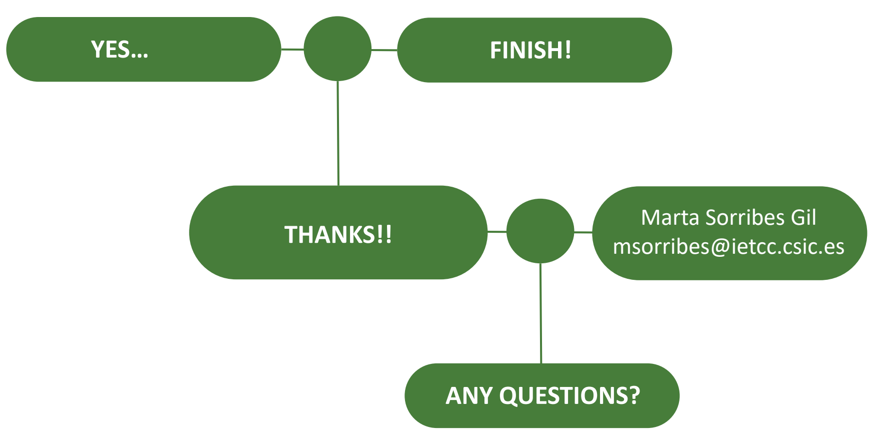
8

3 CONCLUSIONS

- IN HIGH EFFICIENCY BUILDINGS, CONSUMPTION LINK TO AIR TRANSPORT AND VENTILATION SYSTEMS IS SIGNIFICANT AND COMPARABLE TO THAT OF OTHER EPB SERVICES, AND IS THERFORE ESSENTIAL TO MAKE PROGRESS ALONG THE FOLLOWING LINES IN ENERGY REGULATIONS:

  1. ADJUSTMENT OF THE REQUIRED FLOW RATES
  2. IMPROVING THE EFFICIENCY OF EXISTING SYSTEMS AND PROMOTE BEST PRACTICES
  3. FACILITATING INCORPORATION OF NEW TECHNOLOGIES WHEN APPROPRIATE

- AIR QUALITY AND VENTILATION TECHNOLOGIES ARE CLOSELY LINKED TO ACHIEVING THE CLIMATE CHANGE MITIGATION OBJECTIVE AND MUST BE ADDRESSED IN AN INTEGRATED MANNER, PAYING SPECIAL ATTENTION TO BUILDING RENOVATION



Ventilation behaviour of occupants driven by outdoor temperature: 12 case studies

Copenhagen, October 5th, 2023

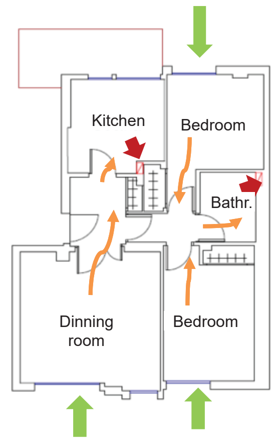
Speaker: Sonia García-Ortega
Eduardo Torroja Institute for construction sciences ETcc - CSIC

Outline

- Objective
- Current situation
- Dwellings selection and characterization
- Measurements

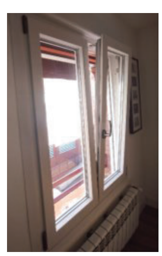
Current situation

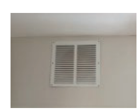
- The traditional way of ventilating dwellings in Spain was by **natural ventilation** based on the operation of **windows and high levels of infiltration** through the building envelope
- Sice the middle of the last century to 2006, the use of **vertical ventilation shafts** in wet rooms of dwellings became widespread and is currently the most common ventilation system in existing dwellings.
- Since 2006, **mechanical or hybrid ventilation** is inforce.

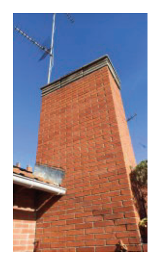


Objective

To find relevant parameters affected IAQ in dwellings with natural ventilated systems, focus on the occupant behaviour.

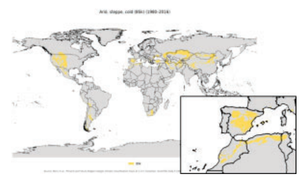


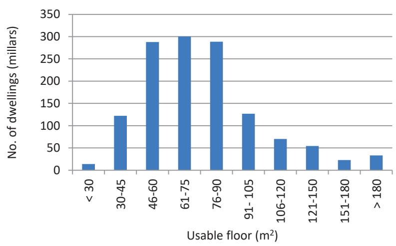


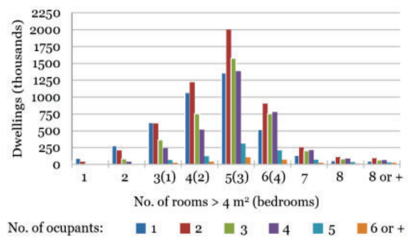


Selection of case studies

- Natural ventilation system
- Consolidated urban environment of the city of Madrid (BSk or continental climate)
- Flats in multi-family buildings
- Usable floor area: 30 to 150 m^2
- No. of rooms: 1 to 7 (rooms > 4 m^2, except bathrooms)
- 1 to 4 occupants

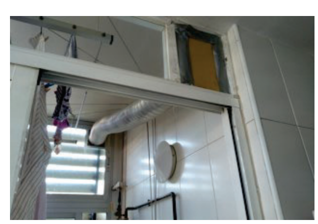






Case studies characterization

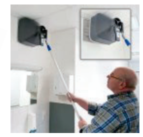
Dwelling code	Year of construction (or main retrofit)	Vertical shafts	Permeability of envelope	Compactness of environment	Compactness of dwelling
01	1986 (2014)	Yes	low	low	medium
02	2000	Yes	high	medium	low
03	1956 (2000)	No	medium	low	higt
04	1960 (2016)	Yes	low	medium	low
05	1987	Yes	high	higt	higt
06	1991	Yes	high	medium	low
07	1970	Yes	medium	medium	higt
08	1963	Yes	medium	medium	low
09	1956	No	medium	higt	medium
10	1982	Yes	high	medium	low
11	1960	Yes	low	medium	medium
12	2011	Yes	Low	higt	medium



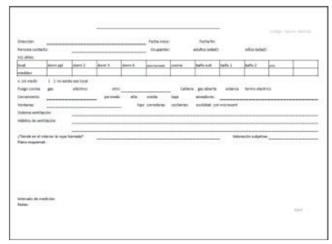
Monitoring and surveys

75 monitorings (42 rooms belongs to 12 differents flats), 37 in summer and 38 in winter

Period: 8 to 21 days (average of 16 days)


Surveys about occupants actions



Findings - Surveys

Dwelling code	No. of occupants	Occupant's behaviour patterns (general surveys)
01	2	Open windows 5' in the morning
02	4	Open windows in function of outdoor temperature and thermal comfort
03	2	Open windows 5' in the morning; all night in summer
04	4	Open windows for a few minutes in the morning and afternoon. Open the windows a lot in summer
05	2	Open windows 10 - 60' in the morning; all night in summer
06	4	No specific habits
07	2	Open windows in the morning. In leaving room: open window all the day except in winter (in winter only open at night)
08	2	No specific habits
09	1	Open the bathroom window after showering, open other windows when feel it is necessary, usually once a day
10	2	Open windows 10' in the morning; in summer leave a small opening all day, and total open window at night
11	4	Open windows 5-10' in the morning
12	1	No specific habits

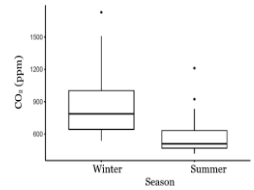
60% open windows in the morning 5-10 minutes
50 % open more time in summer or warm weather

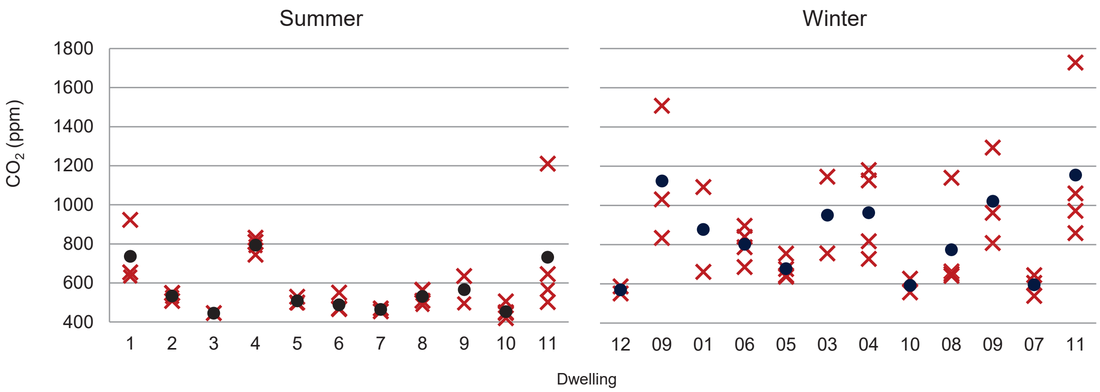
Discrepancies are observed **between** what is expressed in the **surveys** and what is observed during **monitoring**

Monitoring shows:
- **longer ventilation** periods
- in general, **higher ventilation** in warm and summer periods

Findings – Season influence

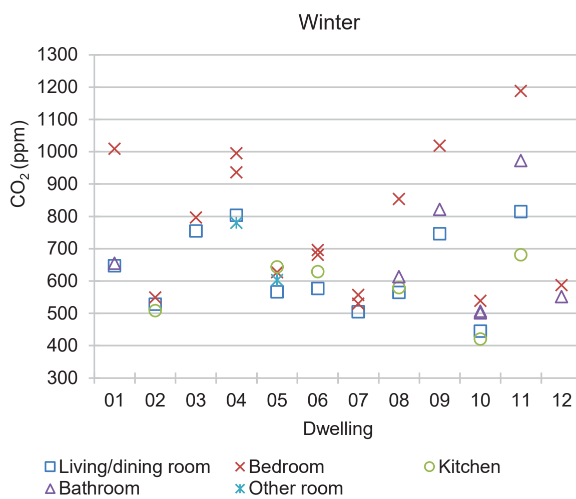
Higher values in winter than in summer





Findings – Season influence

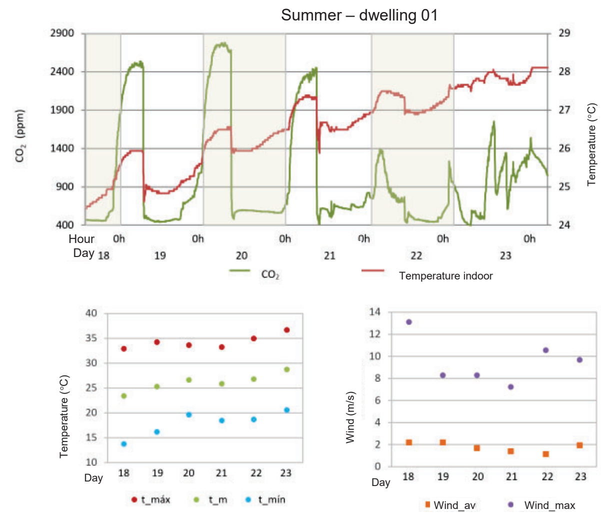
Especially in **bedrooms**



43th AIVC - 11th TightVent & 9th venticool Conference, 2023

Findings - Occupants actions behind season influence

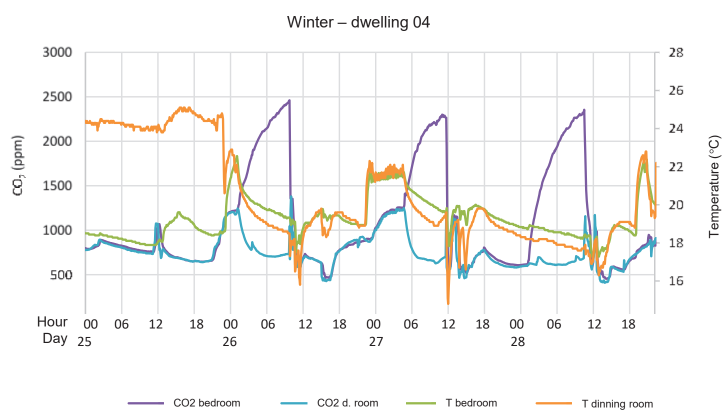
1 - **Increasing of ventilation** with high outdoor temperature, e.g. opening windows more time



43th AIVC - 11th TightVent & 9th venticool Conference, 2023

Findings - Occupants actions behind season influence

2 - **Reduction of volume** to diluted concentrations **with cold outdoor temperature** , e.g. closing indoor doors



Outdoor temperature: minimum: 3°C, medium: 7, maximum: 11

Conclusions for the cases studies

- Main driver of occupant behaviour seems to be **thermal comfort rather than IAQ control** itself, at least when expressed as a function of CO_2 concentration

- Occupant behaviour in relation to IAQ could be considered as a **function of outdoor temperature**

- Occupant behaviour is **not easily captured by general surveys**

Future studies

Established **occupant influence** in IAQ based on **outdoor temperature**

43th AIVC - 11th TightVent & 9th venticool Conference, 2023

Thanks for your attention

Speaker: Garcia_Ortega, Sonia
soniag@ietcc.csic.es

Authors: García-Ortega, Sonia
Linares Alemparte, Pilar

DIGIdat

Indoor air quality in Austrian classrooms

Assessing different ventilation strategies with a citizen science approach

Simon Beck *– simon.beck@uibk.ac.at – 5. October 2023*

43. AIVC Copenhagen – Topical Session on Indoor Air Quality & Ventilation

Paper Authors: Simon Beck, Gabriel Rojas, Sebastian Goreth, Elena Krois, Christian Hechenberger

universität innsbruck
PH Tirol – Pädagogische Hochschule Tirol
OeAD Sparkling Science
funded by: Bundesministerium Bildung, Wissenschaft und Forschung
OeAD Agentur für Bildung und Internationalisierung

DIGIdat

Air Quality in Austrian Schools

15-25 students

55-90 m² classroom

→ Fresh air used up quickly → Standard window airing often insufficient

How is the **situation in existing Austrian schools today**?

What ventilation strategy has what impact?

What role play the **different air pollutants**?

E.g., Austria: **16 out of 18** investigated classroom with **CO_2 concentration too high** (LUKI Studie, Hohenblum et al., 2008)

What we did so far…

DIGIdat

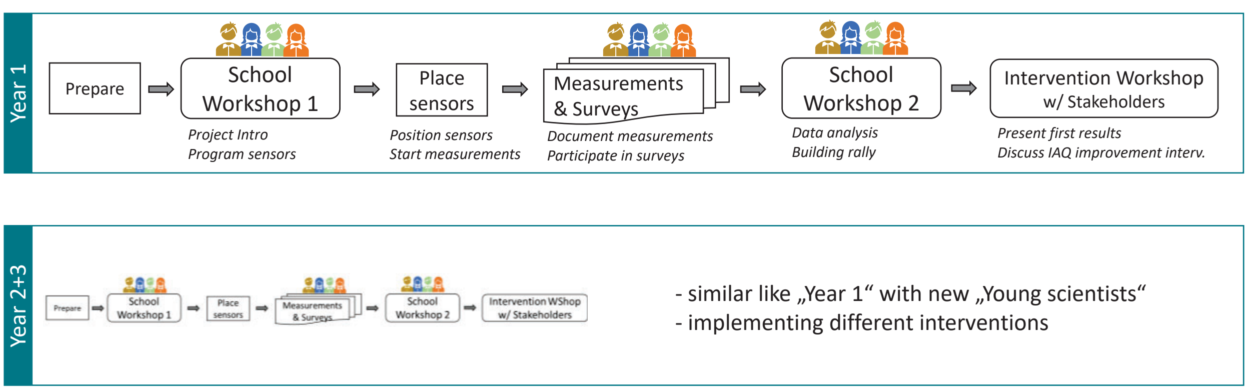
Long term **air quality measurements** in classrooms …
… with help of **children** in schools **as citizen scientists.**

Assessing boundary conditions for the ten participating schools

Data analysis of the measurements in winter/spring
(preliminary results of **project DIGIdat**)

Project concept

DIGIdat

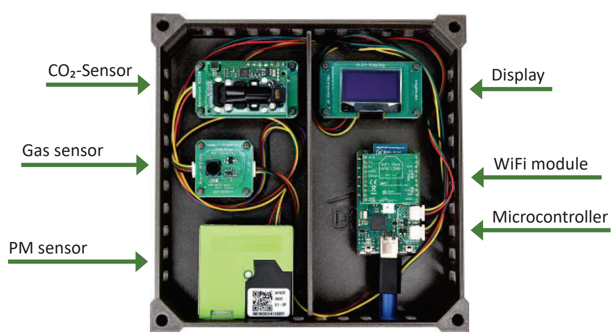


5

Low-cost sensor kit

senseBox

https://sensebox.de/



Sensor	Measurement	Method	Range	Accuracy	Source
BME680	b-VOC_{eq}*	Metal Oxide Semiconductor	0.5 – 1000 ppm**	-	(Bosch Sensortec, 2022)
SCD30	CO_2	Nondispersive Infrared	400 – 10000 ppm	± 30 ppm	(Sensirion, 2020a)
SPS30	$PM_{2.5}$	Optical (light scattering)	0 – 1000 µg/m³	± 10 %	(Sensirion, 2020b)

*calculated from correlation of typical VOCs to gas sensor resistance
**min- and max-output (tested range not available)

Measuring ...

Temperature, Humidity,
Volatile organic compounds (b-VOC_{eq}),
Carbon dioxide (CO_2),
Fine particulate matter (PM_1, $PM_{2.5}$)

Positioning of sensors

housing 3D-printed or crafted by students

mostly on walls in **height of 1 – 1.5 meters**

in **distance** to doors, windows, sinks and other **sources of direct contamination**

mainly **3 sensors per classroom** -> redundance and detection of unreliable sensor readings

Results

Measurement period January – July 2023

Citizen Science approach successful

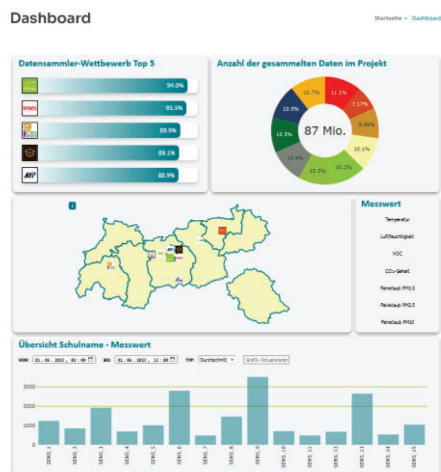
DIGIdat

Students are **responsible** for their sensor-kit

Live transmission of measurements:

-> **online database** (openSenseMap.org)

-> DIGIdat **Dashboard** (digidat.at/dashboard/) ->



92.5 %

actually collected /
potentially collectable
(within timeframe)

universität innsbruck

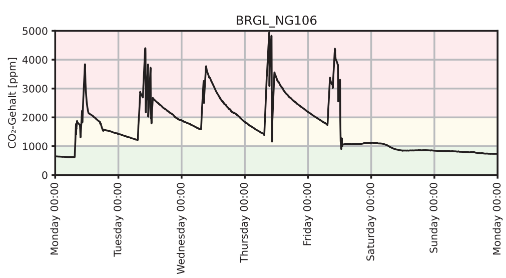
PHTirol Pädagogische Hochschule Tirol

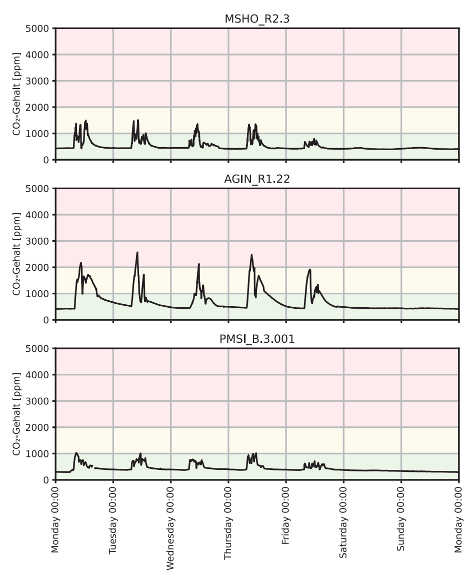
Examples of CO_2 profiles

CO_2 as indirect **IAQ indicator** gas

Measuring every **60 seconds**

Data handling using Python

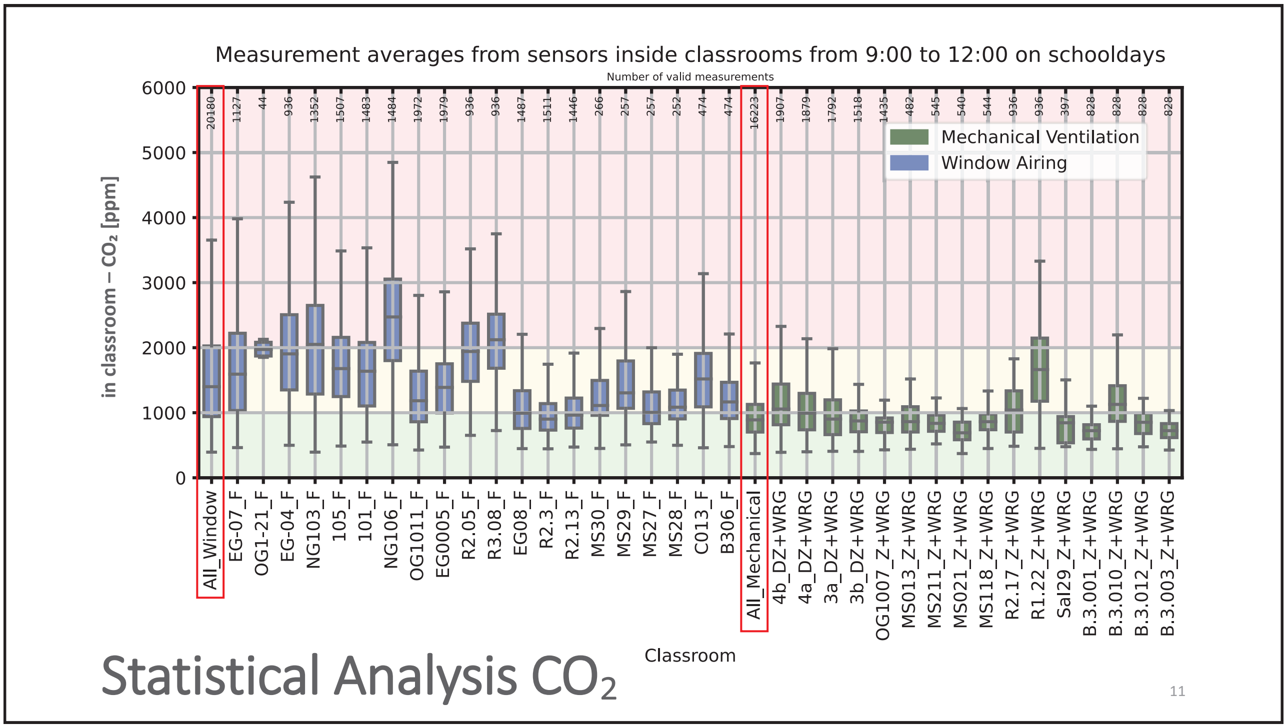




Data from 17.-23. April

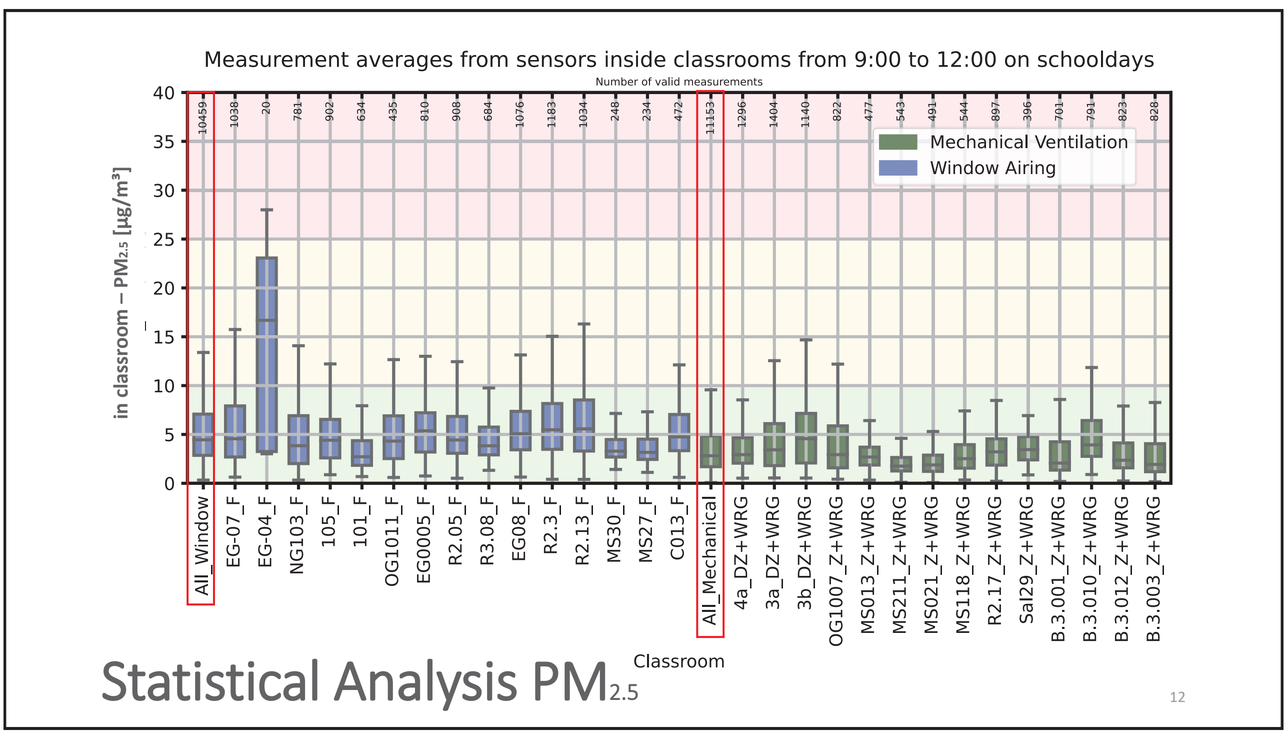
universität innsbruck

PHTirol Pädagogische Hochschule Tirol



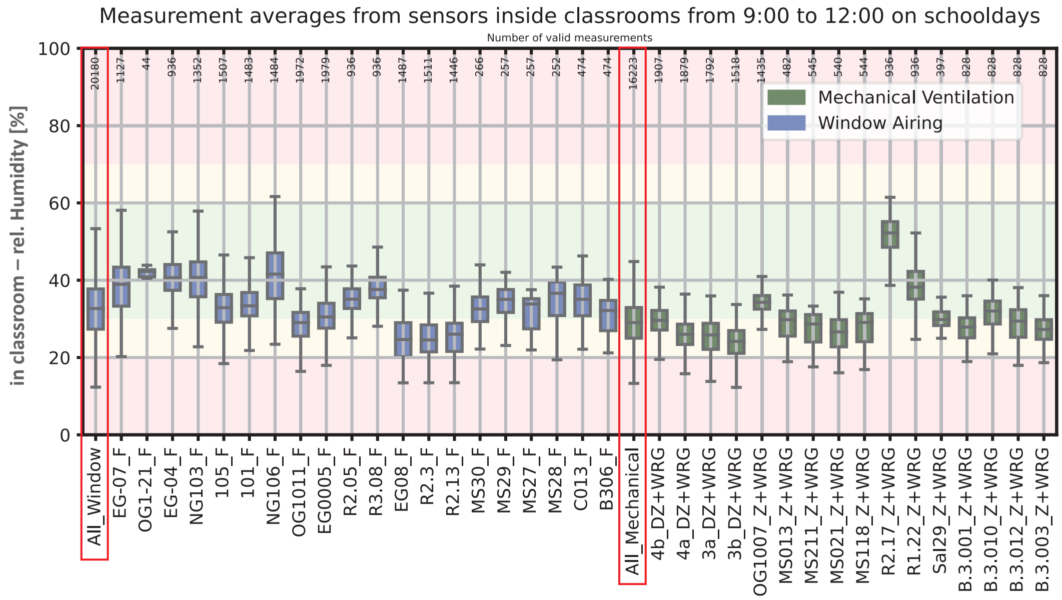
Measurement averages from sensors inside classrooms from 9:00 to 12:00 on schooldays
Number of valid measurements
in classroom – CO₂ [ppm]
6000
5000
4000
3000
2000
1000
0
Mechanical Ventilation
Window Airing
All_Window
EG-07_F
OG1-21_F
EG-04_F
NG103_F
105_F
101_F
NG106_F
OG1011_F
EG0005_F
R2.05_F
R3.08_F
EG08_F
R2.3_F
R2.13_F
MS30_F
MS29_F
MS27_F
MS28_F
C013_F
B306_F
All_Mechanical
4b_DZ+WRG
4a_DZ+WRG
3a_DZ+WRG
3b_DZ+WRG
OG1007_Z+WRG
MS013_Z+WRG
MS211_Z+WRG
MS021_Z+WRG
MS118_Z+WRG
R2.17_Z+WRG
R1.22_Z+WRG
Sal29_Z+WRG
B.3.001_Z+WRG
B.3.010_Z+WRG
B.3.012_Z+WRG
B.3.003_Z+WRG
Classroom
Statistical Analysis CO2
11

11



Measurement averages from sensors inside classrooms from 9:00 to 12:00 on schooldays
Number of valid measurements
in classroom – PM2.5 [µg/m³]
40
35
30
25
20
15
10
5
0
Mechanical Ventilation
Window Airing
All_Window
EG-07_F
EG-04_F
NG103_F
105_F
101_F
OG1011_F
EG0005_F
R2.05_F
R3.08_F
EG08_F
R2.3_F
R2.13_F
MS30_F
MS27_F
C013_F
All_Mechanical
4a_DZ+WRG
3a_DZ+WRG
3b_DZ+WRG
OG1007_Z+WRG
MS013_Z+WRG
MS211_Z+WRG
MS021_Z+WRG
MS118_Z+WRG
R2.17_Z+WRG
Sal29_Z+WRG
B.3.001_Z+WRG
B.3.010_Z+WRG
B.3.012_Z+WRG
B.3.003_Z+WRG
Classroom
Statistical Analysis PM2.5
12

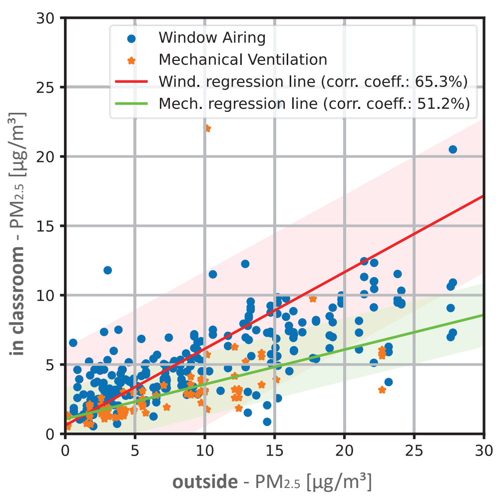
12

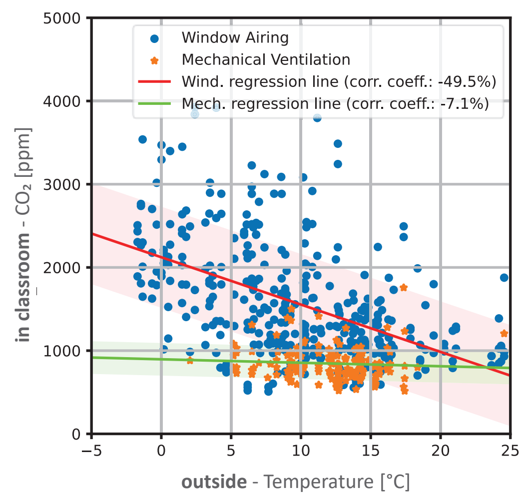


Statistical rel. Humidity

13

13





Correlation inside - outside

14

14

Conclusion

Table 2: Significance of differences: window airing vs. mechanical ventilation (significance level 5%)

Classroom Avg.	Test-Variant	p-Value Wt*	p-Value MWU**	Result
CO_2	window airing > mechanical vent	0.0004 %	0.001 %	very significant
$PM_{2.5}$	window airing > mechanical vent	0.21 %	0.02 %	very significant
b-VOC_{eq}	window airing < mechanical vent	3.74 %	2.51 %	significant
Humidity	window airing > mechanical vent	4.53 %	1.14 %	significant

*Wt … Welch's t-Test
**MWU … Mann-Whitney-U-Test

36 classrooms measured

Statistical significance found
within spring measurement period

- **higher CO_2** concentrations in classrooms **with window airing**
- **colder** temperature **outside** correlates with **higher CO_2** concentrations **in classrooms**
- **higher $PM_{2.5}$** concentrations in classrooms **with window airing**

This indicates that **mechanical ventilation** leads to **lower CO_2 and $PM_{2.5}$** concentrations under **given boundary conditions** (weather and building type)

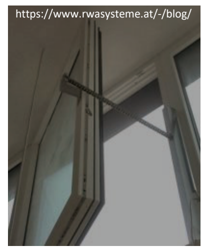
Expanding dataset before and after interventions

Five possible interventions

Raising Awareness

CO_2-Signal

Self-made ventilation system



automatic window opener

Single-Room ventilation system

Problems and upcoming tasks

Problems
- Unsure about **VOC values**, which are calculated by gas sensor
- **Temperature readings** off by about 1°C
- Partly heavy **drift of CO_2 sensors**

Work in Progress
- Own **reference measurements** under controlled conditions -> **quantify errors**
- -> **generate clean data** from measured offset
- Own **calibration** for next measuring period

Next Steps
- **Expanding data set** in coming school years (starting in November)
- Implementing **interventions** and comparing datasets
- Analysis on **influence of boundary conditions** (class size, window orientation, geometry, …)

DIGIdat

Literature and Sources

Hohenblum, P., Kundi, M., Gundacker, C., Hutter, H.-P., Jansson, M., Moosmann, L., Scharf, S., Tappler, P., & Uhl, M. (2008). LUKI – LUft und KInder Einfluss der Innenraumluft auf die Gesundheit von Kindern in Ganztagsschulen; Umweltbundesamt GmbH Spittelauer Lände 5, 1090 Wien/Österreich. http://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0181.pdf

Bosch Sensortec. (2022). *BME680 Datasheet: Digital low power gas, pressure, temperature & humidity sensor*. https://www.bosch-sensortec.com/media/boschsensortec/downloads/datasheets/bst-bme680-ds001.pdf

Fay, M. P. & Proschan, M. A. (2010). Wilcoxon-Mann-Whitney or t-test? On assumptions for hypothesis tests and multiple interpretations of decision rules. *Statistics surveys*, *4*, 1–39. https://doi.org/10.1214/09-SS051

Hedderich, J. & Sachs, L. (2020). *Angewandte Statistik*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-62294-0

Österreichisches Normungsinstitut (2004). *EN ISO 16000-1: Innenraumluftverunreinigungen - Teil 1: Allgemeine Aspekte der Probenahmestrategie*. Wien. Österreichisches Normungsinstitut.

senseBox. (2023a). *Home / senseBox.de*. https://sensebox.de/

openSenseMap. https://opensensemap.org/

Sensirion. (2019). *Mechanical Design and Assembly Guidelines for SPS30*. https://sensirion.com/media/documents/7990F04A/616544B0/Sensirion_Particulate_Matter_AppNotes_SPS30_Mechanical_Design_and_As.pdf

Sensirion. (2020a). *Datasheet Sensirion SCD30 Sensor Module: CO2, humidity, and temperature sensor*. https://sensirion.com/media/documents/4EAF6AF8/61652C3C/Sensirion_CO2_Sensors_SCD30_Datasheet.pdf

Sensirion. (2020b). *Datasheet SPS30: Particulate Matter Sensor for Air Quality Monitoring and Control*. https://sensirion.com/media/documents/8600FF88/616542B5/Sensirion_PM_Sensors_Datasheet_SPS30.pdf

Spiegel, M. R. & Stephens, L. J. (2018). *Schaum´s outlines®: Statistics*. *Schaum's outline series*. McGraw-Hill Education.

19

20

Measurement of ventilation effectiveness and indoor air quality in toilets at mass gathering events

Ben M. Roberts, Filipa Adzic, E. Abigail Hathway, Christopher Iddon, Benjamin Jones, Malcolm J. Cook, and Liora Malki-Epshtein

Dr Filipa Adzic

Department of Civil, Environmental and Geomatic Engineering

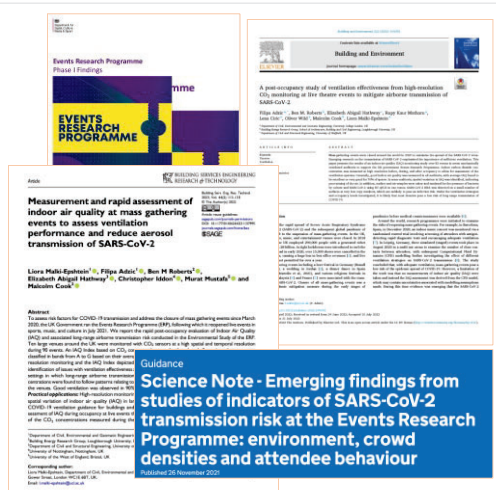
University College London

f.adzic@ucl.ac.uk

1

Research Background

- Mass-gathering events closed in the UK due to COVID-19 in 2020 & 2021, causing a major economic impact.
- The Events Research Programme was established by the UK Government to safely lift restrictions at events.
- Environmental studies focused on identifying where the risks were in event venues.
- Ventilation and air quality were monitored in 10 venues, with 179 individual spaces over 90 events.
- Monitored spaces within venues included main activity areas, bars, restaurants, private boxes, arrival/departure areas and <u>toilets</u>.
- Opportunity to monitor toilets at events with up to 90 000 attendees!



2

Methodology

- Introducing sufficient outdoor air into a space is an important measure to reduce the long-range transmission of airborne viruses.
- CO_2 concentration measurements were used as a proxy for ventilation.
- CO_2, temperature and relative humidity were measured with loggers placed on walls at breathing height, away from doors, windows and vents.
- Non-dispersive infrared sensors with a measurement range of 400-5000 ppm and ±30 ppm accuracy were used.
- Occupancy observations were made by researchers on site and confirmed by CCTV imaging and ticket sales.

Why are toilets of interest?

- Toilets are small and densely occupied for brief periods (e.g. half time at a football match).
- Bioaerosols/virus-laden aerosols are dispersed by toilet flushing.
- UK building regulations (Approved Document F) recommend 6 l/s extraction rate per WC pan or urinal.
- All toilets monitored were mechanically ventilated.

3 venues → 11 toilets → 58 events

Venue	No. of Toilets	No. of Events
Crucible Theatre	6	46
O2 Arena	3	1
Wembley Stadium	2	11

Monitored Venues

Crucible Theatre Sheffield
World Snooker Championship

8-88% occupancy, 46 events;
6 toilets, 3 unisex & 3 male.

Wembley Stadium
Football Games (EURO 2020)

3-100% occupancy, 11 events;
2 toilets, 1 female & 1 male.

O2 Arena, London
Music Awards Ceremony

18% occupancy, 1 event;
3 toilets, 1 female & 2 male.

Air Quality Classification

Classification bands were developed during the Events Research Programme for rapid assessment for risk of transmission based on average and maximum CO_2 values recorded during events.

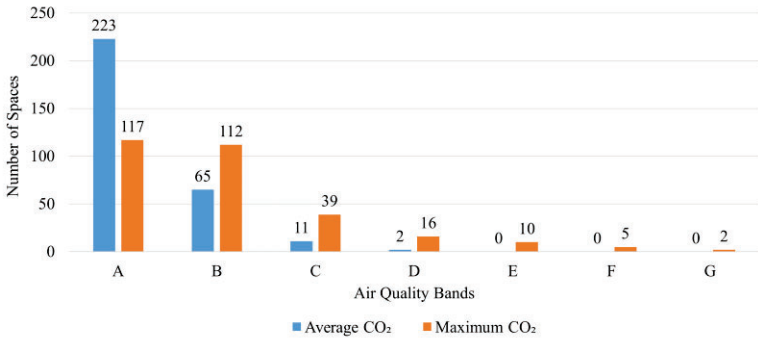
Space classified as band A has high ventilation for monitored occupancy.

Spaces in bands F & G present with low ventilation and are therefore a priority for improvement.

Malki-Epshtein L, Adzic F, Roberts BM, et al. Measurement and rapid assessment of indoor air quality at mass gathering events to assess ventilation performance and reduce aerosol transmission of SARS-CoV-2. Building Services Engineering Research and Technology. 2023;44(2):113-133.

Air Quality Bands	Class	Range of CO_2 – Absolute Values (ppm)
At or marginally above outdoor levels	A	400-600
Target for enhanced aerosol generation (singing, aerobic activity)	B	600-800
High air quality design standards for offices	C	800-1000
Medium air quality	D	1000-1200
Design standards for schools pre-Covid	E	1200-1500
Priority for improvement	F	1500-2000
Low ventilation/dense occupancy. Must be improved	G	>2000

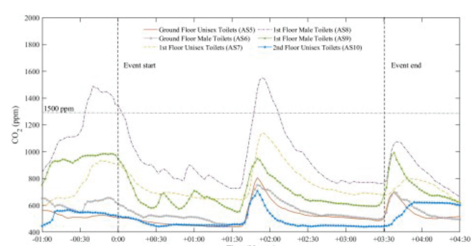
Overall Results



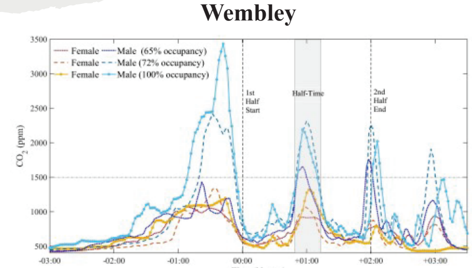
- The spatiotemporal CO_2 average of each toilet over events shows 96% of toilets are A or B. The average includes both low and high occupancy periods.
- Maximum CO_2, observed during high occupancy, shows 76% of toilets are in A or B bands, but 5% of toilets are in E, F and G bands.

Impact of Event Management

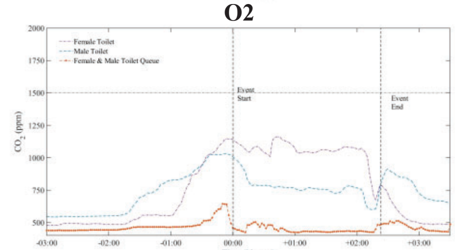
Crucible



Wembley



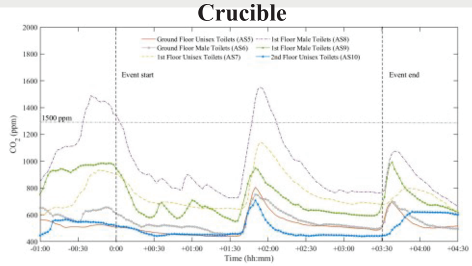
O2



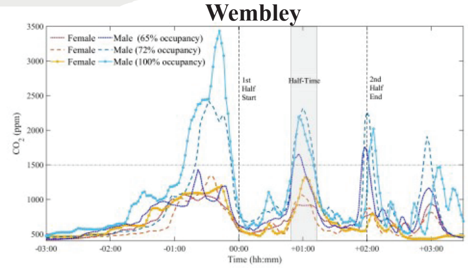
- Three distinct peaks in CO_2 before the event, at the interval and the end of the event noted in Wembley and Crucible events.
- The televised music awards ceremony in the O2 Arena did not have one interval but a series of 15-minute "advert breaks".

Impact of Demographics

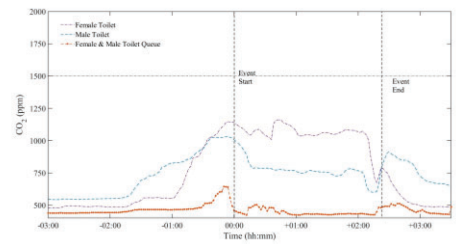
Crucible



Wembley



O2



- Crucible male toilet on the 1st floor presented with higher values than unisex toilets on the same floor.
- Wembley male designated toilets at full occupancy had a maximum concentration of 3431 ppm, compared to 1320 ppm in female toilets.
- In the O2 arena, female toilets presented with higher CO_2 concentrations than male toilets.

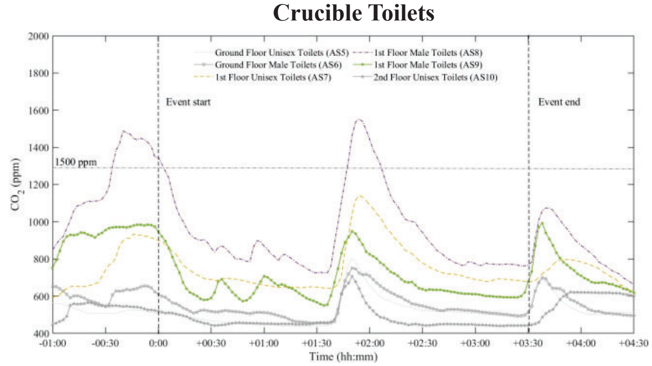
9

Location of Toilets

Toilets on the first floor of Crucible theatre are closer to the main activity area (auditorium) are more frequently visited.

Concentrations in the 1st floor toilets don't fall below 600 ppm because extractor fans draw makeup air from adjacent occupied areas.

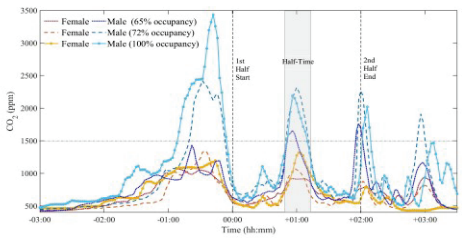
Crucible Toilets



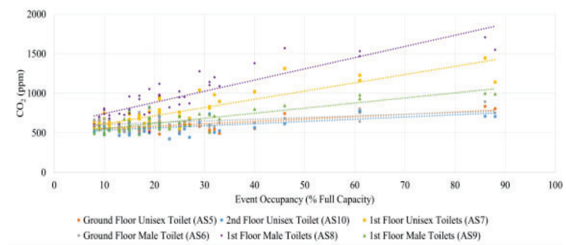
10

Effect of occupancy

Wembley



Crucible



Wembley: CO_2 concentrations continuously over 1500 ppm in male toilets for 44 minutes pre-event, 15 minutes at interval and 8 minutes post-event (full occupancy). Similar levels were observed for 72% occupancy event.

Crucible: Increasing maximum CO_2 concentrations are related to increasing occupancy in the Crucible events, especially toilets close to the main activity area which are more frequently used.

Conclusions & Recommendations

- Insufficient ventilation for the occupancy can facilitate airborne transmission of disease.
- Average CO_2 concentrations in most toilets indicated ventilation was sufficient relative to occupancy.
- Maximum CO_2 concentrations revealed that a small number of toilets were prone to poor ventilation.
- Poor ventilation periods usually occur pre or post event and during event intervals.
- The proximity of toilets to the main-activity area has an impact on the occupancy.

Key Recommendations

- Increase ventilation rates or the room volume in toilets most frequently visited.
- Building operators should be mindful of audience demographics and consider changing toilet gender allocation.
- An increased number of event intervals or their length could spread the occupancy of toilets over a longer period.
- Design of ventilation systems in toilets should take occupancy patterns into consideration.

Further development of this work includes ventilation assessment of toilets and toilet queues, as well as microbiological data sampled during events. Existing risk models will be applied to estimate the risk of long-range transmission in toilets at mass-gathering events.


Thank you.
Questions Welcome
f.adzic@ucl.ac.uk

Impact of the building airtightness and natural driving forces on the operation of an exhaust ventilation system in social housing in Chile

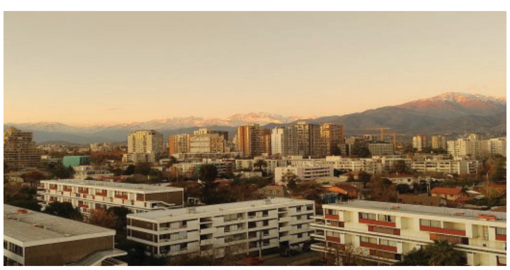
43rd AIVC -11th TightVent & 9th venticool Conference
October 4-5, 2023

Gilles Flamant[1,2], Waldo Bustamante[1], Arnold Janssens[2], Jelle Laverge[2]
[1] Centre for Sustainable Urban Development (CEDEUS), Pontificia Universidad Católica de Chile, Chile
[2] Research Group Building Physics, Ghent University, Belgium

1

Context

Residential buildings stock



	CENSO 1992	CENSO 2002	CENSO 2017
Total houses	3369849	4399952	6499355
Single-family houses	3359639	4380822	6486533
Multi-family houses	10210	19130	12822

Less than 2% of homes built meet minimum thermal performance standards.
(Source OECD/LEED 2014)

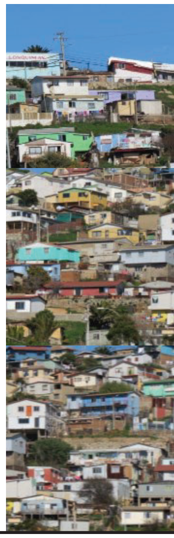
66% have thermal comfort problems.
(RedPE, 2019)

2

2

Context

Social housing



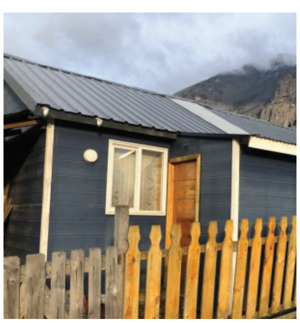
3

3

Context

Retrofitting programs for social housing

Ventilation system



4

4

Research objectives

Evaluate if such mechanical exhaust ventilation system allows ensuring an acceptable IAQ in social housing.

Propose, evaluate and optimize ventilation system and strategies,

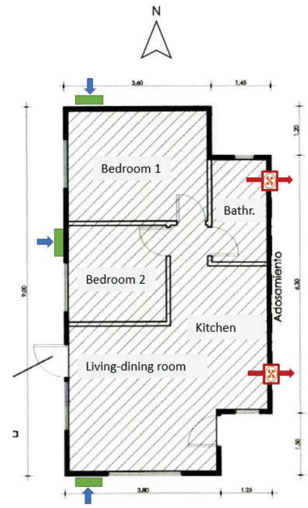
- based on a multi-criteria approach: indoor air quality, energy consumption and total costs over the service life of the building
- considering the climatic conditions and outdoor air pollution levels specific to different areas of the country

Objective of the present study

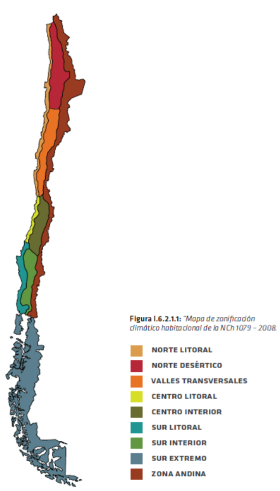
Evaluate by simulation the performances of a mechanical exhaust ventilation system,
- in continuous operation
- in a representative social housing unit in Chile

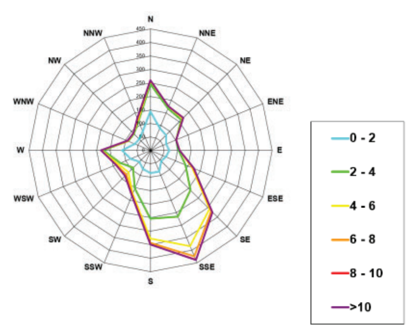
- ➢ Effects of the airtightness level of the building envelope and natural driving forces on the working of the ventilation system and the IAQ
- ➢ Using the CONTAM program
- ➢ Different outdoor climate data sets

Case study description

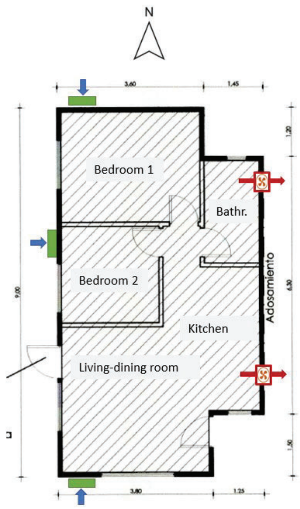


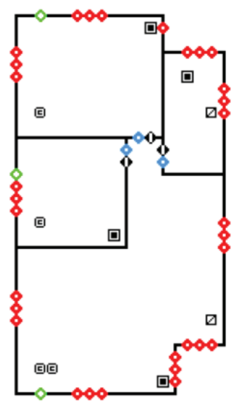
Climatic data



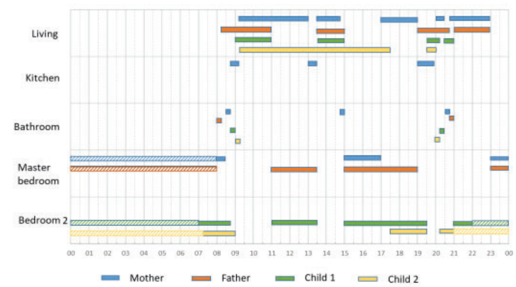


Model and assumptions





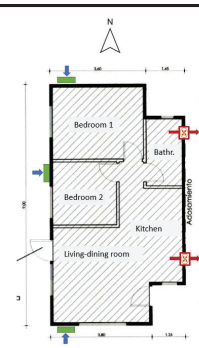
3 levels of n_{50} : 10 h^{-1}, 5 h^{-1}, 0 h^{-1}



Occupancy profile

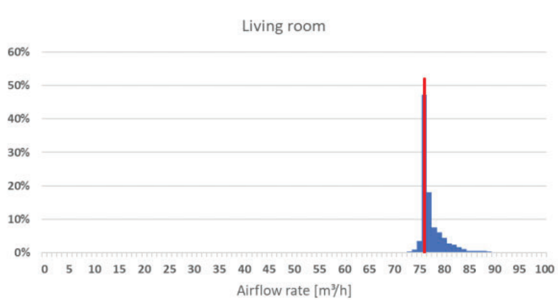
Results

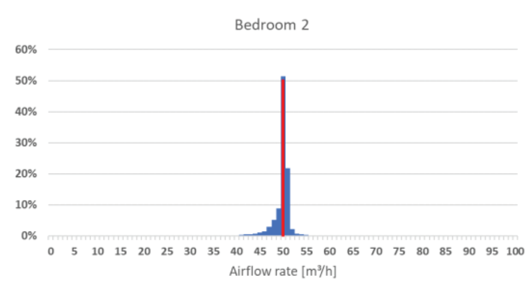
Airflow rates



Perfectly airtight house (n_{50} = 0 h^{-1}) (ideal case)

With Open interior doors



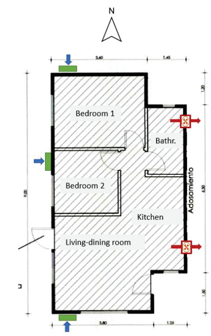


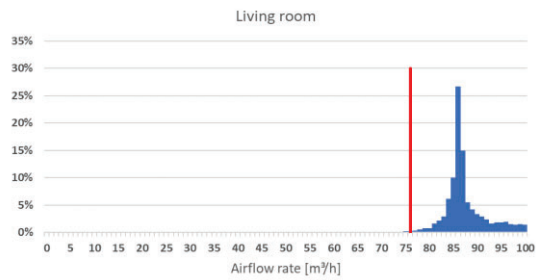
Results

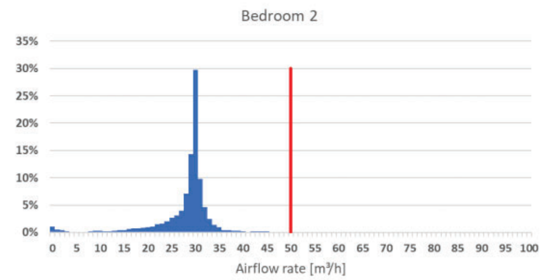
Airflow rates

Leaky house (n_{50} = 10 h^{-1})

With Open interior doors





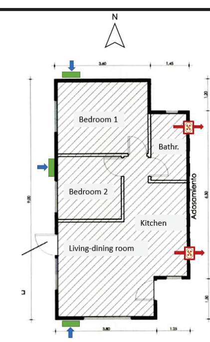


11

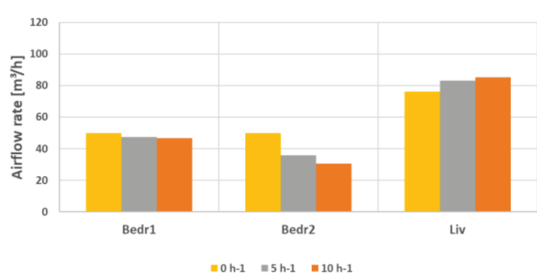
11

Results

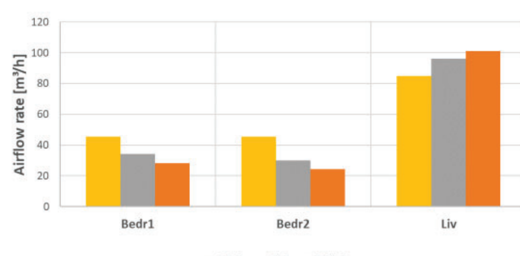
Airflow rates



With Open interior doors



With Closed interior doors

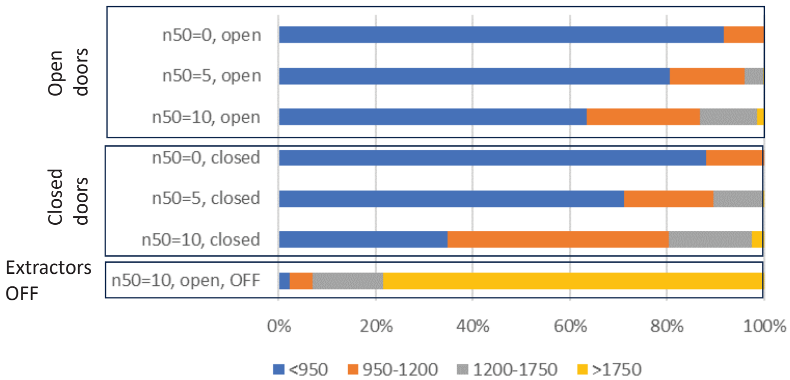


12

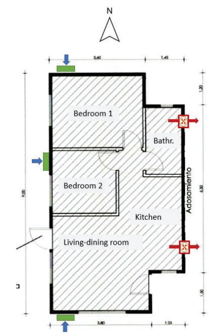
12

Results

CO_2-based indicator



Percentage of time spent in four CO2 concentration (ppm) classes for the family's child



13

Conclusions

- Significant effect of the building airtightness and natural driving forces on the performance of a mechanical exhaust ventilation system.
- Average airflow rate is drastically reduced to almost the half of the design value in one of the bedroom.

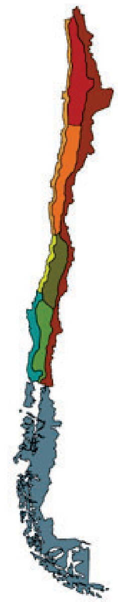
→ Need for improving the level of airtightness of social houses in Chile
→ Need for improving the working of the ventilation system : choice, sizing, control strategy (DCV), …

14

Future work

1. Evaluation of the mech. exhaust ventil. system with a discontinuous working, for several climates and several typologies of social housing units in Chile

2. Propose, evaluate and optimize ventilation systems and strategies
   - Criteria : IAQ, Energy, Costs
   - Several climates & air pollution levels



15

15

Thank you very much for your attention !

ACKNOWLEDGEMENTS

This work was funded by the National Research and Development Agency (ANID), Chile, under research grant FONDECYT 1221666. The authors also gratefully acknowledge the research support provided by CEDEUS, ANID FONDAP 1522A0002. The paper was also developed as part of the Ph.D. program at Ghent University, Belgium.

CEDEUS

GHENT UNIVERSITY

16

16

DTU

43rd AIVC -11th TightVent & 9th venticool Conference
Aalborg University, Copenhagen, Denmark

Metal Oxide Semiconductor sensors (MOS) for measuring Volatile Organic Compounds (VOC) – performance evaluation in residential settings

5.10.2023

Jakub Kolarik
Technical University of Denmark

jakol@dtu.dk

DTU

Introduction - Smart ventilation for residencies ?!

We need suitable sensors!

- Low price
- Low energy use
- Integration with IoT
- Reliable
- Stable over time
- …

Metal Oxide Semiconductor (MOS) sensors

Figure 1: Based on "Main features of smart ventilation" (Durier et al. 2018)

Background - Why MOS VOC sensors?

- Application of MOS VOC sensors seems to be an obvious step towards smart ventilation.
- They offer possibility to not only account for pollution related to occupancy, like CO_2 sensors, but also for diverse odorous events taking place in a space.
- Moreover the MOS technology allows producing sensor units at low price.
- Other advantages claimed by producers include small energy consumption and size.
- This not only makes advanced control achivable, but also allows for use of larger amount of sensors – IoT applications.

3

Background – Challenges, barriers, disadvantages…

- MOS VOC sensors are non-selective = they react to many pollutants!
- MOS VOC sensors provide relative measurement and "non-selectivity" makes calibration difficult.
- Interpretation of measured signal as so called CO_2 equivalent(*).
- They are cross-sensitive to water vapour/humidity.

(*) Herberger et al. (2010), Burdack-Freitag et al. (2009)

4

DTU

Objectives

- Examine MOS VOC sensors during operation in realistic residential environment.
- Determine their properties – sensitivity, linearity, hysteresis by comparing their signal with a reference measurement.
- Discuss their suitability for control of residential ventilation.

DTU

Methods

- Three sensors from different established manufacturers.
- Two specimen of each sensor, integrated on Arduino board with Wi-Fi module.
- Portable photo-ionization (PID) gas detector as a reference measurement (TVOC isobuthylen equivalent).
- Standard IEQ monitoring – temperature, relative humidity, CO_2 concentration.
- Total measurement period of almost one year.

The test site

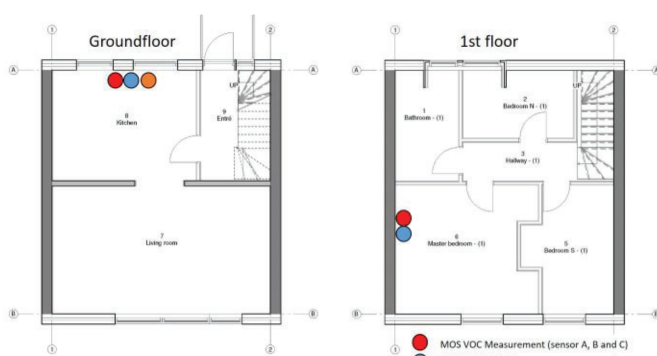


Figure 2: The test site – floor plan

Results – Sensor signals

Example for two weeks in October 2021 (the house was unoccupied during the first week) - MOS VOC sensors placed in the kitchen.

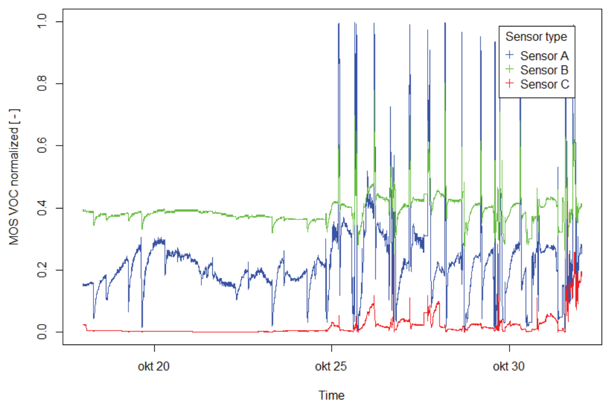


Figure 3: Normalized signals

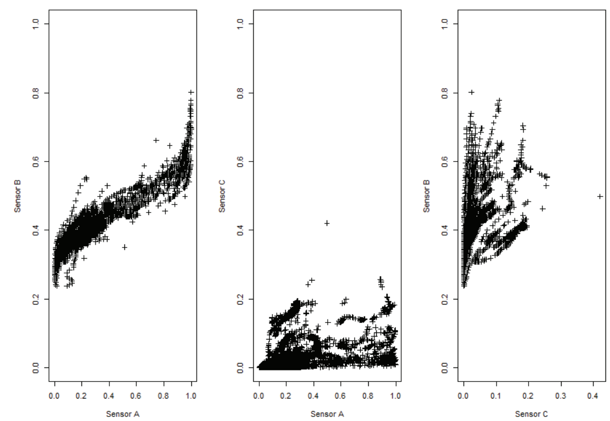
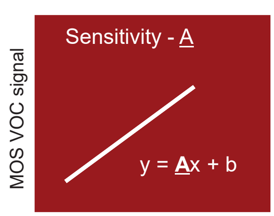


Figure 4: Cross-plot of normalized signals

Results – Sensor characteristics

Sensitivity(*)



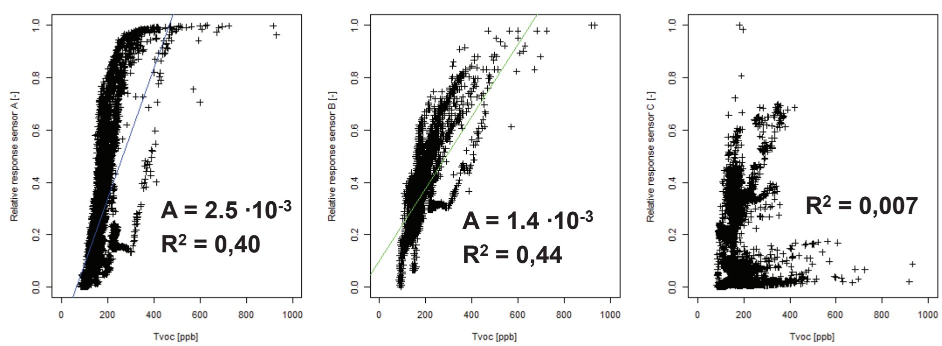
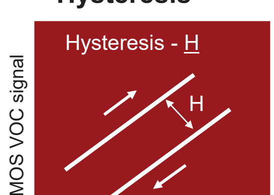


Figure 5: Characteristic curves for tested MOS VOC sensors (PID monitor as reference); period 7.3.2022 – 12.3.2022

Hysteresis (*)



- Low linearity of sensor C during longer measurements, comparable to A and B for one-day. Needs more investigation.
- Low hysteresis of 0.123, 0.014 and 0.121 for sensors A, B and C respectively.

(*)Fahlen et al. (1996)

Results – CO_2 versus CO_2 equivalent signals

- Close agreement between CO_2 and CO_2eq in the bedroom.
- In the kitchen, CO_2eq substantially drifts from the CO_2 signal.
- Challenge with establishing a set-up to avoid “over ventilation”.

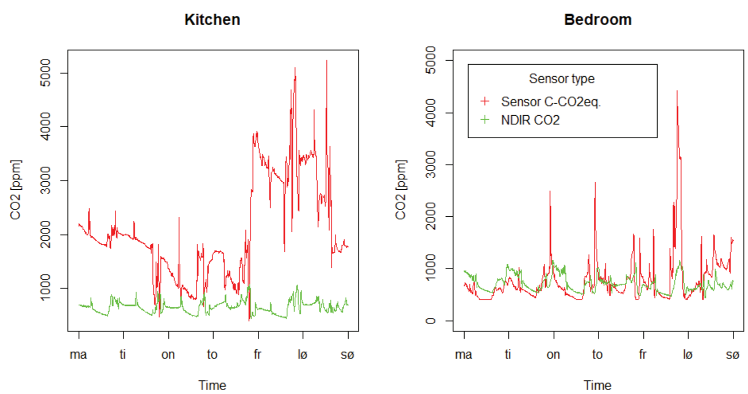


Figure 6: Comparison of CO_2 and CO_2 equivalent signal for measurements in the kitchen and bedroom

Conclusions

- All three tested sensors were able to indicate the pollution events.
- Two of the sensors had comparable behaviour in terms their sensitivity determined using reference PID measurements.
- Cross-relation between their output signals indicates that both sensors would behave in similar manner when used for IAQ control.
- The difference in absolute values of their sensitivity and thus in the amplitude of their response, needs to be taken into account in the case of their use of control.
- The investigated sensors had small hysteresis. The analysis was however conducted on relatively small sample of measurements. Analysis of broader range of build-up and decay periods is needed to confirm the results.

DTU

Conclusions

- The CO_2 equivalent signal corresponded to pure CO_2 measurements in the case of measurements in the bedroom.
- In the kitchen where the human bioeffluents were not the main pollution source, there were large discrepancies.
- This is not necessarily a problem for the ventilation control, but careful choice of the set point would be needed to avoid unnecessary ventilation.
- In general the results of the study indicate, that the MOS VOC sensors represent a considerable alternative to currently used sensors. This however requires that their characteristics are properly considered in control algorithms.

DTU

References:

- Burdack-Freitag A, Rampf R, Mayer F, Breuer K (2009) Identification of anthropogenic volatile organic compounds correlating with bad indoor air quality. In: Proceedings of the 9th International Conference and Exhibition Healthy Buildings 2009, Syracuse, NY
- Durier, F. Carrié, R., Sherman, M. (2018) What is smart ventilation? Ventilaiton Information Paper n°38, Air Infiltration and Ventilation Centre, INIVE EEIG, Brussels Belgium
- Fahlen P, Andersson H, Ruud S (1992) Sensor Tests, Demand Control Ventilation Systems, SP Report ISBN 91-7848-331-331-X, Swedish National Testing and Research Institute, Boras, Sweden
- Herberger S, Herold M, Ulmer H, Burdack-Freitag A, Mayer F (2010) Detection of human effluents by a MOS gas sensor in correlation to VOC quantification by GC/MS. Building and Environment, 45, 2430-2439

Acknowledgements:

Funding by Bjarne Saxhofs Fond, Denmark is greatly acknowledged.

RÉPUBLIQUE FRANÇAISE
*Liberté
Égalité
Fraternité*

LOCIE — UNIVERSITÉ SAVOIE MONT BLANC — Cerema CLIMAT & TERRITOIRES DE DEMAIN

TOWARDS PERFORMANCE-BASED APPROACHES FOR SMART RESIDENTIAL VENTILATION

A ROBUST METHODOLOGY FOR RANKING THE SYSTEMS AND DECISION-MAKING

33rd AIVC -11th TightVent & 9th venticool Conference
October 4-5, 2023
Aalborg University, Copenhagen, Denmark

Dr. Baptiste Poirier
Dr. Gaëlle Guyot
Pr. Monika Woloszyn

1

INTRODUCTION

ENERGY, INDOOR AIR QUALITY AND VENTILATION

28% of the total final energy consumption in the European Union
(Directorate-General for Energy (European Commission),2022)

60% to 90% time spend inside a building
For an average European

30 000 deaths & 19 billion € cost/year

How to **aggregate performance** indicators
and balance IAQ and energy performance assessment
to provide a robust **ranking of the ventilation systems?**

Improvements of the airtightness and insulation of the buildings
to reduce heat losses

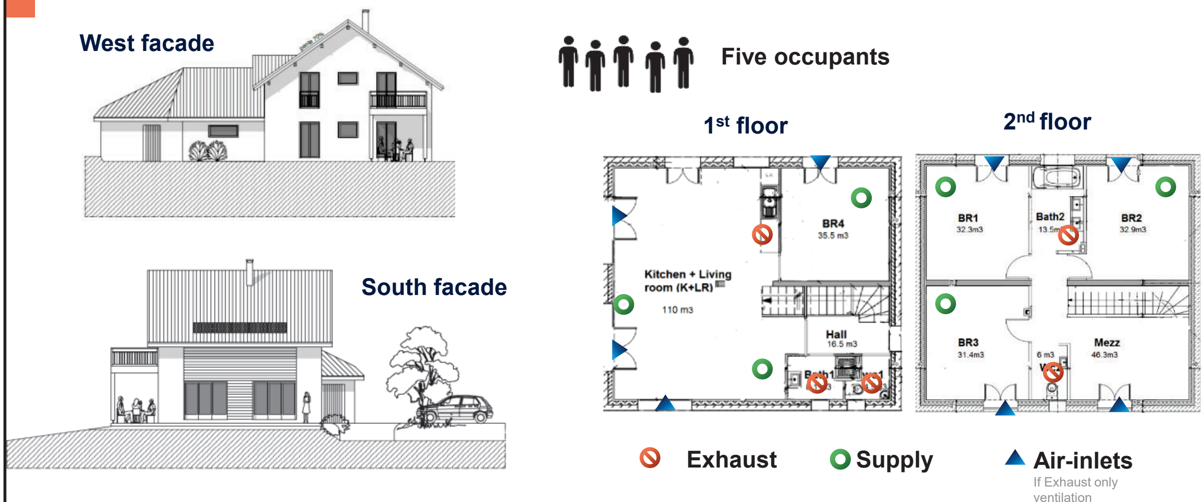
Ventilation

Renewal of indoor air
source of heat losses and of energy consumption

2

INTRODUCTION

A FRENCH LOW ENERGY HOUSE CASE STUDY

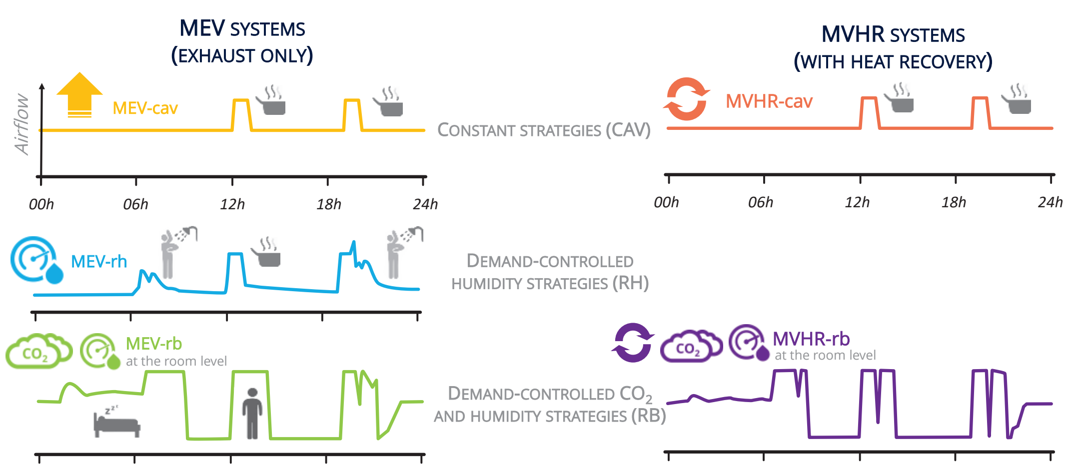


RÉPUBLIQUE FRANÇAISE

Cerema CLIMAT & TERRITOIRES DE DEMAIN

INTRODUCTION

FROM CONSTANT VENTILATION TO SMART VENTILATION

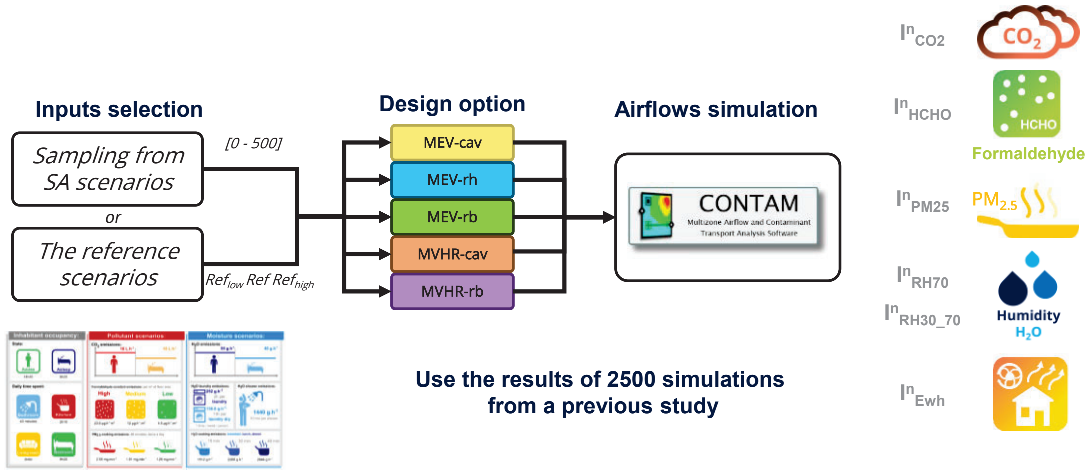


RÉPUBLIQUE FRANÇAISE

Cerema CLIMAT & TERRITOIRES DE DEMAIN

INTRODUCTION

DESIGN OPTION PERFORMANCE CALCULATION



(Poirier et al., 2021b; Poirier, 2023)

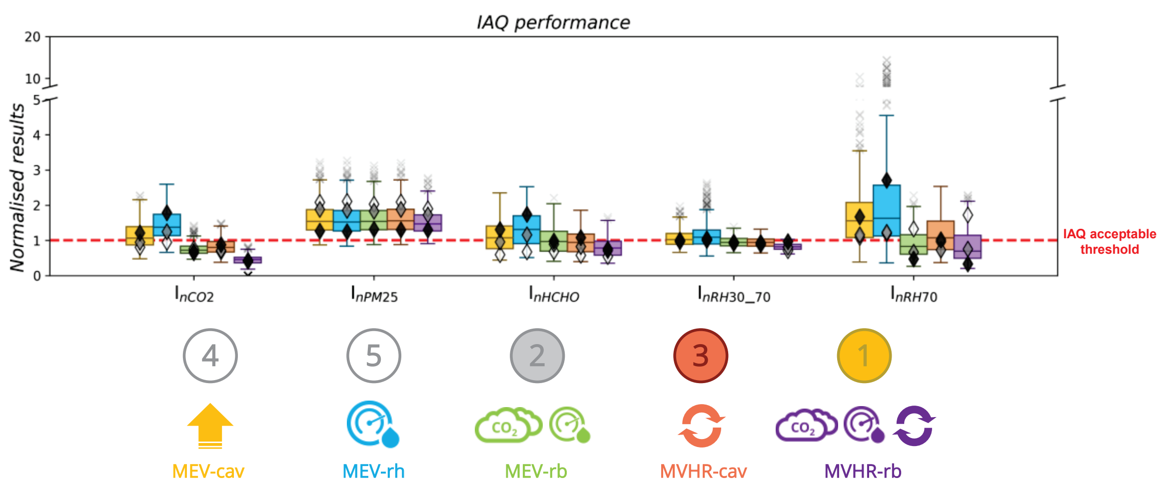
TOWARDS PERFORMANCE-BASED APPROACHES
FOR SMART RESIDENTIAL VENTILATION
A ROBUST METHODOLOGY FOR RANKING THE SYSTEMS AND DECISION-MAKING

5

5

PERFORMANCE RAKING

BASED ON IAQ PERFORMANCE ?



TOWARDS PERFORMANCE-BASED APPROACHES
FOR SMART RESIDENTIAL VENTILATION
A ROBUST METHODOLOGY FOR RANKING THE SYSTEMS AND DECISION-MAKING

6

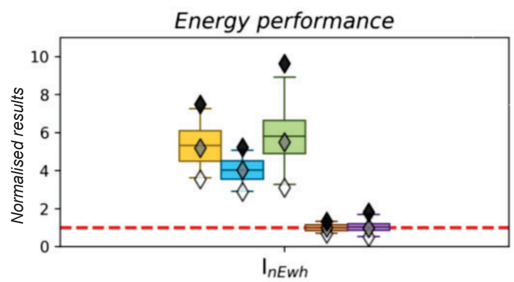
6

PERFORMANCE RAKING

BASED ON ENERGY PERFORMANCE ?

Heat losses from exhausted airflows

$$H_{th} = \frac{C_{p_m}}{3600}\cdot\left(1 - \varepsilon_{heat_{ex}}\right)\int q_m(t).\left[T_{in}(t) - T_{ex}(t)\right].dt$$



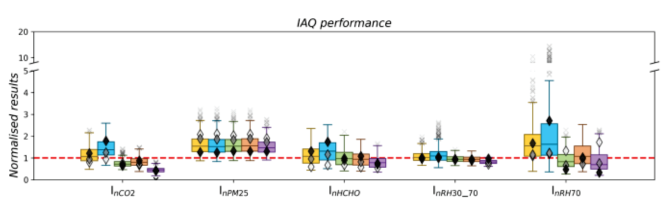
MVHR_cav median performance proposed as reference threshold

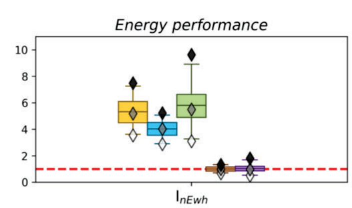
5	3	4	1	2
MEV-cav	MEV-rh	MEV-rb	MVHR-cav	MVHR-rb

PERFORMANCE RAKING

BASED ON IAQ AND ENERGY PERFORMANCE ?

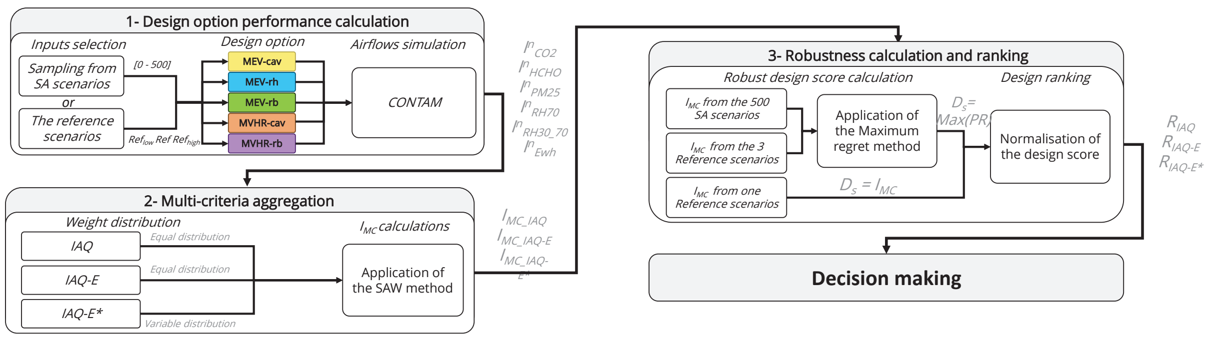
How to choose the most relevant one from global performance point-of-view ?





?	?	?	?	?
MEV-cav	MEV-rh	MEV-rb	MVHR-cav	MVHR-rb

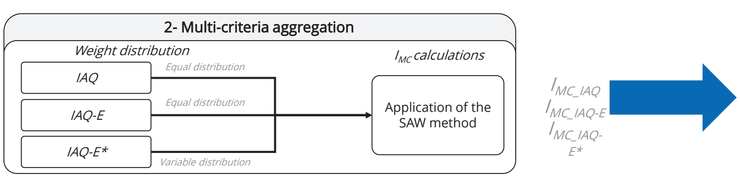
A SIMPLIFIED APPROACH IN 3 KEYS STEPS



BASED ON EXISTING ROBUST ASSESSMENT METHODS ADAPTED TO BUILDING SECTOR

(Kotireddy et al., 2018; Velasquez and Hester, 2013; Hoes et al., 2009; Sharma and Bhattacharya, n.d.)

MULTI-CRITERIA AGGREGATION



From the six indicators to one aggregated value for each simulation

Simple Additive Weighting (SAW) method

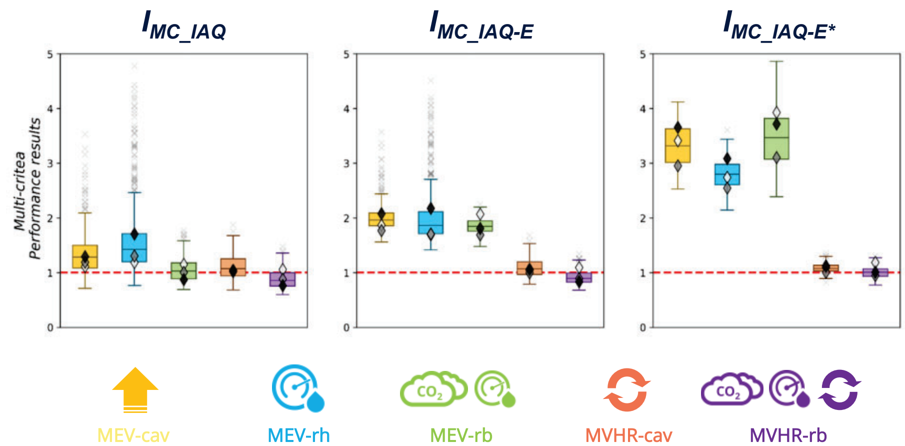
$$I_{MC} = \sum_i \omega_i . I_i$$

(Podvezko, 2011)

Distribution	Weight ω_i I^n_{CO2}	I^n_{RH70}	$I^n_{RH30\_70}$	I^n_{PM25}	I^n_{HCHO}	I^n_{Ewh}	
I_{MC_IAQ}	0.2	0.2	0.2	0.2	0.2	0	
I_{MC_IAQ-E}	0.16	0.16	0.16	0.16	0.16	0.16	**16% Energy / 84% IAQ**
I_{MC_IAQ-E*}	0.071	0.071	0.071	0.143	0.143	**0.5**	**50% Energy / 50% IAQ**

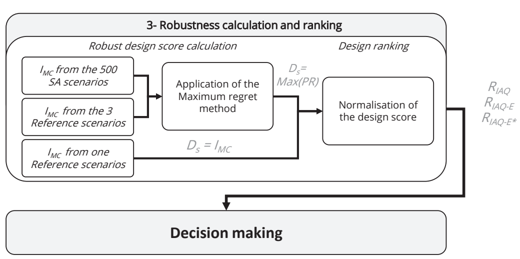
A ROBUST METHOD FOR PERFORMANCE RANKING

MULTI-CRITERIA AGGREGATION



A ROBUST METHOD FOR PERFORMANCE RANKING

ROBUST DESIGN SCORE CALCULATION AND RANKING



Integrating into one design score (D_s) all the individual performance indicators **I_{MC}** across the tested scenarios.

The minimax regret method

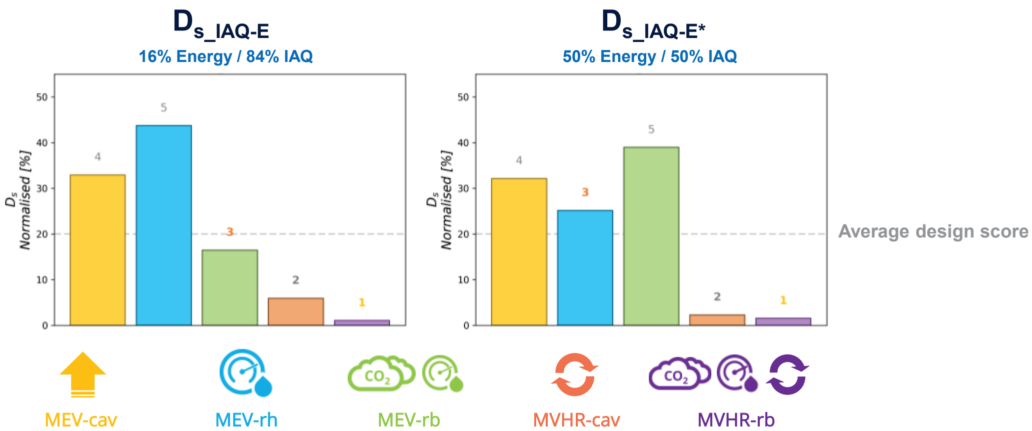
(Kotireddy et al., 2019)

$$PR = I_{MC,Dopt,s} - C_s \; ; with \; C_s = \underset{s}{\mathrm{Min}}(I_{MC(all\_Dopt),s})$$

$$MPR = \underset{D_{opt}}{\mathrm{Max}}(PR)$$

A ROBUST METHOD FOR PERFORMANCE RANKING

DESIGN SCORE RESULTS

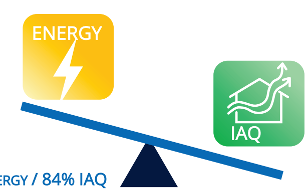


Design score calculation with the minmax regret method

design scores were normalized In [%] by $\Sigma(D_s)_{D_{opt}}$ the sum of all the design scores

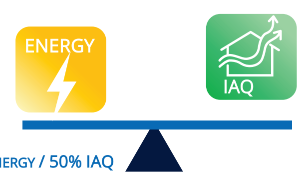
CONCLUSION

LEARNINGS REGARDING ROBUSTNESS



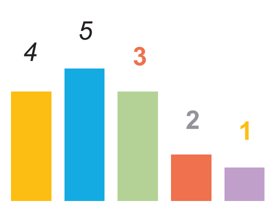
16% ENERGY / 84% IAQ

***IAQ-E distribution**: a conservative approach with **IAQ priority** for the decision maker*



50% ENERGY / 50% IAQ

***The IAQ-E* for** a decision maker with **equal proportion between IAQ and energy**.*



***The design score highlights the difference between the ventilation systems**, in order to rank them, including the uncertainty **from several simulations**.*

THANK YOU

FOR YOUR ATTENTION

43rd AIVC, 11th TightVent and 9th venticool Conference: "Ventilation, IEQ and health in sustainable buildings"

IMPORTANCE OF GOOD RESILIENT BUILDING DESIGN AND STANDARDS TO ENSURE GOOD VENTILATIVE COOLING PERFORMANCE TO REDUCE OVERHEATING AND ENVIRONMENTAL IMPACT

Introduction to topical session

Christoffer Plesner, Jannick K. Roth
VELUX A/S & WindowMaster International A/S
christoffer.plesner@velux.com
jkr.dk@windowmaster.com

1

What is ventilative cooling?

- **Proposed definition of Ventilative cooling; (*)**
  - *"Utilization of outside air at its actual temperature and humidity aimed at improving indoor thermal comfort or decreasing cooling loads. Air transfer may be by natural, mechanical or hybrid means"*

- VC can reduce overheating and deliver good thermal comfort in buildings to achieve good well-being

- The climate target plan towards 2030 in terms of the EPBD revision aims to reduce energy use for heating and cooling by 18% in buildings.

- **Ventilative cooling types**
  - **Natural ventilative cooling** is an aspect of ventilative cooling whose operation is *based solely on the effect of wind and stack effect*
  - **Mechanical ventilative cooling** is an aspect of ventilative cooling whose operation is *based solely on the operation of fans*
  - **Hybrid ventilative cooling** is an aspect of ventilative cooling whose operation is *based on the combination or alternation of natural and mechanical ventilative cooling*

(*) "Ventilative cooling systems – Design" (CEN/TS, draft 2023)

2

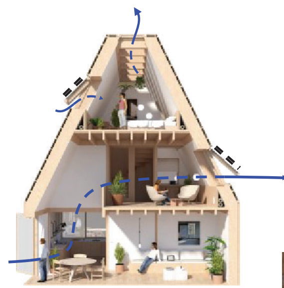
What can be done?

Build sustainable!

<u>VELUX has built Living places in Copenhagen to show sustainable building</u>

- 3x lower carbon footprint than avg. Danish home
- 3x better indoor climate than avg. Danish home
- Scalable solution
- Thoughtful building design ensuring good stack effect and cross ventilation!

Sustainable cooling solutions
- Controlled natural ventilative cooling (façade+roof windows)
- External solar shading
- No mechanical cooling
- Solar cells



Human Developments

A growing population, as well as rapid growth in purchasing power in emerging economies and developing countries means that energy demand in buildings could **increase by 50% by 2060 (**)**

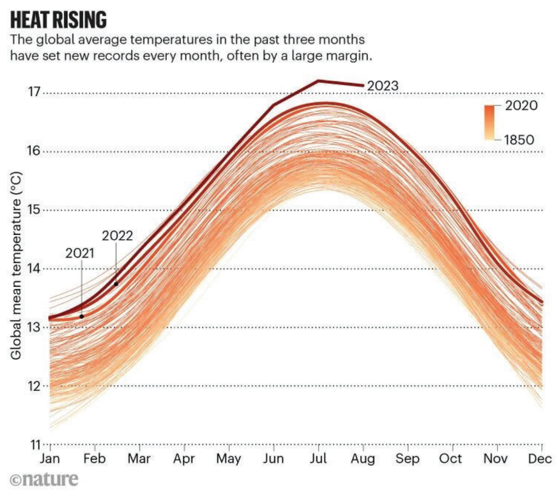
Peak and mean summer temperatures will increase by 10℃ across most European capitals by 2080 (***)

Energy use for cooling of buildings rose +212% from 2010-2019 !. (****)

Researchers at the French National Center for Weather Research have concluded that **if Paris doubles its A/C** use by 2030, it **could raise outdoor temperatures in the city by 1,6 - 2,2˚C**.

(*) IEA – The Future of Cooling
(**) www.globalabc.org/ & UN Environment, Global Status Report 2017
(***) Overheating calculation methods, criteria, and indicators in European regulation for residential buildings (Attia, et. Al, 2023)
(****) EEA europe

Why important – a burning Platform



Alert: Earth Nearing 1.5°C Warming
Model indicate that there's now a 55% likelihood of reaching 1.5°C warming in 2023. What matters most is that this year (2023) is on track to be the hottest on record.

Climate change is expected to drive an increasing frequency of heat waves, which can cause significant morbidity and mortality (**)

3 x increase in the global energy use for space cooling towards 2050 (*) - corresponding to almost a **2 x in CO_2 emissions** for space cooling (***)

All member states must revise their national energy calculation methods and address discomfort problems under climate changes scenarios by the end of 2025 (**)

(*) United in Science 2022, WMO
(**) Overheating calculation methods, criteria, and indicators in European regulation for residential buildings (Attia, et. Al, 2023)
(***) IEA – The Future of Cooling

How does Ventilative Cooling fits in this agenda?

Overall

#1: Resiliency

Ventilative cooling can:

Support the robustness and resilience of buildings by having key resilience indicators when designing future buildings for VC

Show resilience by using manual openable windows or by solar-powered solutions

#2: Indoor climate

Ventilative cooling can:

Be an effective measure to reduce buildings energy use, meeting some or all of the cooling requirement limiting use of A/C

Improve IAQ (by reducing CO_2 levels) due to already elevated air change rates

#3: Environmental impact

Ventilative cooling can:

Save resources (energy and material use)

Be considered as a renewable energy solution for cooling according to EU Renewable energy directive II,2018

Have a lowered direct impact on outside temperatures

Agenda

Introduction

1) Introduction to topical session
Christoffer Plesner, VELUX A/S, Denmark

&

Jannick Roth, Window-Master International A/S, Denmark

#1: Good building design

2) Update on resilient cooling and indicators from IEA EBC Annex 80
Patryk Czarnecki, Institute of Building Research & Innovation, Austria

3) Resilient ventilative cooling in Design practice: where next?
Paul O'Sullivan, MeSSO Research at Munster technological university, Ireland

#2: Case studies

4) Life cycle assessment: A design element for ventilation system selection
Jannick Roth, Window-Master International A/S, Denmark

5) Lessons learned from Irish schools: Early-stage insights on Overheating
Adam O'Donovan, MeSSO Research at Munster technological university, Ireland

6) Resilient cooling in office buildings: case study in Belgium
Hilde Breesch, KU Leuven, Belgium

#3: Standards

7) Design procedures for ventilative cooling integrated in new standards
Christoffer Plesner, VELUX A/S, Denmark

8) Closing and open Discussion

Facilitated by *Christoffer Plesner and Jannick Roth*

IEA EBC Annex 80 - Resilient Cooling

Patryk Czarnecki
Institute of Building Research & Innovation
Vienna, Austria

Institute of Building Research & Innovation ZT-GmbH | AIVC | venticool | INIVE | Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology

2023-10-04

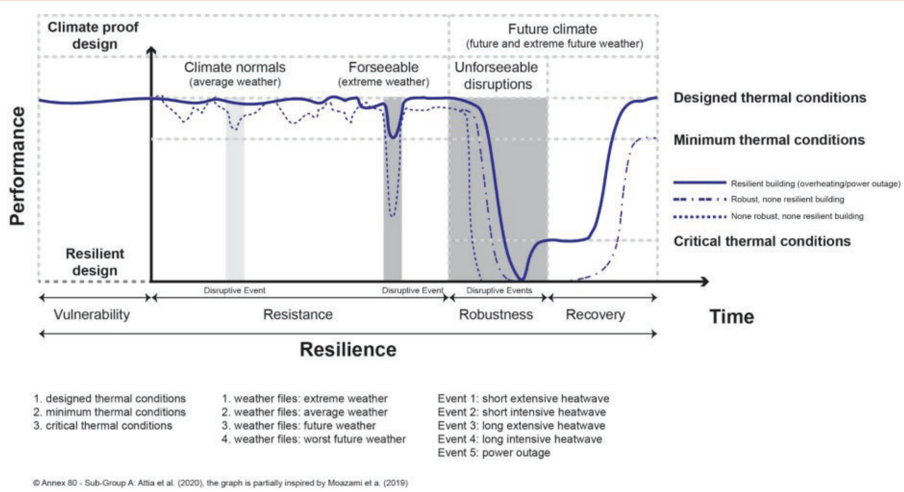
Topical Session
Update on Resilient cooling and indicators from the IEA EBC Annex 80

Institute of Building Research & Innovation ZT-GmbH | AIVC | venticool | INIVE | Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology

Definition of Resilience

- Resilience is the new sustainability
  - Needs a precise definition
- Annex 80 focused on resilience against heatwaves and power outages

Definition of Resilience



LIÈGE université

Technology Profiles

What?

– Structured Information about the Essential Resilient Cooling Technologies

Who?

– Planners, Property Owners and Investors, Interested Public

5

Technology Profiles - Chapters

1.	**Reducing Heat Loads to People and Indoor Environments**
1.1.	Solar Shading Technologies
1.2.	Cool Envelope Materials
1.3.	Glazing Technologies
1.4.	Ventilated Façades
1.5.	Green Roofs and Green Façades
2.	**Removing Heat from Indoor Environments (Production, Emission and Combined)**
2.1.	**Ventilative Cooling**
2.2.	Thermal Mass Utilization
2.3.	Evaporative Cooling
2.4.	Sky Radiative Cooling
2.5.	Compression Refrigeration
2.6.	Adsorption Chillers
2.7.	Natural Heat Sinks
2.8.	Radiant Cooling
3.	**Increasing Personal Comfort Apart from Space Cooling**
3.1.	Comfort Ventilation and Elevated Air Movement
3.2.	Micro-cooling and Personal Comfort Control
4.	**Removing Latent Heat from Indoor Environments**
4.1.	Dehumidification

6

Technology Profiles - Chapter Structure

- Description
- Key Technical Properties
- Performance and Application
- Further Reading

7

Technology Profiles – Ventilative Cooling

TPS Ventilative Cooling.pdf

8

Resilience of Ventilative Cooling

- Highly resilient (operation without electricity is possible)
- Emergency operation possible (Natural Ventilation)
- Vulnerable against strong heat waves

Reduce Solar Gain

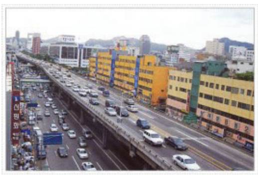
Focus on what is effective

- (External) Sun Shading
- Glass Surfaces
- 5-10% Openable Surfaces per m^2
- Electrical control
- Demand Ventilative Cooling in Building Standards

Preparing a new Annex-Proposal (?)

Resilient Cooling in Cities

Passive Climate Mitigation:	Green, Blue and "White" infrastructures.
Hybrid Cooling:	Hybrid Cooling solutions in time and space including latent cooling.
Heat sinks on urban scale:	Seasonal storage in soil and water. Deep Radiative Cooling.
Urban grids:	Thermal & electric networks.



Cheonggyecheon stream revitalization project. Downtown Seoul, South Korea, 2003 – 2005
Source: https://www.ser-rrc.org/project/south-korea-restoration-of-the-cheonggyecheon-river-in-downtown-seoul/ (04.10.2022), foto credits: City of Seoul.

Preparing a new Annex-Proposal (?)

If you are interested in joining this new Annex, please contact us!

Peter Holzer, peter.holzer@building-research.at
Philipp Stern, philipp.stern@building-research.at
Patryk Czarnecki, patryk.czarnecki@building-research.at

Institute of Building Research & Innovation
Vienna, Austria

Energy in Buildings and Communities Programme

Thank you for your attention.

Institute of Building Research & Innovation ZT-GmbH

venticool the platform for resilient ventilative cooling

Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

MeSSO
MECHANICAL ENERGY SYSTEM SIMULATION OPTIMISATION

Lessons Learned from Irish Schools: Early-stage Insights on Overheating

Adam O' Donovan[1,2],
Elahe Tavakoli[1,2], Paul D O'Sullivan[1,2]

[1]MeSSO Research Group, Department of Process, Energy and Transport Engineering, MTU, Cork, Ireland
[2] MaREI Centre for Energy, Climate, and Marine, Ireland.

43rd AIVC | 11th TightVent & 9th Venticool Conference | Copenhagen, Denmark, October 4-5, 2023

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND
AIVC
Tight Vent Europe
venticool the platform for resilient ventilative cooling

www.mtu.ie

1

Contents

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

- Background and context (RESILIENCE and schools)
- Materials and methods (Data, Information and Simulations)
- Results and discussion (**A: Do schools overheat, why and what about the future?)**
- Conclusions and lessons learned (What can we learn from this?)

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND
MeSSO MECHANICAL ENERGY SYSTEM SIMULATION OPTIMISATION

www.mtu.ie

2

Background and context

www.mtu.ie

Mission and Aim

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

RESILIENCE: MAPPING ADAPTIVE NV INDOOR ENVIRONMENTS IN IRISH LOW ENERGY BUILDINGS (SEAI, RD&D 2019)

Focus on overheating in naturally ventilated (NV) low energy or nZEB built environments in non-residential or commercial buildings. This research aims to:

"Systematically map and quantify how low or Nearly Zero Energy (i.e. nZEB's) commercial building design, construction and operation in Ireland has affected or will affect indoor thermal environments in buildings that rely exclusively on passive strategies for the supply of fresh air and, more specifically, the removal of heat build-up that would otherwise lead to an unacceptable thermal experience for building occupants. "

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

RESILIENCE

Succeeding Together

www.mtu.ie

Mission and Aim

Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

RESILIENCE: MAPPING ADAPTIVE NV INDOOR ENVIRONMENTS IN IRISH LOW ENERGY BUILDINGS (SEAI, RD&D 2019)

Focus on overheating in naturally ventilated (NV) low energy or nZEB built environments in non-residential or commercial buildings. This research aims to:

"Systematically map and quantify how low or Nearly Zero Energy (i.e. nZEB's) commercial building design, construction and operation in Ireland has affected or will affect indoor thermal environments in buildings that rely exclusively on passive strategies for the supply of fresh air and, more specifically, the removal of heat build-up that would otherwise lead to an unacceptable thermal experience for building occupants. "

SUSTAINABLE ENERGY AUTHORITY OF IRELAND

RESILIENCE

Due for completion in 2024

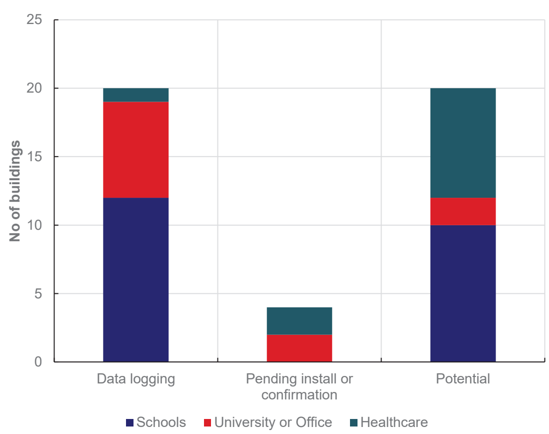
Succeeding Together

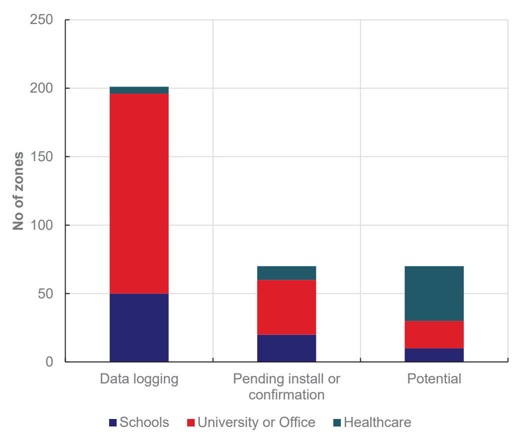
www.mtu.ie

5

Actual sample (April 2023)

Ollscoil Teicneolaíochta na Mumhan
Munster Technological University





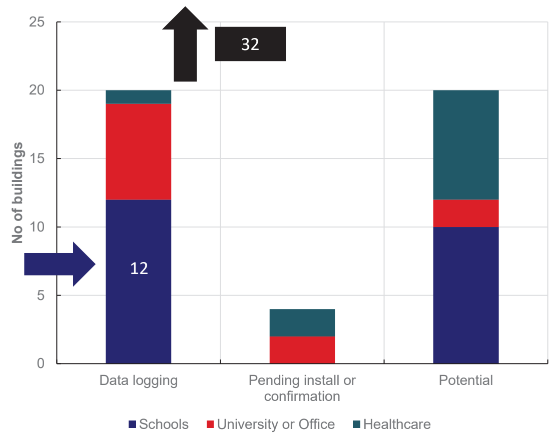
Succeeding Together

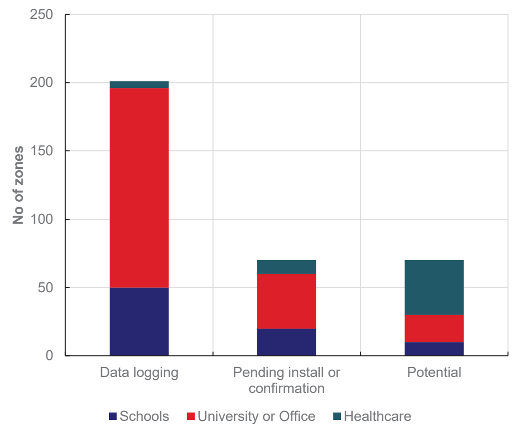
www.mtu.ie

6

Actual sample (April 2023)

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University





Succeeding Together

www.mtu.ie

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Materials and Methods

www.mtu.ie

Materials and Methods

List of schools in the study

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Table 1: List of 12 case study school buildings (as of August 2023) and monitoring systems installed

School Name	Location	Building Type	No of Zones	Monitor Type	Accuracy
PS1	South	New	5	Stand-alone	±0.3°C
PS2	South	New	5	Stand-alone	±0.5°C
PS3	South	New	>5	Wifi-based	±0.1°C
PP1	South-West	Extension	5	Wifi-based	±0.3°C
PP2	Midlands	New	>5	BMS/ Stand-alone	±0.5°C
PS4	Mid-West	Extension/Retrofit	>5	BMS	±0.5°C
PS5	South	New	5	Stand-alone	±0.5°C
PS6	South	Extension/Retrofit	5	Wifi-based	±0.3°C
PS7	North-East	Retrofit	>5	BMS	±0.5°C
PP3	South-East	Retrofit	>5	BMS	±0.5°C
PP4	South-East	Extension	5	Wifi-based	±0.3°C
PS8	West	Existing	>5	BMS	±0.5°C

Succeeding Together

www.mtu.ie

9

Materials and Methods

List of schools in the study

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Table 1: List of 12 case study school buildings (as of August 2023) and monitoring systems installed

School Name	Location	Building Type	No of Zones	Monitor Type	Accuracy
PS1	South	New	5	Stand-alone	±0.3°C
PS2	South	New	5	Stand-alone	±0.5°C
PS3	South	New	>5	Wifi-based	±0.1°C
PP1	South-Wes			ifi-based	±0.3°C
PP2	Midlands			Stand-alone	±0.5°C
PS4	Mid-West			BMS	±0.5°C
PS5	South			and-alone	±0.5°C
PS6	South	Extension/Retrofit	5	Wifi-based	±0.3°C
PS7	North-East	Retrofit	>5	BMS	±0.5°C
PP3	South-East	Retrofit	>5	BMS	±0.5°C
PP4	South-East	Extension	5	Wifi-based	±0.3°C
PS8	West	Existing	>5	BMS	±0.5°C

60-80 classrooms

Succeeding Together

www.mtu.ie

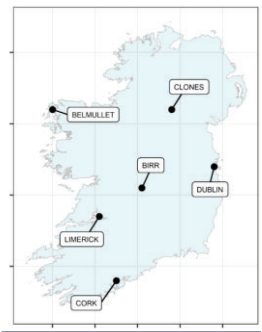
10

Materials and Methods

Information, Data, Simulation

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

- Minimum 1-hour interval space air temperature data
- Building information mapping examples:
  - Area of openings, height
  - Opening types, Cooling Strategy and Principle
  - Number of occupants
- Calibrated Dynamic Simulation into the Future (IES-VE)
  - Design summer year data (2021 to 2071)
  - Climate data for thermal modelling of buildings



MET éireann The Irish Meteorological Service

Succeeding Together

www.mtu.ie

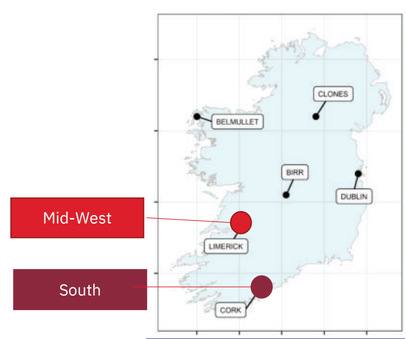
11

Materials and Methods

Information, Data, Simulation

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

- Minimum 1-hour interval space air temperature data
- Building information mapping examples:
  - Area of openings, height
  - Opening types, Cooling Strategy and Principle
  - Number of occupants
- Calibrated Dynamic Simulation into the Future (IES-VE)
  - Design summer year data (2021 to 2071)
  - Climate data for thermal modelling of buildings



MET éireann The Irish Meteorological Service

Succeeding Together

www.mtu.ie

12

Materials and Methods

Metrics for schools (comfort or performance)

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

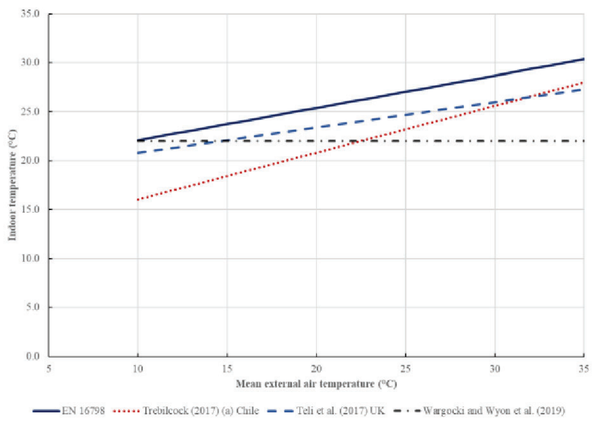


Figure 1: Comparison of adaptive thresholds for adults, children as well as thresholds reflective of relative learning performance

- Limited examples of adaptive comfort in school settings
- Should school be about comfort or performance
- **1.3°C to 3.1°C** difference **between adults and children**
- **0.1°C to 8.4°C** between **comfort and performance**

Succeeding Together

www.mtu.ie

13

Materials and Methods

Metrics for schools (comfort or performance)

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

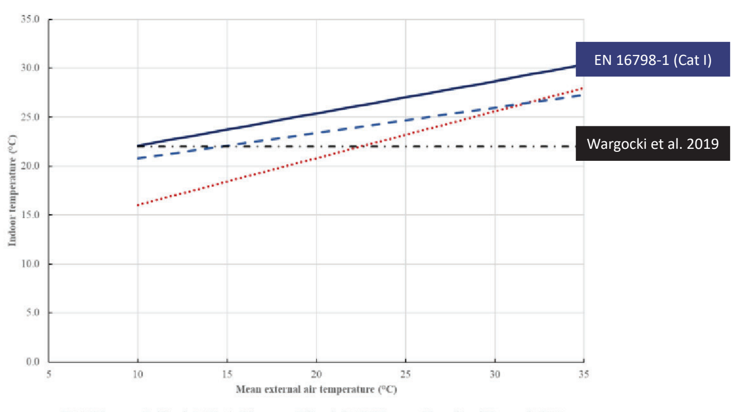


Figure 1: Comparison of adaptive thresholds for adults, children as well as thresholds reflective of relative learning performance

- Limited examples of adaptive comfort in school settings
- Should school be about comfort or performance
- **1.3°C to 3.1°C** difference **between adults and children**
- **0.1°C to 8.4°C** between **comfort and performance**

Succeeding Together

www.mtu.ie

14

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

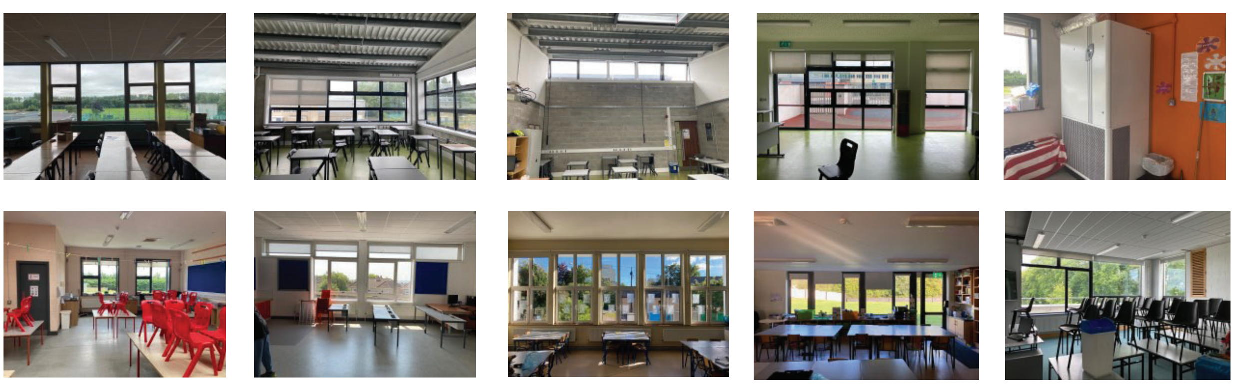
Results and Discussion

www.mtu.ie

Results and Discussion

Information – examples of strategies

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University



Succeeding Together

www.mtu.ie

Results and Discussion

Information – building information (preliminary) 50 zones

- Strategy – **92%** natural, 4% mechanical, 4% both
- NV principle – **90%** single-sided with multiple openings, 10% use cross
- **6 to 11** openable windows per classroom (mainly top-hung outward opening)
- Openings typically open between **14cm and 32cm** (some exceptions 100cm)
- Opening height **0.57m to 1.4m** (floor-to-ceiling height 2.6m to 3.2m)
- Typically around **26** seating allocations (maximum 35)

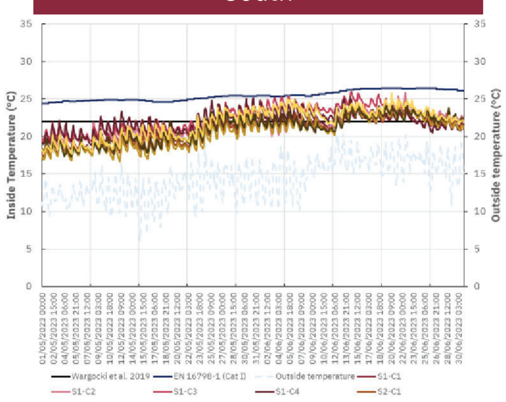
Succeeding Together

www.mtu.ie

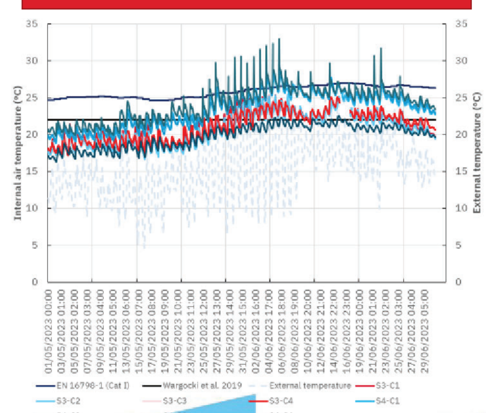
Results and Discussion

Data – May/June 2023 (4 schools in Munster)

South



Mid-West



Succeeding Together

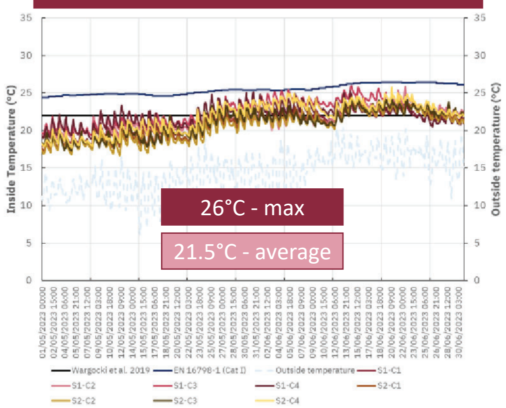
www.mtu.ie

Results and Discussion

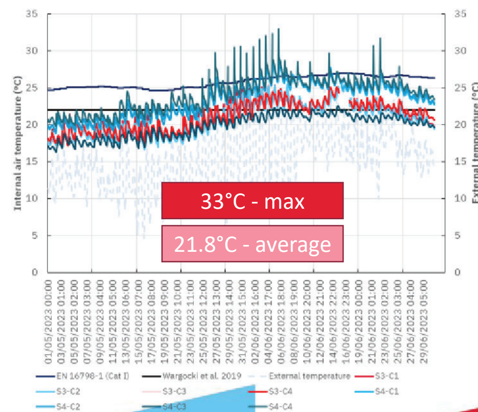
Data – May/June 2023 (4 schools in Munster)

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

South



Mid-West



Succeeding Together

www.mtu.ie

19

Results and Discussion

Data – May/June 2023 (4 schools in Munster) - summary

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

South

Classroom	> Cat I	> 22°C
S1-C1	0%	44%
S1-C2	0%	50%
S1-C3	0%	65%
S1-C4	0%	63%
S2-C1	0%	37%
S2-C2	0%	29%
S2-C3	0%	42%
S2-C4	0%	59%

Mid-West

Classroom	> Cat I	> 22°C
S3-C1	0%	40%
S3-C2	0%	32%
S3-C3	0%	46%
S3-C4	0%	46%
S4-C1	8%	67%
S4-C2	10%	66%
S4-C3	0%	2%
S4-C4	22%	79%

***08:00 – 16:00**

Succeeding Together

www.mtu.ie

20

Results and Discussion

Data – May/June 2023 (4 schools in Munster) - summary

South

Classroom	> Cat I	> 22°C
S1-C1	0%	44%
S1-C2	0%	50%
S1-C3	0%	65%
S1-C4	0%	63%
S2-C1	0%	37%
S2-C2	0%	29%
S2-C3	0%	42%
S2-C4	0%	59%

Mid-West

Classroom	> Cat I	> 22°C
S3-C1	0%	40%
S3-C2	0%	32%
S3-C3	0%	46%
S3-C4	0%	46%
S4-C1	8%	67%
S4-C2	10%	66%
S4-C3	0%	2%
S4-C4	22%	79%

***08:00 – 16:00**

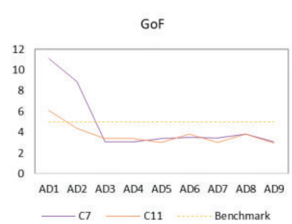
Succeeding Together

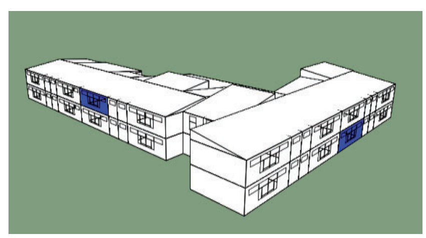
www.mtu.ie

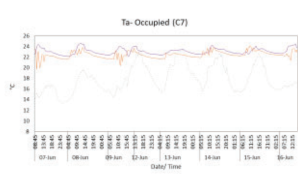
Results and Discussion

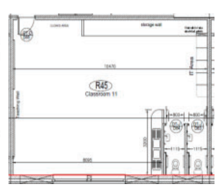
Simulation – Generic Repeatable Design (Calibration)

- Model calibrated with data from two classrooms (**RMSE < 1°C**)
- Model used to simulate performance in 2 locations (Cork and Limerick)
- Two weather files:
  - DSY1-2021 (Moderate overheating)
  - DSY2-2071 (Prolonged overheating events)









Succeeding Together

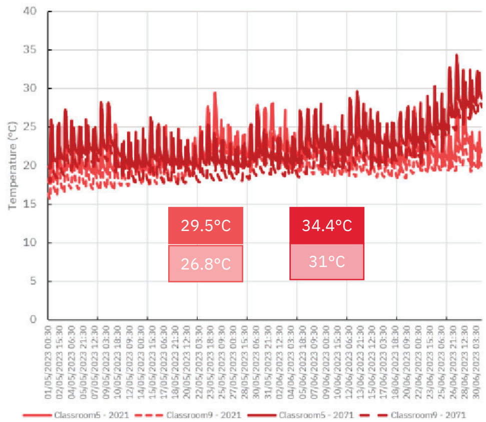
www.mtu.ie

Results and Discussion

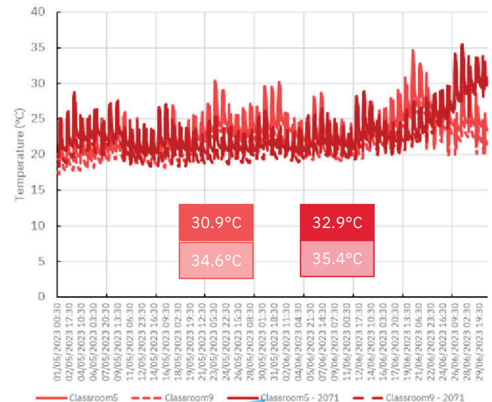
Simulation – Generic Repeatable Design (preliminary)

Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

South



Mid-West



Succeeding Together

www.mtu.ie

23

Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Conclusion and lessons learned

www.mtu.ie

24

Conclusion and future work

Renewable cooling in Ireland

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

- **Conclusions**
  - **Overheating exists** in some Irish classrooms. **Day-time ventilation only** may not be sufficient **in future**.
- **Lessons learned**
  - **SS very common**, limited height of openings, **more use of stack**, atria and guiding components (older buildings not worse in some cases).
  - Issues in getting access to BMS data proved troublesome. (**Bespoke data logging required**)
  - **Limited** degree of **automation** of natural openings (investment in controls required?)
  - Use of mechanical demand controlled VC single-zone could be a useful retrofit solution going forward.
  - **New buildings will need further upgrades for heat waves**.

Succeeding Together

www.mtu.ie

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

MeSSO
MECHANICAL ENERGY SYSTEM SIMULATION OPTIMISATION

Thank You, Any Questions?

adam.odonovan@mtu.ie

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

AIVC

TightVent Europe

venticool
the platform for resilient ventilative cooling

www.mtu.ie

Life Cycle Assessment:
A design element for ventilation system selection

WINDOW MASTER®
Fresh Air. Fresh People.

WINDOW MASTER®
Fresh Air. Fresh People.

Danish Building regulation

Office building in Denmark

Comparing LCA (CO_2-eq) and LCC for hybrid and mechanical ventilative cooling

Designed for hybrid ventilative cooling

About the building

- Constructed in 2017
- 1230 m^2
- Automated controlled solar shading

Ventilative cooling strategies

Hybrid (HVC)

- Heating season: MVHR
- Cooling season: NVC
  Automated natural ventilation via facade- and roof openings

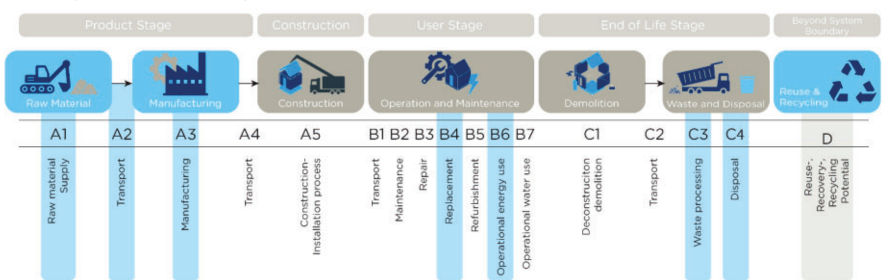
Mechancal (MVC)

- Heating season: MVHR
- Cooling season: MVHR

Phases included (blue)

Environmental impact over a lifespan of 50 years

According to Danish Building code



Components assessed

- EPD's
  - Natural ventilation components
  - AHU
- Rest by weight

Ventilation components to be included

According to Danish Building regulation

Kategori	Type	Bygningsdel	Eksempler	Med	Detaljeringsniveau
	Ventilation	Kanaler		Ja	Kun lige ventilationskanaler.
		Ventilationsaggregat		Ja	Evt. som mængde råmateriale. Inkl. varmegenvinding.
		Varmeflader, el og vandbårne		Ja	Evt. som mængde råmateriale.
		Køleflader		Ja	Evt. som mængde råmateriale.
		Befugtere		Ja	Evt. som mængde råmateriale.
		Affugtere		Ja	Evt. som mængde råmateriale.
		Lyddæmpere		Nej	
		Flamme og røgspjæld		Nej	
		Brand og røgspjæld		Nej	
		Overtryksspjæld		Nej	
		Røgspjæld		Nej	
		Spjæld on/off		Nej	
		Volumenstrømsregulatore		Nej	
		Filtre		Nej	
		Ventilatorer		Ja	Evt. som mængde råmateriale.
		Processudsugningsventilatorer		Nej	Uanset typen af ventilatoren
		Dyser		Nej	
		Fortrængningsarmaturer		Nej	
		Loftsarmaturer		Nej	
		Loftsarmaturer synlig montage		Nej	
		Renrumsarmaturer		Nej	
		Riste/Vægarmarturer		Nej	
		Indblæsningsposer		Nej	
		Kontrolventiler		Nej	
		Overtryksventiler		Nej	
		Emhætter		Nej	
		Punktsug		Nej	
		Kemikalieskabe		Nej	
		Stinkskabe		Nej	
		Lafbænke		Nej	
		Sluser		Nej	
		Aftrækskasser		Nej	
		Dekontaminatorer		Nej	
		Afkasthætter		Nej	
		Indtagshætter		Nej	
		Afkastsskorstene		Nej	
		Indtagsskorstene		Nej	
		Indtagsriste i vægge		Nej	
		Taggennemføringer		Nej	
		Membrangennemføringer		Nej	
		Isolering		Ja	Længder svarende til rørlængder.
		Bæringer		Nej	

Included in BR

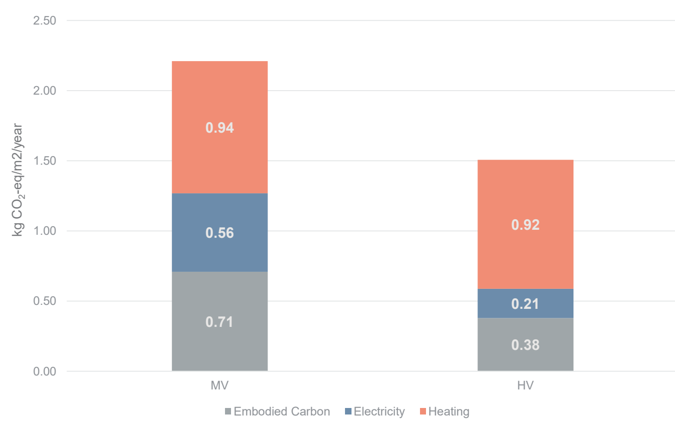
- Ducts
- AHU
- Heating or cooling units
- Humidifiers and dehumidifiers
- Silencers
- Fans
- Insulation

Extended

- +
- Air diffusers
- Facade grill
- Air flow damper, regulator
- End cap
- …

Results – extended

Environmental calculation focusing on CO_2-eq

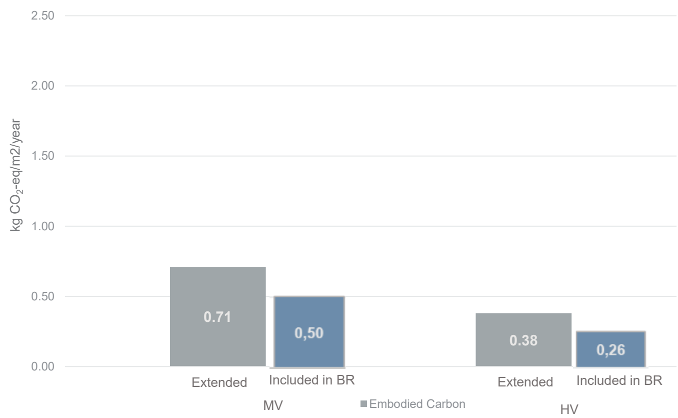


Remarks

- **Embodied Carbon NV: 0.033 kg CO_2eq/m^2/year**
- Compared to mechanical ventilation (MV) the hybrid ventilation (HV) can reduce the CO_2-eq from:
  - Embodied by more than 40%
  - Electricity by more than 50%
  - Heating same level
  - In total by more than 30%

Results – extended vs. included

Environmental calculation focusing on CO_2-eq



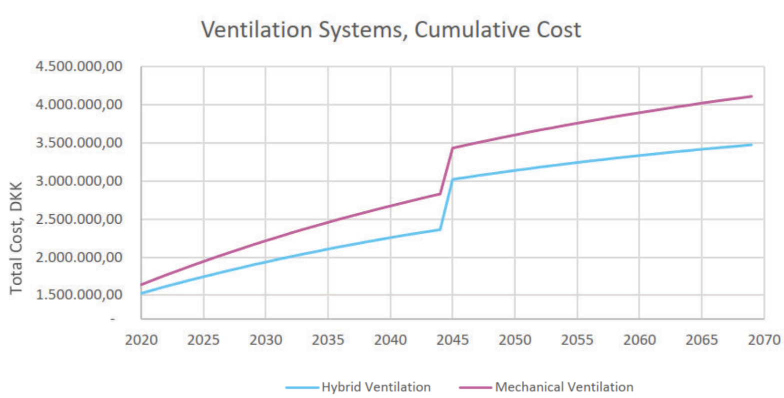
Remarks

- Mecahnical ventilation has a 40% increased CO2 emission from embodied carbon compared to what should be included according to the Danish Building regulation.

09-10-2023 7

7

LCC



Hybrid ventilative cooling offers

- Lower capital and runing cost compared to pure mechanical ventilation.

09-10-2023 8

8

Conclusion

- **<u>Designed</u> hybrid ventilative cooling can reduce carbon emissions and cost compared to a pure mechanical ventilative cooling system.**
- **By adding embodied carbon from natural ventilative cooling of 0.033 kg CO_2eq/m^2/year one can reduce the CO_2-eq:**
  - Embodied by more than 40%
  - Electricity by more than 50%
  - In total by more than 30%

Compared to pure mechanical ventilative cooling.

Questions?

Jannick Roth. jkr.dk@windowmaster.com

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

MeSSO
MECHANICAL ENERGY SYSTEM SIMULATION OPTIMISATION

AIVC · TightVent Europe · venticool

Ventilative Cooling Design in Practice: Where Next?

Paul D O'Sullivan

Adam O Donovan, Maha Sohail, Christoffer Plesner, Jannick Roth, Beat Frei, Annamaria Belleri, Valentina Radice

43rd AIVC, Copenhagen, 4th & 5th October 2023

5 October 2023

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND · Fondúireacht Eolaíochta Éireann sfi Dá bhfuil romhainn

Department of Process, Energy & Transport Engineering
www.mtu.ie

1

Agenda & Context

Ventilative Cooling Design in Practice

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

- Recap from 2022, early-stage intervention in VC design
- Practitioner Perceptions of VC: A survey
- Insights from Interviews with designers
- Resilient VC Design: A two stage design process

Succeeding Together

www.mtu.ie

2

Recap from AIVC 2022

Early-stage intervention to improve resilience

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

- Need to translate expert knowledge into simple but informed methods to evaluate resilience
- Embed VC & Resilient Principles from the outset of the design
- Architects, Planners, Stakeholders need to be part of the resilience and heat wave/extreme event planning

Fig 4: MacLeamy Curve: Influence of Early Effective Decision-making on Project Outcomes

Succeeding Together
www.mtu.ie

3

Designing in Thermal Resilience

Early Stage ~~Non-Expert~~ Interventions

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Conceptual stage design frameworks that Resilient VC non-experts (some architects etc) can use to evaluate resilience

- Is early stage interventions in the design process useful to reducing the cooling performance gap?
- Is early stage pre-design identified as an important stage for VC designers?
- How is early stage design done?

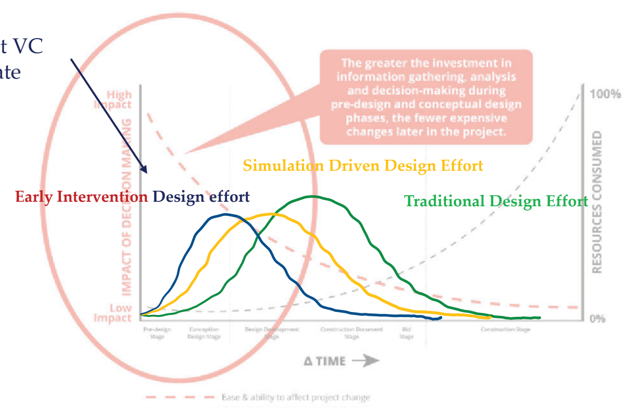


Fig 4: MacLeamy Curve: Influence of Early Effective Decision-making on Project Outcomes

Succeeding Together
www.mtu.ie

4

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Practitioner Perceptions of VC: A Survey

www.mtu.ie

5

Practitioner Perspectives

Findings from a UK/Ireland Survey

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

- Surveyed 71 building design practitioners in Ireland & UK, "Perception of ventilative cooling in building design practices".
- 57 Questions, 40 respondents completed survey fully (Architects, Engineers etc)
- The aim was an attempt to harvest information about how designers perceive ventilative cooling and how they approach VC design

M., Sohail, A., O'Donovan, C., Plesner, P.D. O'Sullivan, (2023), A survey of building design practitioner perceptions of ventilative cooling in their building design processes. AIVC 2023, Copenhagen, Denmark, October 2023

Succeeding Together

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Fondúireacht Eolaíochta Éireann sfi Dá bhfuil romhainn

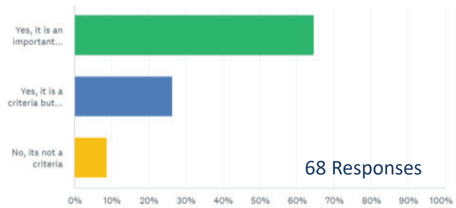
MeSSO

www.mtu.ie

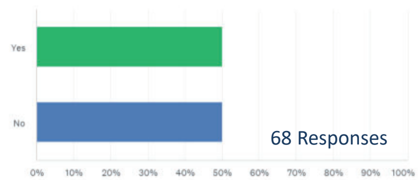
6

Practitioner Perspectives
Findings from a UK/Ireland Survey

Would you identify cooling of the indoor environment in buildings an important design criteria amongst your profession in your particular climate/country?



Are you familiar with the term "Ventilative Cooling"?



M., Sohail, A., O'Donovan, C., Plesner, P.D. O'Sullivan, (2023), A survey of building design practitioner perceptions of ventilative cooling in their building design processes. AIVC 2023, Copenhagen, Denmark, October 2023

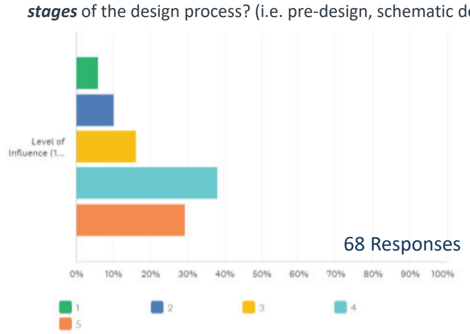
Succeeding Together

www.mtu.ie

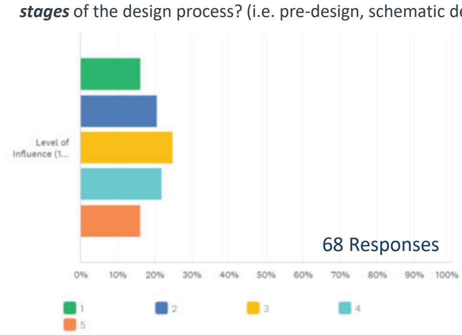
7

Practitioner Perspectives
Findings from a UK/Ireland Survey

In your experience, is **ventilating of the indoor environment** an influential criteria in the overall building design ***at the early stages*** of the design process? (i.e. pre-design, schematic design)



In your experience, is **cooling of the indoor environment** an influential criteria in the overall building design ***at the early stages*** of the design process? (i.e. pre-design, schematic design).



M., Sohail, A., O'Donovan, C., Plesner, P.D. O'Sullivan, (2023), A survey of building design practitioner perceptions of ventilative cooling in their building design processes. AIVC 2023, Copenhagen, Denmark, October 2023

Succeeding Together

www.mtu.ie

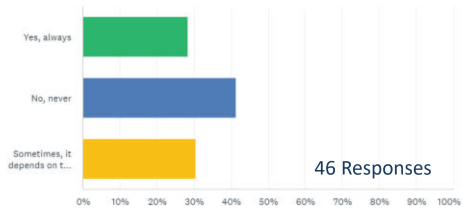
8

Practitioner Perspectives

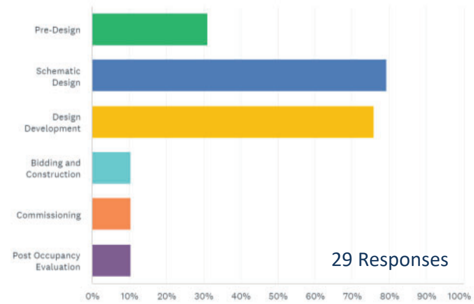
Findings from a UK/Ireland Survey

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Do you use any tools or software for making a ventilative cooling design decision?



At what stage(s) of your building design process, have you used this/these tools?



M., Sohail, A., O'Donovan, C., Plesner, P.D. O'Sullivan, (2023), A survey of building design practitioner perceptions of ventilative cooling in their building design processes. AIVC 2023, Copenhagen, Denmark, October 2023

Succeeding Together

www.mtu.ie

9

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

Insights from Interviews with VC Designers

www.mtu.ie

10

Insights From Interviews

The experience of the VC designer [UK & Ireland]

- Interviewed 10 VC design experts in Ireland & UK [summer 2023]
- 40 to 80 minute interviews. Data still being processed, not available yet.
- The aim was an attempt to build from the survey work and get a first-hand impression of how VC design is actually done in practice.

Succeeding Together

www.mtu.ie

11

Insights From Interviews

The experience of the VC designer [UK & Ireland]

" Tools are not the problem, **the people** using them are"

"There are plenty of tools available in the market and each company has in house tools as well, therefore **a new VC tool won't be useful in the industry unless it is part of a building regulation (law)/compliance procedure**"

"**Combination of passive and hybrid ventilation strategies** lead to a resilient VC strategy in view of design practitioners in industry"

"There are buildings existing that have an excellent VC design process that still works, they mostly had **collaboration of all building design stakeholders at early/concept stages**"

"Lack of collaboration between engineers, consultants and the Architect **at early stages** is often the reason of poor building designs as far as VC is concerned"

"The business of design gets in the way of better design"

Succeeding Together

www.mtu.ie

12

Insights From VC Designers

The experience of the VC designer [UK & Ireland]

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

- Hand sketches (pen and paper) and excel are the two most important tools used in **early concept stages of building design** by practitioners
- IES is the most popular tool in case of non-domestic VC decision making, **but it is mostly used at detailed phases of building design**. PHPP is also very popular for domestic buildings among Architects in particular, also often used at detailed stages.
- **A database of different non-domestic archetypes with VC strategies that work from history can be useful in industry** ← Informative Annex of Archetypes
- Experienced practitioners, Architects especially (age 50+) do not always appreciate new tools/forced technological advancements for their own usage, they rather believe in hand sketches or learning from history of each climate for better building design at early stages

Succeeding Together

www.mtu.ie

13

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

New CEN Ventilative Cooling Technical Specification
//
Resilient VC Design: A Two Stage Process

www.mtu.ie

14

New CEN VC Technical Specification

Developing a VC design process/approach

Some challenges

- Early-stage evaluation of complex solutions where performance prediction is difficult without advance tools
- Design is a combination of both iterative processes and sequential stages
- Does a prescriptive approach to VC design exist? (i.e. min recommended ACRs / no performance checks)

15

New CEN VC Technical Specification

Identifying the steps…

So far……

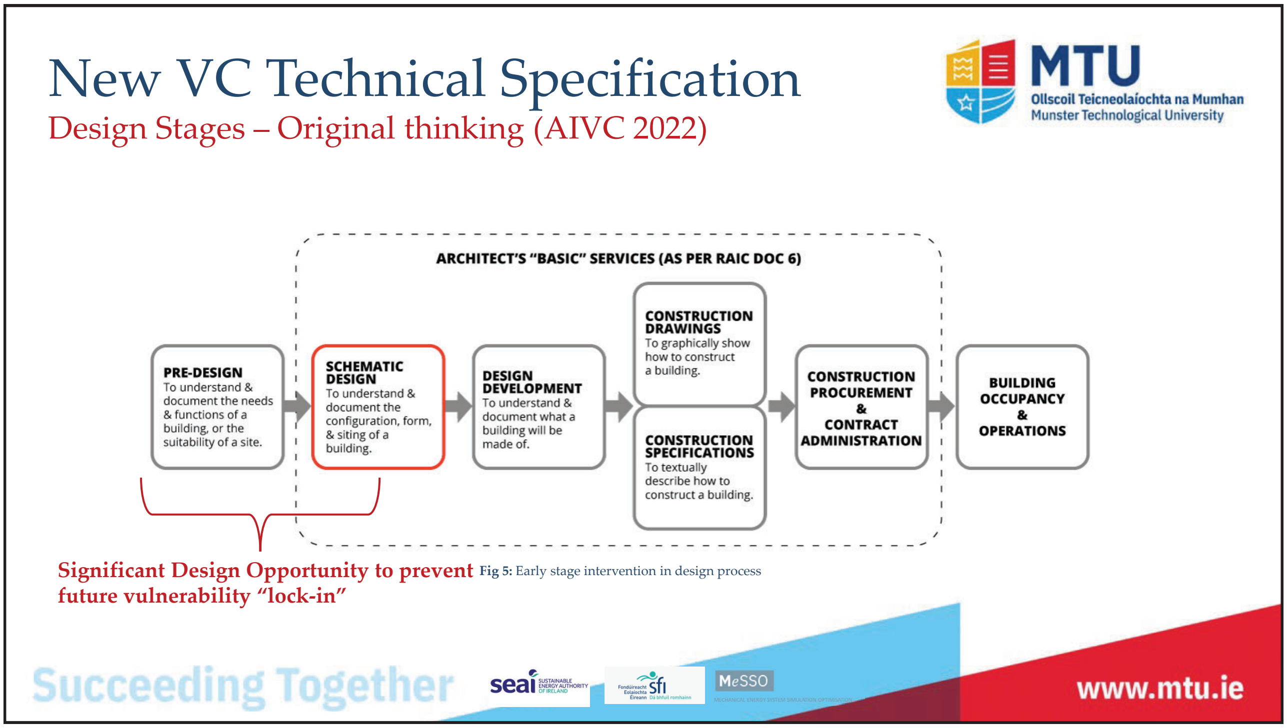
Identified 7 stages in ventilative cooling design **[courtesy Beat Frei]:**

1. Set performance criteria
2. Specify design assumptions
3. Evaluate cooling potential
4. Define ventilation operating principle
5. Develop ventilation strategy
6. Consider and accommodate the need for supplementary cooling
7. Define controls and operation

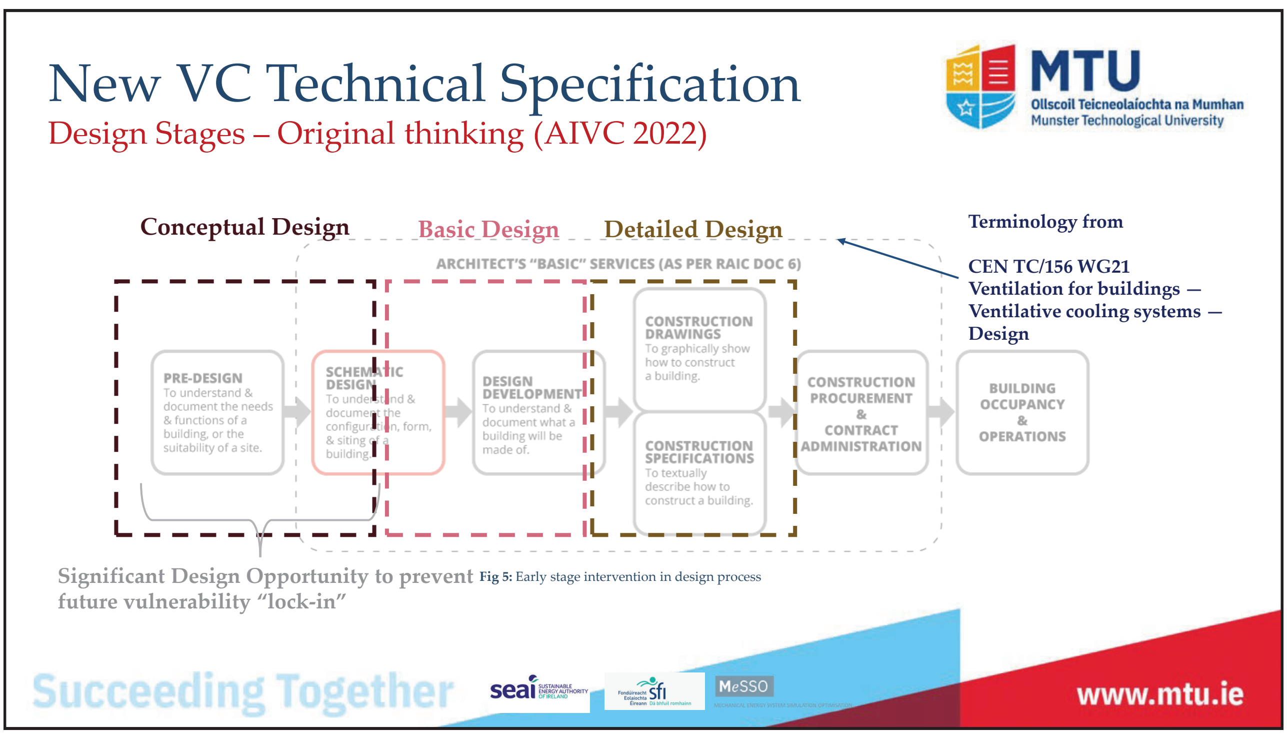
These steps continuously repeat with increasing levels of detail throughout the design. Milestones are fluid, design is a live shared space.

Complex solutions to overcome cooling limitations in basic/simple designs are captured in "supplementary cooling"

16


New VC Technical Specification
Design Stages – Original thinking (AIVC 2022)
MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University
ARCHITECT'S "BASIC" SERVICES (AS PER RAIC DOC 6)
PRE-DESIGN
To understand & document the needs & functions of a building, or the suitability of a site.
SCHEMATIC DESIGN
To understand & document the configuration, form, & siting of a building.
DESIGN DEVELOPMENT
To understand & document what a building will be made of.
CONSTRUCTION DRAWINGS
To graphically show how to construct a building.
CONSTRUCTION SPECIFICATIONS
To textually describe how to construct a building.
CONSTRUCTION PROCUREMENT & CONTRACT ADMINISTRATION
BUILDING OCCUPANCY & OPERATIONS
Significant Design Opportunity to prevent future vulnerability "lock-in"
Fig 5: Early stage intervention in design process
Succeeding Together
seai
MeSSO
www.mtu.ie

17


New VC Technical Specification
Design Stages – Original thinking (AIVC 2022)
MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University
Conceptual Design
Basic Design
Detailed Design
Terminology from
CEN TC/156 WG21
Ventilation for buildings —
Ventilative cooling systems —
Design
ARCHITECT'S "BASIC" SERVICES (AS PER RAIC DOC 6)
PRE-DESIGN
To understand & document the needs & functions of a building, or the suitability of a site.
SCHEMATIC DESIGN
To understand & document the configuration, form, & siting of a building.
DESIGN DEVELOPMENT
To understand & document what a building will be made of.
CONSTRUCTION DRAWINGS
To graphically show how to construct a building.
CONSTRUCTION SPECIFICATIONS
To textually describe how to construct a building.
CONSTRUCTION PROCUREMENT & CONTRACT ADMINISTRATION
BUILDING OCCUPANCY & OPERATIONS
Significant Design Opportunity to prevent future vulnerability "lock-in"
Fig 5: Early stage intervention in design process
Succeeding Together
seai
MeSSO
www.mtu.ie

18

New VC Technical Specification

A two stage process

MTU Ollscoil Teicneolaíochta na Mumhan Munster Technological University

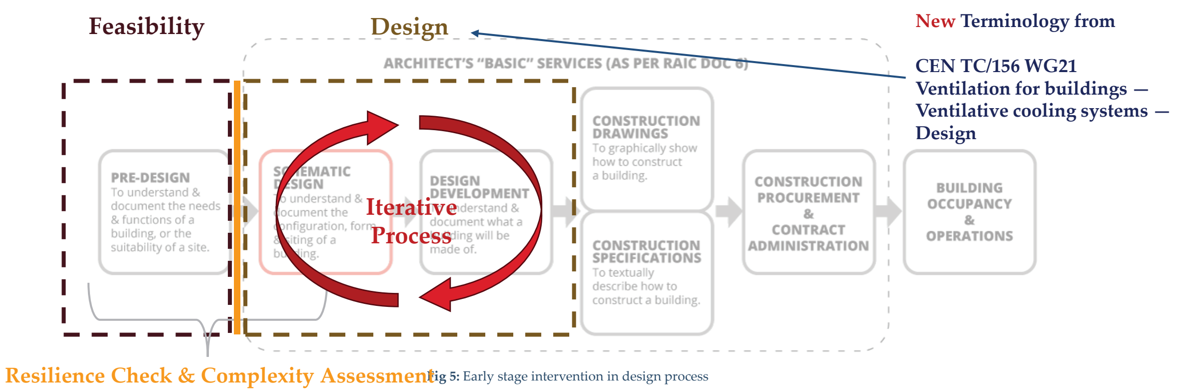
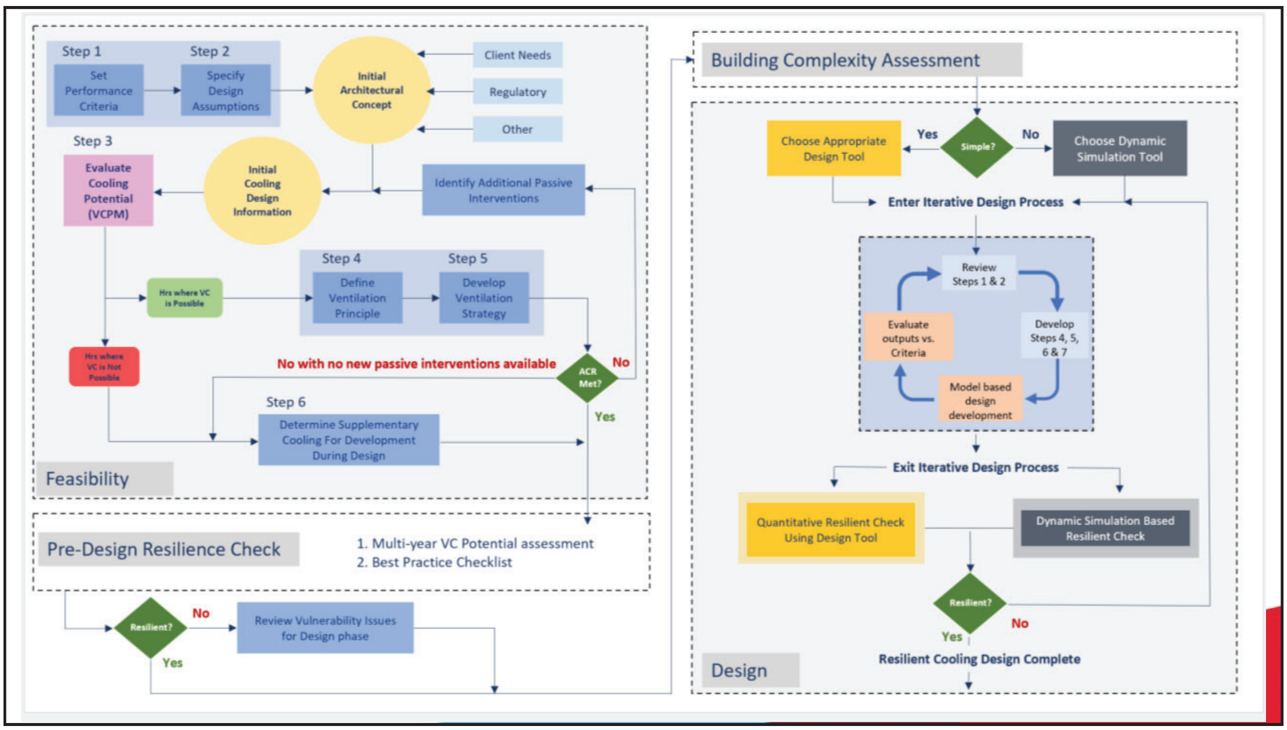


Fig 5: Early stage intervention in design process

Succeeding Together www.mtu.ie

19



20

In Closing…

- Easy stage intervention in VC design leads to better design outcomes
- The new Technical Specification will provide a framework for (reasonably) easy assessment of the feasibility of VC designs
- Need early stage guidance that recognises the design culture of VC practitioners
- How best can we address early-stage resilience evaluations?
- Reliable early-stage evaluations of complex supplementary solutions? (i.e. hybrid, double skin facades, cool materials etc)

Succeeding Together

www.mtu.ie

21

MECHANICAL ENERGY SYSTEM SIMULATION OPTIMISATION

Thanks for listening.

paul.osullivan@mtu.ie

6 OCT 2022

www.mtu.ie

22

KU LEUVEN archipelago UNIVERSITEIT GENT

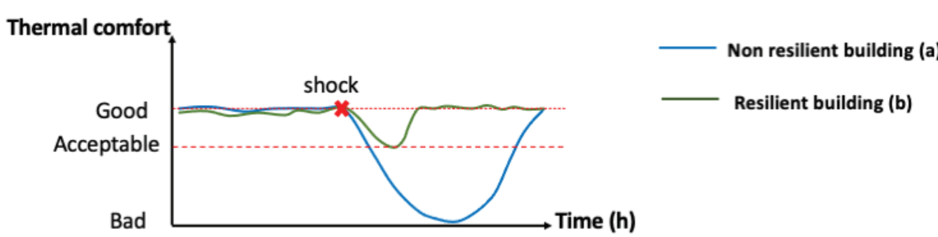
Resilient cooling in office buildings: case study in Belgium

Shiva Khosravi[1], Joost Declercq[1], Abantika Sengupta[2,3], Hilde Breesch[2]

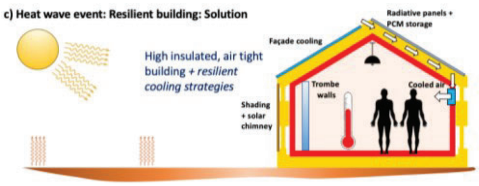
[1] archipelago architects, [2] KU Leuven, [3] Ghent University

Challenges

- Contempory buildings vulnerable to face extreme events or **shocks**
- **Design** of buildings resilient to overheating
  - Unexpected events not included in daily design practice
  - No framework in building standards
  - Limited knowledge influencing building design parameters resilient buildings



ReCOver++



- Aim
  - Improve resilience of buildings to overheating
  - Making resilience tangible & actionable concept for designers & manufacturers
- Case studies

Office buildings

School

Residential

FLANDERS INNOVATION & ENTREPRENEURSHIP flux50 RENSON Creating healthy spaces ARCADIS UNIVERSITEIT GENT archipelago KU LEUVEN

Case study

- New low-tech office building in Leuven (BE)

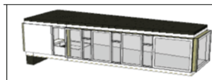
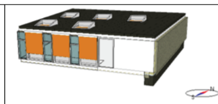
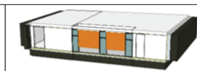
Location	Leuven, Belgium
Building Type	Offices
Floors	2
Occupants in each floor	32
Surroundings (Urban/Rural)	Urban
Year of construction	New construction
Floor Area (m²)	1019
Windows area to floor area ratio (%)	40%
Window-to-wall ratio (%)	21%
Climate zone	4 (ASHRAE 90.1)

Annex 80: Resilient Cooling Guidelines

UNIVERSITEIT GENT archipelago KU LEUVEN

Resilience assessment

- Approach
  - Step 1: Analysis passive design strategies current & future weather -> best thermal comfort + lowest energy use
  - Step 2: Resilience assessment
- Shocks
  - Heat wave (current + long term future)
  - Heat wave + 24h power outage
- Indicators
  - Occupied hours above temperature
  - Energy use (kWh)
  - Overheating escalation factor (OEF)

		
Zone A	Zone B	Zone C
+0	+0	-1
reception	open office	open office
$89m^2$	$225m^2$	$315m^2$

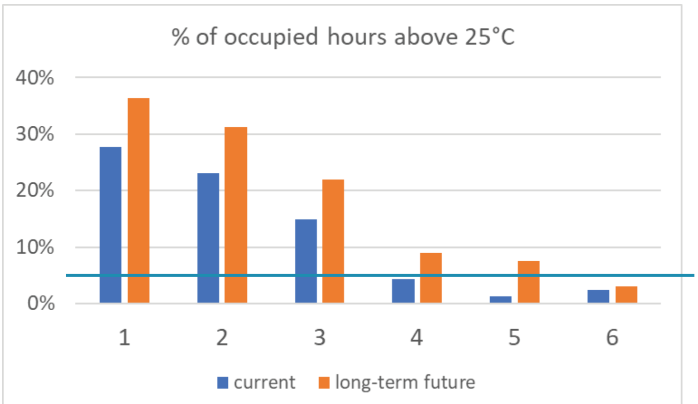
Simulation scenarios

- Cooling strategies
  - Shading
  - Ventilative cooling (+ thermal mass)
  - Mechanical cooling
    - Radiant panel
    - TABS

Scenario	**Auto-mated shading**	**Mechani-cal ventila-tive cool-ing 24/7**	**Natural ventilative cooling 24/7**	**Ther-mal mass (DIN 4108-1)**	**Mechanical heating and cooling de-vices**
					zone level
1	no	no	no	light	radiant panel
2	yes	no	no	light	radiant panel
3	yes	yes	no	light	radiant panel
4	yes	no	yes	light	radiant panel
5	yes	no	yes	heavy	radiant panel
6	yes	No	yes	heavy	TABS

Step 1: passive design analysis

- Thermal comfort (zone B)

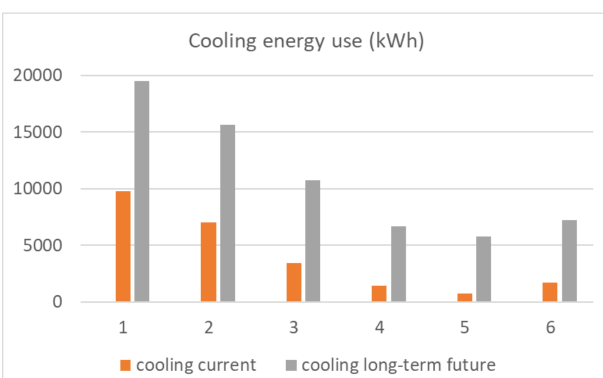


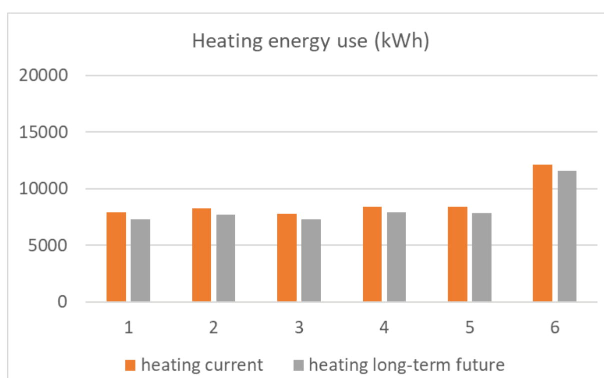
Zone B

UNIVERSITEIT GENT archipelago KU LEUVEN

Step 1: passive design analysis

- Energy use cooling (3 zones)
- Energy use heating (3 zones)

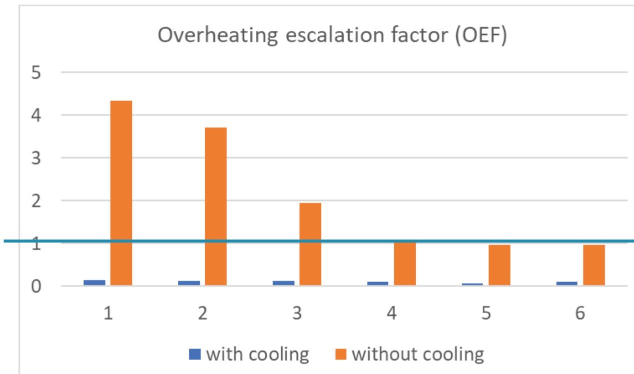




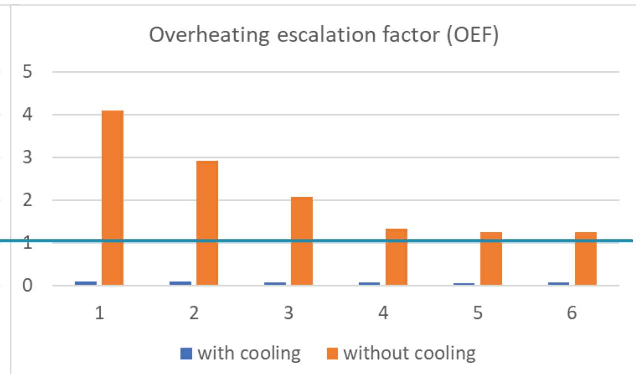
UNIVERSITEIT GENT archipelago KU LEUVEN

Step 2: resilience assessment

- Heat wave (current – 25d)



- Heat wave (future long-term – 44d)



Summary

- Case study office building resilient to overheating
- Passive design analysis: 2 step approach
  - Thermal comfort and energy use
  - Resilience to overheating
- Need for resilience indicator
  - Explaining how buildings react to shocks
  - Communicable to stakeholders

43rd AIVC, 11th TightVent and 9th venticool Conference: "Ventilation, IEQ and health in sustainable buildings"

IMPORTANCE OF GOOD RESILIENT BUILDING DESIGN AND STANDARDS TO ENSURE GOOD VENTILATIVE COOLING PERFORMANCE TO REDUCE OVERHEATING AND ENVIRONMENTAL IMPACT

Design procedures for ventilative cooling integrated in new standards

Christoffer Plesner
christoffer.plesner@velux.com

VELUX®

1

Projects in CEN & ISO (ventilation)

- **What:**
  - Technical documents in CEN/TC 156 and ISO/TC 205 have started up, dealing with Design of "**Ventilative cooling systems**"
  - Plan is to **support content of European EPBD standards** in revision; e.g. EN 16798-1 (indoor air quality, thermal comfort, energy performance)
  - These technical documents should:
    - Refer to relevant standards (performance requirements and calculation standards) but make their own design framework
    - Give extra focus on good design guidance in conceptual design phase to assist in finding the **Ventilative cooling potential** early on
- **Overall purpose:**
  - Make technical documents focusing on setting criteria and giving guidance to design of ventilative cooling systems in buildings for good thermal comfort
  - Guide designers/engineers to know what to be aware of when designing ventilative cooling systems in order to fulfill the set criteria
  - To make a common design procedure to design ventilative cooling systems in 3 stages

2

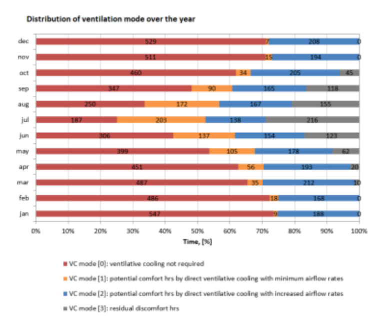
New ventilative cooling projects (P) in CEN & ISO

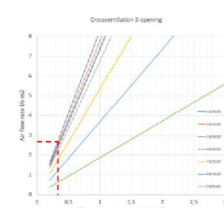
- **P1: “Ventilative cooling systems – Design” (<u>in all buildings</u>)**
  - Main focus: Thermal comfort (reduce cooling loads and reduce overheating)
  - Type: <u>A CEN Technical specification</u>
  - Applicable to: Natural, mechanical and a combination (hybrid) ventilative cooling systems & interaction with supplementary and mechanical cooling systems
  - **Wish**: Be a reference in revision of EN 16798-1-2 (design and assessment of thermal comfort)
- **P2: “Design process of ventilative cooling systems; Part 1 - non-residential buildings”**
  - Main focus: Thermal comfort (reduce cooling demand and reduce overheating)
  - Type: <u>An ISO standard (series)</u>
  - Applicable to: Natural, mechanical and a combination (hybrid) ventilative cooling systems & interaction with supplementary and mechanical cooling systems
  - **Wish**: Be a reference in revision of ISO 17772-1 (equivalent to EN 16798-1)

Expected publication(s), CEN: Q2:2026!!

Ventilative cooling systems (CEN/TS)

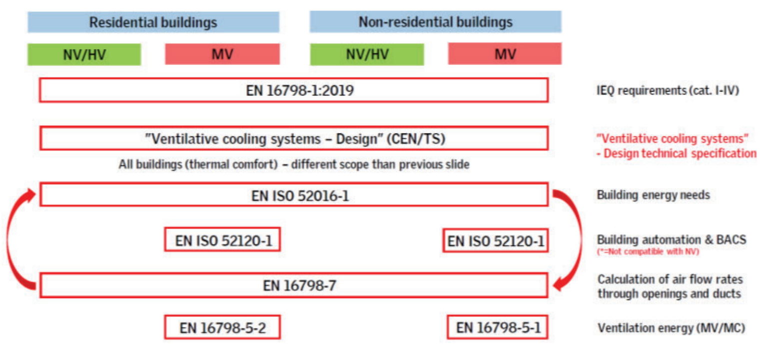
- **Methods to achieve the aim in our new technical documents:**
  - **Common design procedure phases** for ventilative cooling systems
    - **Conceptual** (feasibility)
    - **Basic** (choose air flow rates..)
    - **Detailed** (choose actual components)
  - Continuous **resilience checks** in each design phase (from simple questionnaires to actual Key performance indicators)
  - Use of **Ventilative Cooling Potential Method** in early conceptual design phase for evaluation of the ventilative cooling potential
    - Different ventilative cooling modes, e.g. VC mode 2 = increased air flow rates
    - To hear more: Go to Annamari Belleri's (EURAC) presentation
  - **Method** to find the needed opening area (e.g. for openable windows), based off the needed air change rate (e.g. output from VCPM)
    - EN 16798-7 can be used (see picture)
  - Guidance to **supplementary interventions and modulations (VC+)** on room and building level, e.g. add wall switches, solar shading or thermal mass
  - A **flow diagram overview** for design procedure is in the works for more clarity for designer





Ventilative cooling systems (CEN/TS)

- Reference to EPBD standards in CEN/TS
  - Aim for CEN/TS to fit into EPBD standards (e.g. EN 16798-1-2 ; thermal comfort) so referring to compatible standards is important
  - Not full compatibility for natural and hybrid ventilative cooling (to be worked in)



Conclusion

- Ventilative cooling can if the building is designed optimally be a good hybrid solution and alternative to mechanical cooling, to save peak load cooling loads and increase the design flexibility in buildings
- Important to have more technical documents highlighting more means like VC to combat the increasing impacts of climate change
- VC+ (ventilative cooling and solar shading) has shown to reduce overheating, often helped by robust early design evaluations like Ventilative cooling potential method
- Our CEN/TS is a good supplement to the EPBD EN standards, mostly telling which IEQ requirements to fulfill and not how
- Implementation of more **human needs** into standards and legislation (part of well-being) is important, e.g. adaptive comfort approach

Conclusion

- Putting ventilative cooling on the agenda as a good alternative to mechanical cooling
- Presenting a "simplified" evaluation methods in the early conceptual design phase to estimate the ventilative cooling potential (fx for how long can VC be used during different months/years)
- Showcasing that openable windows, louvres, etc can be used in the ventilative cooling system – pretty unclear in other documents
- To be put as reference in revision of EN 16798-1-2 (thermal comfort), when talking of non-mechanically cooled buildings

Thank you!

43rd AIVC, 11th TightVent and 9th venticool Conference: “Ventilation, IEQ and health in sustainable buildings”

IMPORTANCE OF GOOD RESILIENT BUILDING DESIGN AND STANDARDS TO ENSURE GOOD VENTILATIVE COOLING PERFORMANCE TO REDUCE OVERHEATING AND ENVIRONMENTAL IMPACT

Discussion

Christoffer Plesner, Jannick K. Roth
VELUX A/S & WindowMaster International A/S
christoffer.plesner@velux.com
jkr.dk@windowmaster.com

1

Questions

- Can ventilative cooling be the optimal solution in future for resilient buildings, if the building is designed correctly?
- Can or should future standards and legislation be more flexible towards human-behaviour etc.?
- How can ventilative cooling best be used in future, with increasing outdoor temperatures?

- What is the main barrier for implementation of ventilative cooling in buildings and standards?

2

Ventilative cooling systems (CEN/TS)

- What do you think of the following global design procedure for design of ventilative cooling systems ?

- General design procedure – key decisions (draft proposal)
  1. Setting performance criteria and requirements.
  2. Specifying design assumptions
  3. Evaluate the ventilative cooling potential
  4. Defining an operating principle
  5. Defining a ventilation strategy for ventilative cooling
  6. Check for interaction between ventilative cooling systems with supplementary and mechanical cooling (if needed).
  7. Defining controls and operation

3

Thank you!

4

Sensitivity Analysis of CO_2 Concentrations as Ventilation Metrics

Dr. Tobi Oke & Dr. Andrew Persily

National Institute of Standards and Technology
Gaithersburg, Maryland USA

43rd AIVC – 11th TightVent & 9th Venticool conference, 2023
Copenhagen, Denmark, 4-5 October, 2023

Courtesy of David Meyer, Shenandoah University

1

MOTIVATION

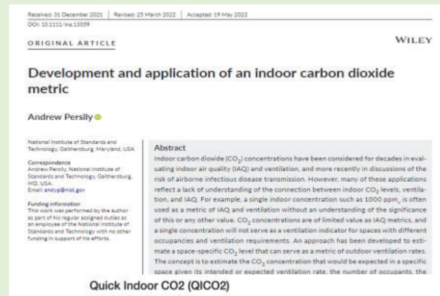
- CO_2 monitoring for ventilation and IAQ assessment often involves a single CO_2 concentration (e.g., 800 ppmv to 1000 ppmv) for all spaces
- A single value ignores important differences between spaces and occupants.
- CO_2 metrics for ventilation adequacy need to consider the following :
  - (i) Target ventilation rate
  - (ii) Space volume
  - (iii) Indoor activities performed (metabolic rates)
  - (iv) Occupant characteristics and schedule

2

PRIOR WORK

- ❑ Development of an Approach to Calculating Space-Specific CO2 Metrics of Ventilation (Persily, 2022)

- ❑ Online tool, QICO2 to facilitate the application of this approach (Persily and Polidoro, 2022)



Received: 31 December 2021 | Revised: 25 March 2022 | Accepted: 19 May 2022
DOI: 10.1111/ina.13059

ORIGINAL ARTICLE

WILEY

Development and application of an indoor carbon dioxide metric

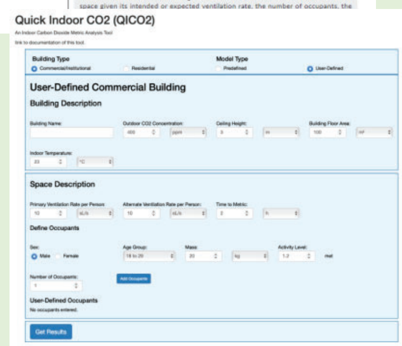
Andrew Persily

National Institute of Standards and Technology, Gaithersburg, Maryland, USA

Correspondence
Andrew Persily, National Institute of Standards and Technology, Gaithersburg, MD, USA.
Email: andyp@nist.gov

Funding information
This work was performed by the author as part of his regular assigned duties as an employee of the National Institute of Standards and Technology with no other funding in support of his efforts.

Abstract
Indoor carbon dioxide (CO_2) concentrations have been considered for decades in evaluating indoor air quality (IAQ) and ventilation, and more recently in discussions of the risk of airborne infectious disease transmission. However, many of these applications reflect a lack of understanding of the connection between indoor CO_2 levels, ventilation, and IAQ. For example, a single indoor concentration such as 1000 ppm_v is often used as a metric of IAQ and ventilation without an understanding of the significance of this or any other value. CO_2 concentrations are of limited value as IAQ metrics, and a single concentration will not serve as a ventilation indicator for spaces with different occupancies and ventilation requirements. An approach has been developed to estimate a space-specific CO_2 level that can serve as a metric of outdoor ventilation rates. The concept is to estimate the CO_2 concentration that would be expected in a specific space given its intended or expected ventilation rate, the number of occupants, the



- ❑ The concept requires assumptions and we don't know the associated uncertainties

3

OUR AIM

Investigate the uncertainties associated with the CO_2-based ventilation metrics approach

4

METHODS

STEP 1:

- Single-zone CONTAM simulations of CO_2 concentrations **over a range of input values**:
  - Outdoor ventilation rates
  - Occupant characteristics
    - Ratio of male to female
    - Body mass (kg)
    - Metabolic rates

STEP 2:

- A two-level, full factorial design with **a 10-step exploratory data approach (EDA)** to identify:
  - The most important factors
  - The impact of each input value and interactions between the input values

Output

- The sensitivity of these factors to the CO_2 concentration after **1 hour after full occupancy** and at **steady state**

5

MODEL INPUTS & DATA SOURCES

- Single-zone CO_2 concentrations in each space:

$$V\frac{dC}{dt} = Q\,[C_{out} - C(t)] + G \implies C_{ss} = C_{out} + \frac{G}{Q}$$

- Individual CO2 generation rate:

$$V_{CO2} = \text{BMR} * \text{M} * ({}^{T}/_{P}) * 0.000179$$

BMR = Basal metabolic rate ~ f (sex, age, body mass)

- Volumetric flow of air in & out of the space

$$V_{bz} = R_p \times P_z \times R_a \times A_z$$

ASHRAE Standard 62.1 Ventilation Rate Procedure

DATA SOURCES

Occupant density values
ASHRAE Standards 62.1

Metabolic rates
Adults (Ainsworth et al., 2011)
Youth (Butte et al., 2018)

Body mass
2015-2018 NHANES survey data

6

BASELINE INPUT VALUES: OCCUPANT CHARACTERISTICS AND VENTILATION RATES

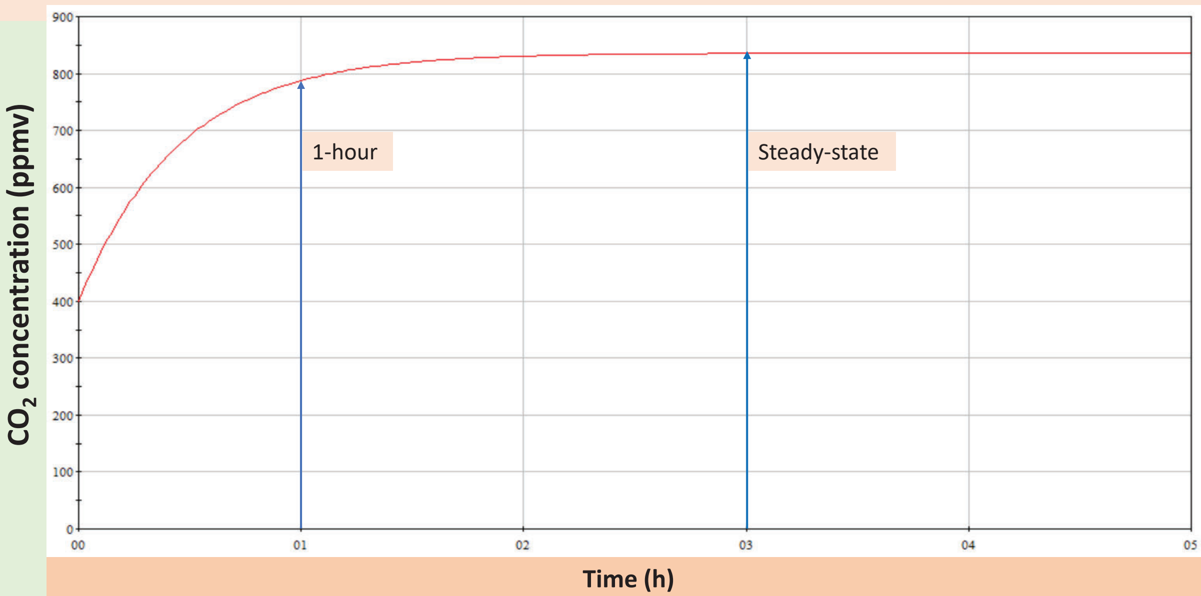
SPACE TYPE	OCCUPANT DENSITY (#/100 M^2)	MF RATIO	BODY MASS M/F (KG)	METABOLIC RATE (MET)	VENTILATION RATE (M^3/H)
Classroom (5 y to 8 y)	25	12 : 12 (1 adult Teacher)	Students: 26.4 / 25.8 Teacher: 93.4 / 79.6	Student: 1.5 Teacher: 2.1	185
Lecture classroom	65	32 : 32 (1 adult Lecturer)	Students: 83.6 / 73.7 Lecturer: 93.4 / 79.6	Student: 1.7 Lecturer: 2.1	277
Restaurant dining room	70	Customer: 33:33 Workers: 2 : 2	93.4 / 79.6	Customer: 1.7 Server: 2.2	356
Conference meeting room	50	25 : 25	93.4 / 79.6	1.7	155
Office space	5	2.5 : 2.5	93.4 / 79.6	1.9	42.5
Active Lobby	150	75 : 75	93.4 / 79.6	2.2	405
Mellow Lobby	150	75 : 75	93.4 / 79.6	1.9	405
Retail	15	7.5 : 7.5	93.4 / 79.6	2.1	117

SENSITIVITY ANALYSIS

- ❑ Primary objective is to provide insight into the data, which includes a **graphical** component that can be interpreted more easily.
- ❑ Settings in a **two-level design**, indicating higher (+1) and lower values (-1).
- ❑ Number of simulation based on 2^k factorial design, where k = number of factors ; $2^k = 2^4$ = **16 for each space**
- ❑ Baseline values of the studied inputs were varied by +/- 20 %.
  20 % not based on specific data, but rather to represent realistic variation

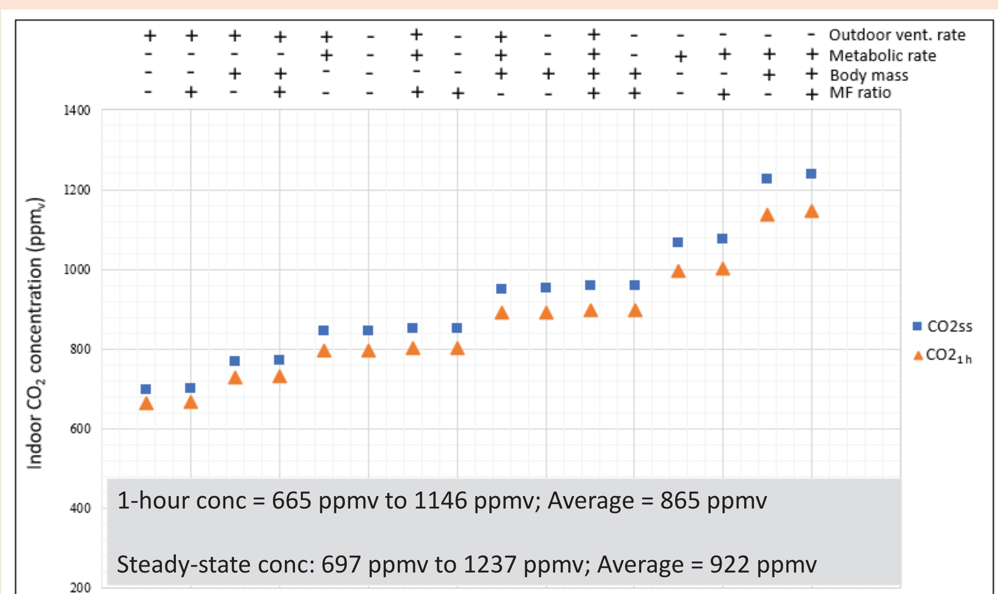
X1 Male to female ratio	X2 Body mass	X3 Metabolic rate	X4 Outdoor ventilation rate	Y CO2 concentration
-1	+1	-1	+1	893
+1	-1	-1	+1	890

SIMULATION RESULTS FOR CLASSROOM WITH STUDENTS 5-8 YEARS AND FEMALE TEACHER



9

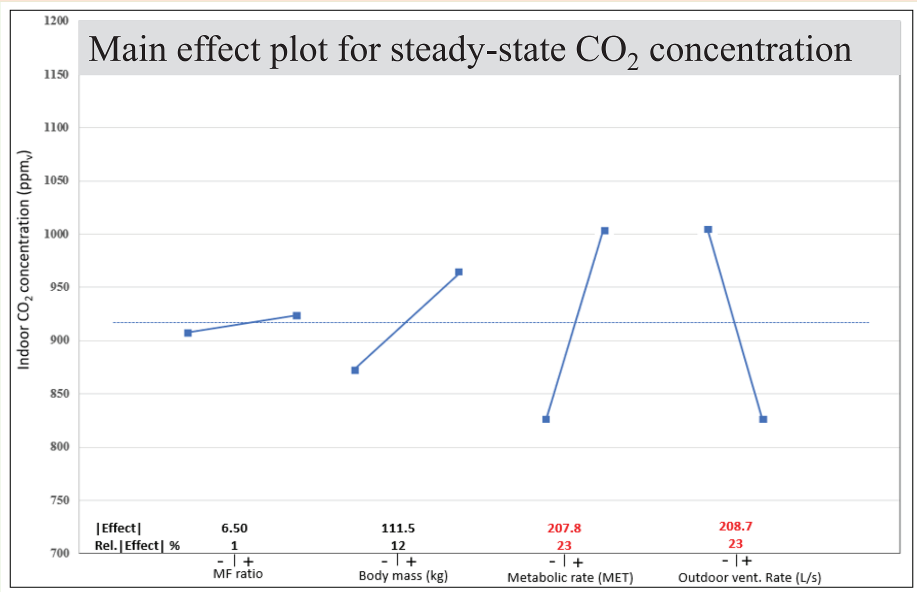
5-8 YEAR CLASSROOM WITH FEMALE TEACHER



Ordered data plot for steady-state and 1-hr CO_2 concentration

10

5-8 YEAR CLASSROOM WITH FEMALE TEACHER



Main effect = All higher values – all lower values

PERCENT DIFFERENCE IN 1-HOUR CONCENTRATIONS FOR +/- 20 % INPUT VARIATION

Space type	Minimum/maximum concentration (mean) ppm_v	MF ratio	Body mass	Metabolic rate	Ventilation rate
Classroom (5 y to 8 y, male teacher)	665/1146 (865)	1	11	**21**	**22**
Classroom (5 y to 8 y, female teacher)	659/1129 (855)	1	11	**21**	**21**
Lecture classroom (male lecturer)	1175/2825 (1846)	3	21	**33**	**31**
Lecture classroom (female lecturer)	1171/2812 (1838)	3	21	**33**	**31**
Restaurant dining room	1134/2509 (1700)	3	15	**31**	**31**
Conference meeting room	1380/3312 (2170)	4	16	**35**	**33**
Office space	595/953 (742)	2	9	**17**	**18**
Active Lobby	2146/5456 (3504)	5	18	**35**	**35**
Mellow Lobby	1855/4520 (2952)	5	17	**33**	**35**
Retail	761/1546 (1074)	7	13	**28**	**25**

- **Ventilation and metabolic rates** impact 1-hour and steady-state CO_2 concentrations more than **body mass and MF ratio.**
- Varying these two parameters by +/- 20 % results in variations in the CO_2 concentrations of about **20 % to 35 %.**

CONCLUSIONS

- The results of this analysis clarify potential range in CO_2 metric values based on variation in key input values
- **Outdoor ventilation rates and metabolic rates** have most significant effects on CO_2 metric values.
- The **target ventilation rate** will generally be known with a higher degree of confidence based on the standard or guidance value one is attempting to verify
- **The met rate for the space is inherently difficult to determine** as values in literature are based on specific activities; do not address met rates for spaces.
- The uncertainty in the CO_2 metric values associated with variations in met rates needs to be explicitly acknowledged and quantitatively considered.

13

THANK YOU!

14

Topical Session (6A)

The role of carbon dioxide and particulate matter for assessing ventilation and respiratory disease transmission in buildings

Evaluation of Uncertainties of Using CO_2 for Studying Ventilation Performance and Indoor Airborne Contaminant Transmissions

Presenter: Ibrahim Reda, Université de Sherbrooke

Authors: Liangzhu (Leon) Wang[1,*], Ibrahim Reda[2], Shujie Yan[1], Eslam Ali[1],

Dahai Qi[2], Theodore Stathopoulos[1], and Andreas Athienitis[1]

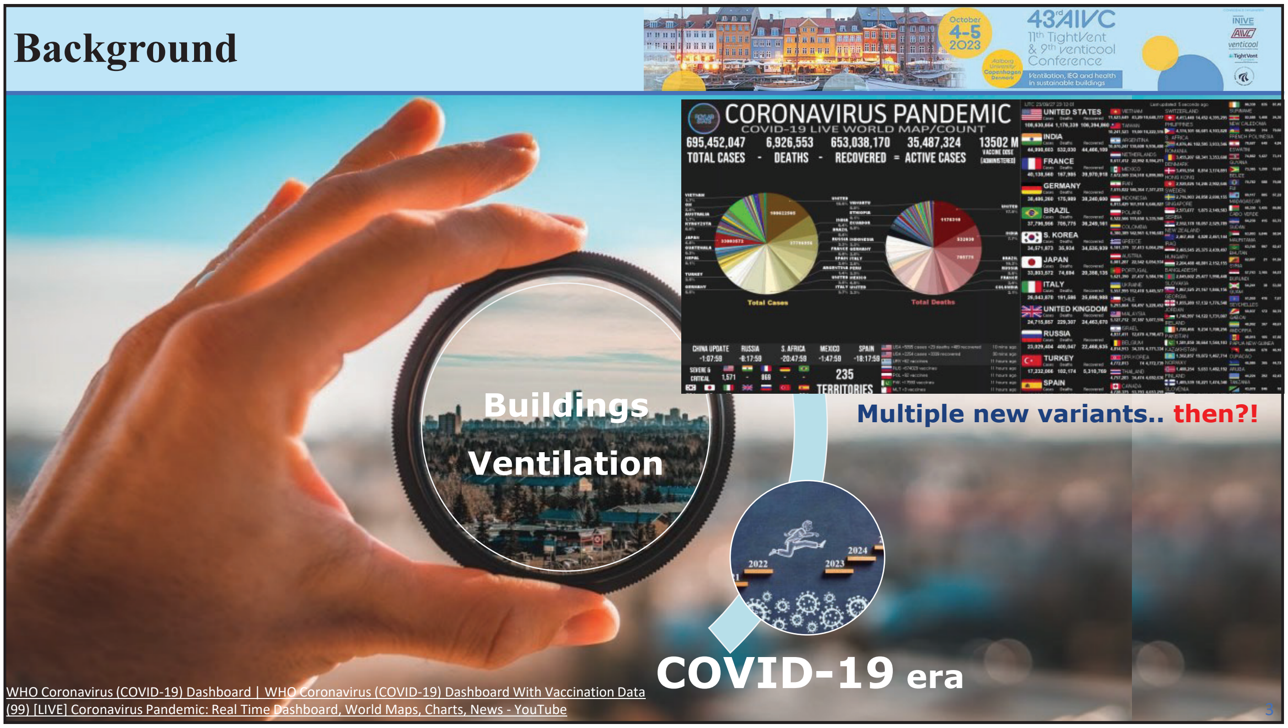
[1]Centre for Zero Energy Building Studies, Concordia University, Canada

[2]Department of Civil and Building Engineering, Université de Sherbrooke, Canada

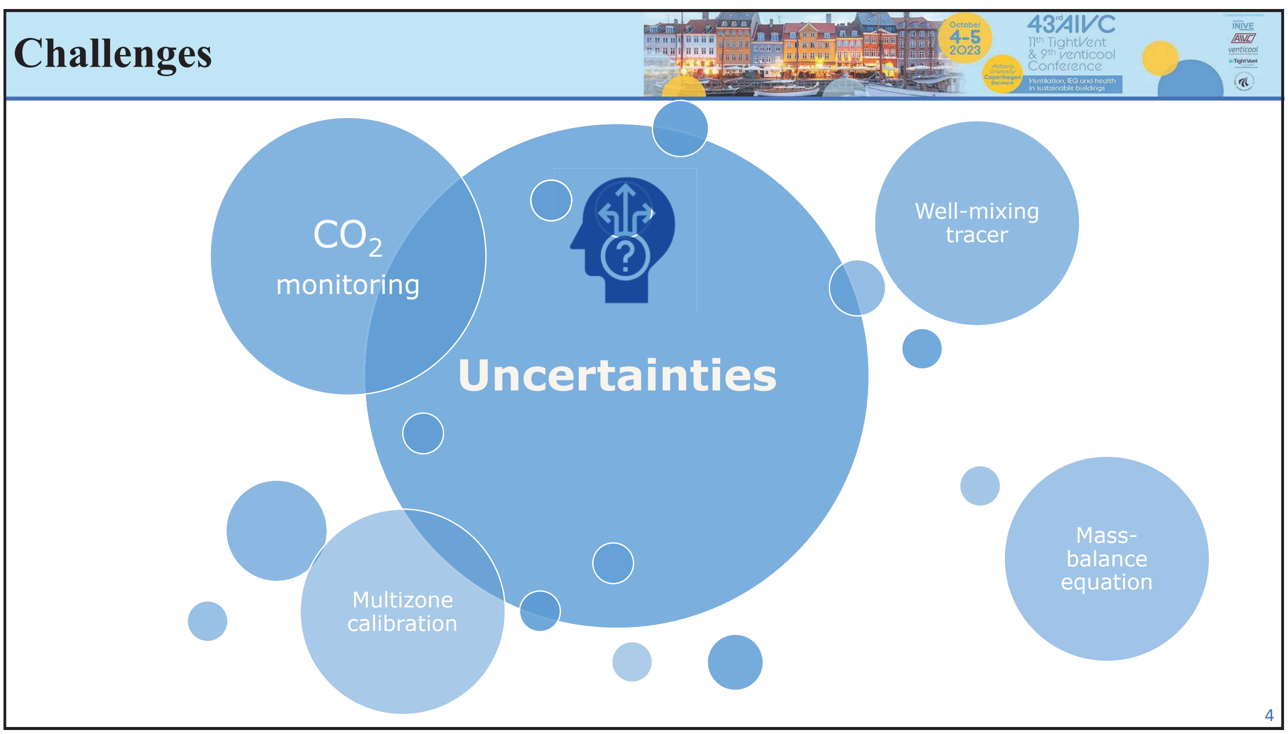
Date: October 5, 2023
Time: 11:00 – 12:30

Room A

Contents


Background
October 4-5 2023
43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings
CORONAVIRUS PANDEMIC
COVID-19 LIVE WORLD MAP/COUNT
695,452,047 TOTAL CASES - 6,926,553 DEATHS - 653,038,170 RECOVERED = 35,487,324 ACTIVE CASES
Buildings
Ventilation
Multiple new variants.. then?!
2022
2023
2024
COVID-19 era
WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus (COVID-19) Dashboard With Vaccination Data
(99) [LIVE] Coronavirus Pandemic: Real Time Dashboard, World Maps, Charts, News - YouTube

3


Challenges
October 4-5 2023
43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings
CO_2 monitoring
Uncertainties
Well-mixing tracer
Mass-balance equation
Multizone calibration
4

4

Objectives

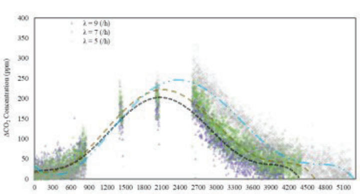
01

02

03

Objectives

Well-mixing tracer

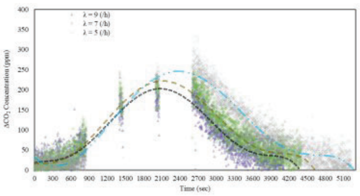


02

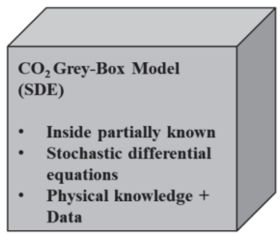
03

Objectives

Well-mixing tracer



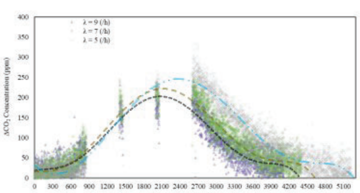
Stochastic grey-box model, integrating Bayesian inference



03

Objectives

Well-mixing tracer



02

03

Modified decay method (MDM)

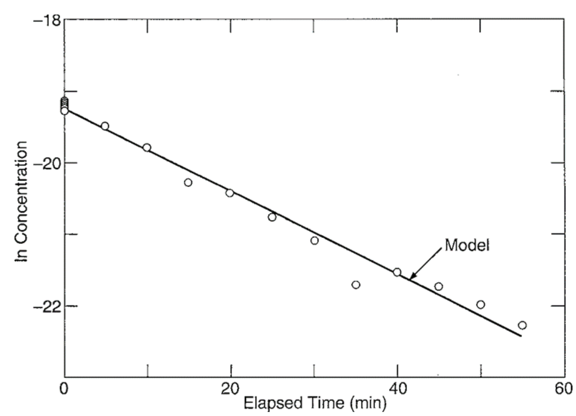
Challenges

Decay method assumptions and limitations

- Stable and inert tracer.
- No adsorption processes.
- Single zone.
- Constant ventilation rate.
- **Well-mixed space.**

To what extent
Well-mixed space
is real?

$$\lambda = \boxed{?}\ \frac{\ln C(t2) - \ln C(t1)}{t2 - t1}$$

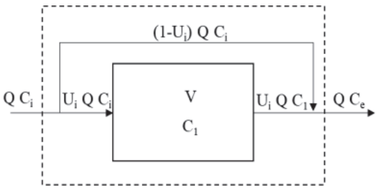


Regression method of estimating air change rates using decay method [ASTM E741].

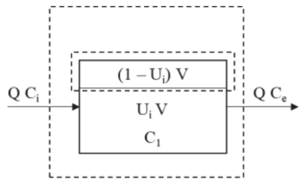
Solution

Modified decay method and non-uniform mixed space (MDM)

Short-circuiting



Stagnant region



Calculations of uniformity index using spatial variation of CO_2 concentrations

L × W × H

S_f — $S_f = \frac{L_e \times W_e}{H_e (L_e + W_e)}$

16 locations

CO_2 test

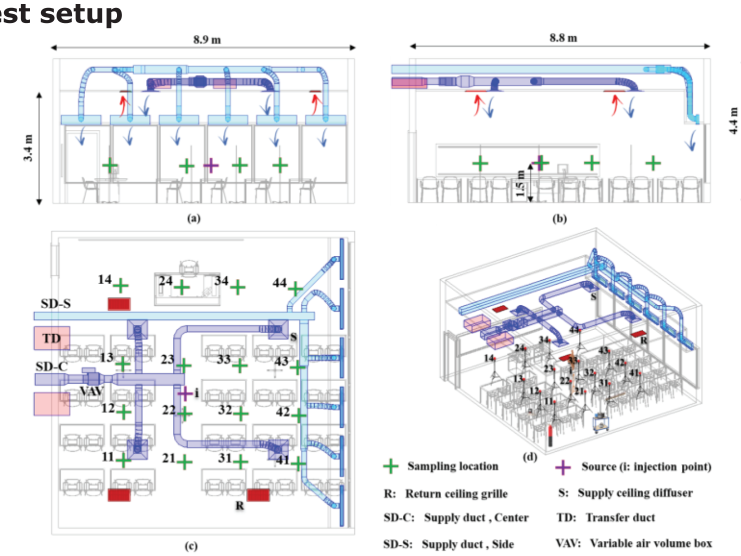
U_i — $U_i = \frac{C_{min}}{C_{avg}}$

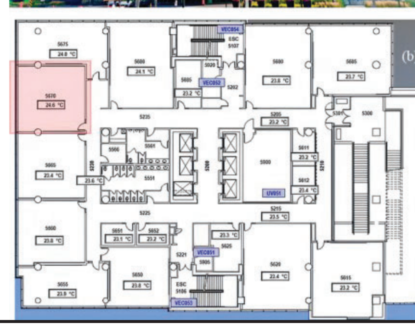
$$\lambda(U_i) = \begin{cases} \lambda_{wm} = \frac{1}{(t - t_0)} \ln \frac{(C - C_{bg})}{(C_0 - C_{bg})}, & \text{Well-mixed if } \lambda_{wm} = \lambda_m \\ \lambda_{sc} = \frac{1}{U_i (t - t_0)} \ln \frac{(C - C_{bg})}{(C_0 - C_{bg})}, & \text{Short-circuiting if } \lambda_{wm} < \lambda_m \\ \lambda_{sr} = \frac{U_i}{(t - t_0)} \ln \frac{(C - C_{bg})}{(C_0 - C_{bg})}, & \text{Stagnant region if } \lambda_{wm} > \lambda_m \end{cases}$$

A Modified Decay Method Based on a Proposed Uniformity Index for Measuring Air Change Rates in Non-Uniform Air Mixed Spaces by Ibrahim Reda, Eslam Ali, Dahai Qi, Liangzhu (Leon) Wang, Theodore Stathopoulos, Andreas Athienitis :: SSRN

Case study

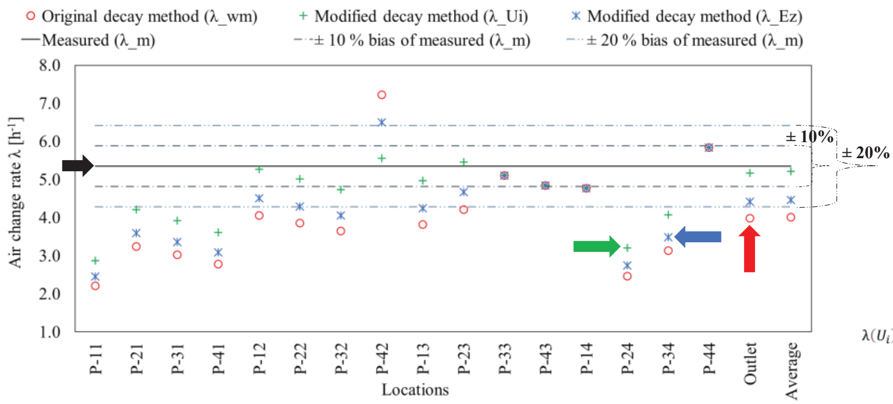
Test setup

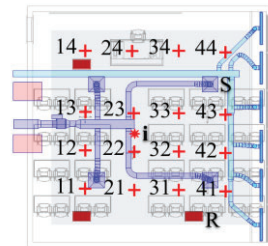




Zone description and test setup at Longueuil campus, University of Sherbrooke

Validation of the modified decay method





$$\lambda(U_i) = \begin{cases} \lambda_{wm} = \dfrac{1}{(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} = \lambda_m \\ \lambda_{sc} = \dfrac{1}{U_i(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} < \lambda_m \\ \lambda_{sr} = \dfrac{U_i}{(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} > \lambda_m \end{cases}$$

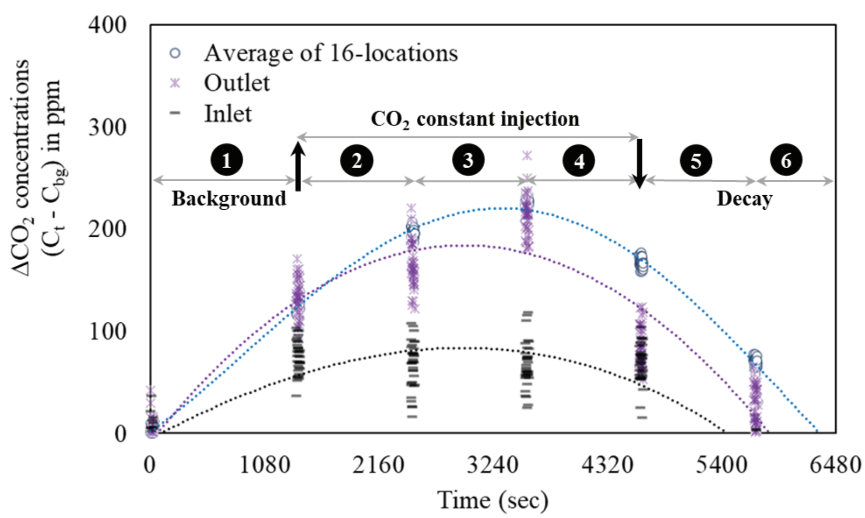
$$\lambda(E_z) = \begin{cases} \lambda_{wm} = \dfrac{1}{(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} = \lambda_m \\ \lambda_{zsc} = \dfrac{1}{E_z(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} < \lambda_m \\ \lambda_{zsr} = \dfrac{E_z}{(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} > \lambda_m \end{cases}$$

λ_{Ui}	Estimated air change rate using modified decay method and uniformity index [/h]		
λ_{wm}	Estimated air change rate using original decay method [/h]		
λ_{sc}	Estimated air change rate for a non-uniform mixed space with a short-circuiting of the inlet to outlet location [/h]		
λ_{sr}	Estimated air change rate for a non-uniform mixed space with stagnant regions [/h]		
U_i	Uniformity index	E_z	Zone distribution effectiveness
C	The indoor concentration of tracer gas [g/m³]	C_{bg}	Background concentration [g/m³]
C_o	The initial concentration of tracer gas [g/m³]		

13

13

Sampling representative



14

14

Conclusions

MDM

15

Conclusions

MDM

For the original decay method:

70% of sampling locations have underestimated λ (ε = 59%)
5% of sampling locations have overestimated λ (ε = 35%)
25% of sampling locations have acceptable λ (ε = 11%)

16

Conclusions

MDM

For the original decay method:
- 70% of sampling locations have underestimated λ (ε = 59%)
- 5% of sampling locations have overestimated λ (ε = 35%)
- 25% of sampling locations have acceptable λ (ε = 11%)

For the modified decay method:
- ε decreased from 25.6% to 3.4% at the outlet
- ε decreased from 25.0% to 2.5% at the average concentrations

17

Conclusions

MDM

For the original decay method:
- 70% of sampling locations have underestimated λ (ε = 59%)
- 5% of sampling locations have overestimated λ (ε = 35%)
- 25% of sampling locations have acceptable λ (ε = 11%)

For the modified decay method:
- ε decreased from 25.6% to 3.4% at the outlet
- ε decreased from 25.0% to 2.5% at the average concentrations

For the proposed uniformity index (U_i):
- U_i is more effective than ASHRAE Ez in enhancing the accuracy of λ measurements, with an improvement ranging from 7.8% to 17.5%.

18

Future needs

Generalizing the developed method (MDM)

CFD simulations and field tests for various geometrical and ventilation configurations will be performed to develop a referenced data (table) of uniformity index (U_i), which will be used for the proposed novel decay method.

Behind project

National Research Council
NRC·CNRC
Canada

Fonds de recherche
Nature et
technologies
Québec

Thanks! | Questions

**Corresponding author: leon.wang@concordia.ca*

Presenting author: ibrahim.reda@usherbrooke.ca

Effects of ventilation on airborne transmission: particle measurements and performance evaluation

Huijuan Chen, Caroline Markusson, Svein Ruud

RISE Research institutes of Sweden

2023-10-05

1

Introduction

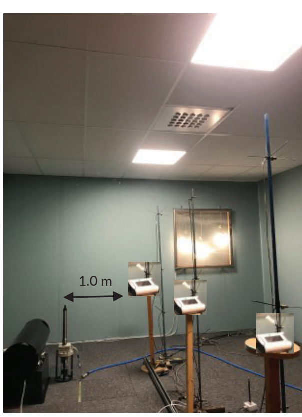
- Aim: evaluate different ventilation configurations for control of airborne transmission in a room
  - Different set-ups, flow rates, affect ventilation effectiveness on airborne particle removal
- Focus on mixing ventilation
- Part of the Eureka international network project (2020 December - 2024 March)

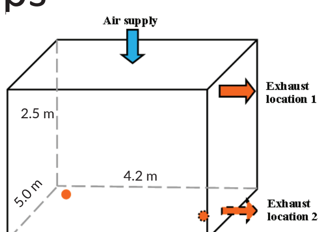
2

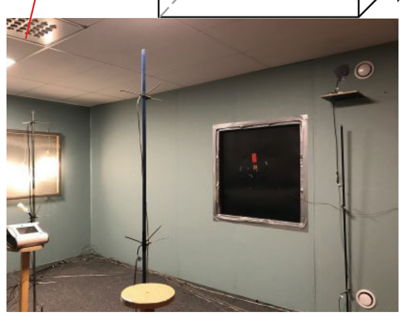
Method

- Test method: based on the concept of ventilation effectiveness adapted to aerosol particles.
  - Local ventilation effectiveness: $\varepsilon_p = (C_e - C_s)/(C_p - C_s)$
  - Particles with different size fractions
- Airborne particles up to 5 µm which stay in air for a long time and follow strictly with ventilation air stream.

Test room and set-ups







Test room (elderly care home room)

- Size: 4.2 (L) x 5.0 (D) x 2.5 (H)
- Internal heat load
  - Dummy (77 W)
  - Simulated TV (120 W)
  - Lighting (2 * 30 W)
- Mixing ventilation
  - Air supply and exhaust position

Measured parameters

- Particle concentration (4) at 1.2 m above the floor
- Air temperature (PT 100)
  - Air supply, exhaust and inside the test room
  - 0.1, 0.6, 1.1 and 1.7 m
  - Airflow rate

Thermal comfort was NOT Studied.

Particle generation and measurement

Palas AGK 2000
KCL solution (NaCl)

- TSI OPS 3330
- 0.3-10 µm up to 16 channels
- 0.3-0.4, 0.4-0.55, 0.55-0.7, 0.7-1, 1-1.3, 1.3-1.6, 1.6-2.2, 2.2-3, 3.0-4.0, 4-5.5, 5.5-7, 7-10.0
- 4 particle counters

Ventilation flow rate

Ventilation level	Flow rate (l/s)
Low	8
Medium	15
High	30
Very high	40

- 8 l/s: The Swedish National Board of housing, Building and Planning (BBR) 0.35 l/s per m2
- 15l/s: Swedish work environment authority 0.35 l/s per m2 + 7 l/s per person
- 30l/s: double the flow rate
- 40l/s: even higher flow rate

Measurement cases

Test nr.	Exhaust location	Flow rate (l/s)	Air discharge mode	Δt (room - supply) °C
1	High	8	Swirl	4.5±0.5 (4-5)
2		15		
3		30		
4		40		
5	Low	8	Swirl	4.5±0.5 (4-5)
6		15		
7		30		
8		40		
9		15	Swirl	4.5±0.5 (4-5)

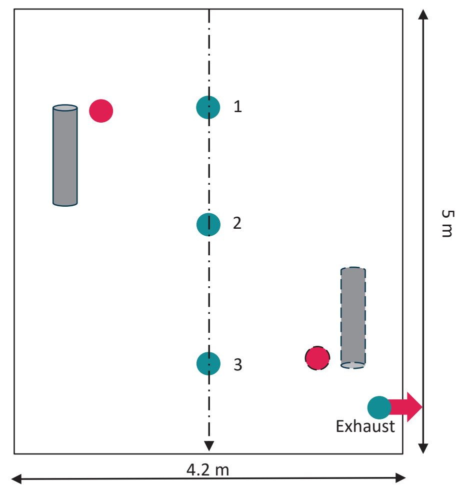
Extra case: exhaust location in relation to ventilation exhaust, tested at 15 l/s

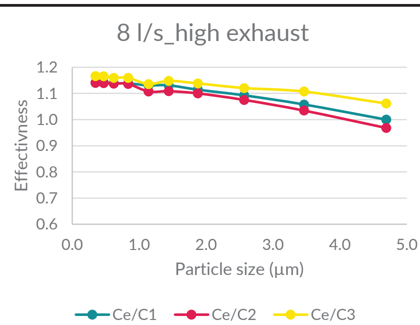
Measurement procedure

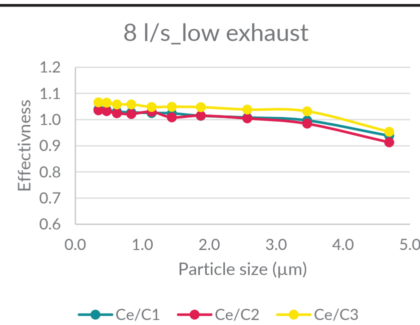
- Start ventilation and turn on heat sources and wait until getting stabilized flow and temperature field.
- Inject particles and taking the measurement data until get stabilized particle concentrations in the test room.
- Steady state measurement (1 hour).
- Correlation measurement to reduce relative bias among the particle counters
  - Turn off ventilation and head loads

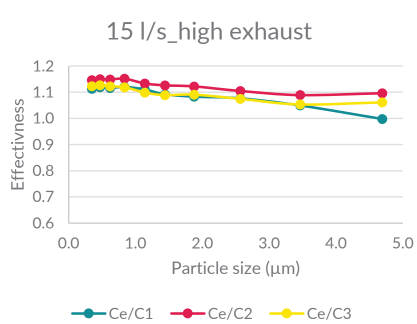
Results

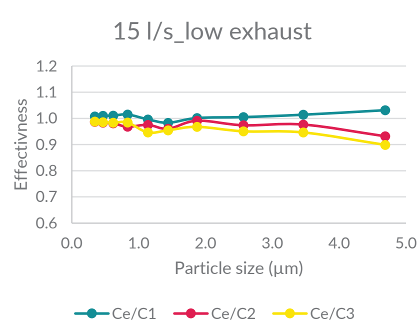
- Ventilation effectiveness
  - $\varepsilon_p = (C_e - C_s)/(C_p - C_s)$
    - $C_s = 0$
  - $\varepsilon_1 = C_e/C_1$
  - $\varepsilon_2 = C_e/C_2$
  - $\varepsilon_3 = C_e/C_3$

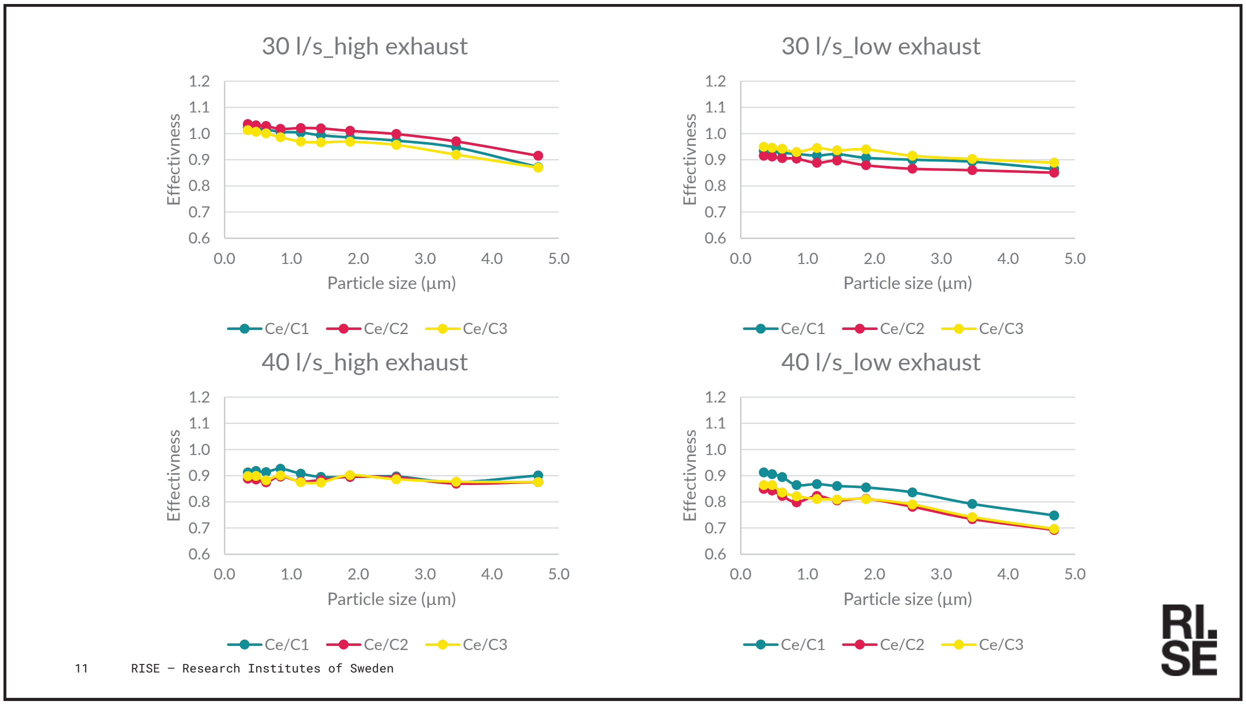


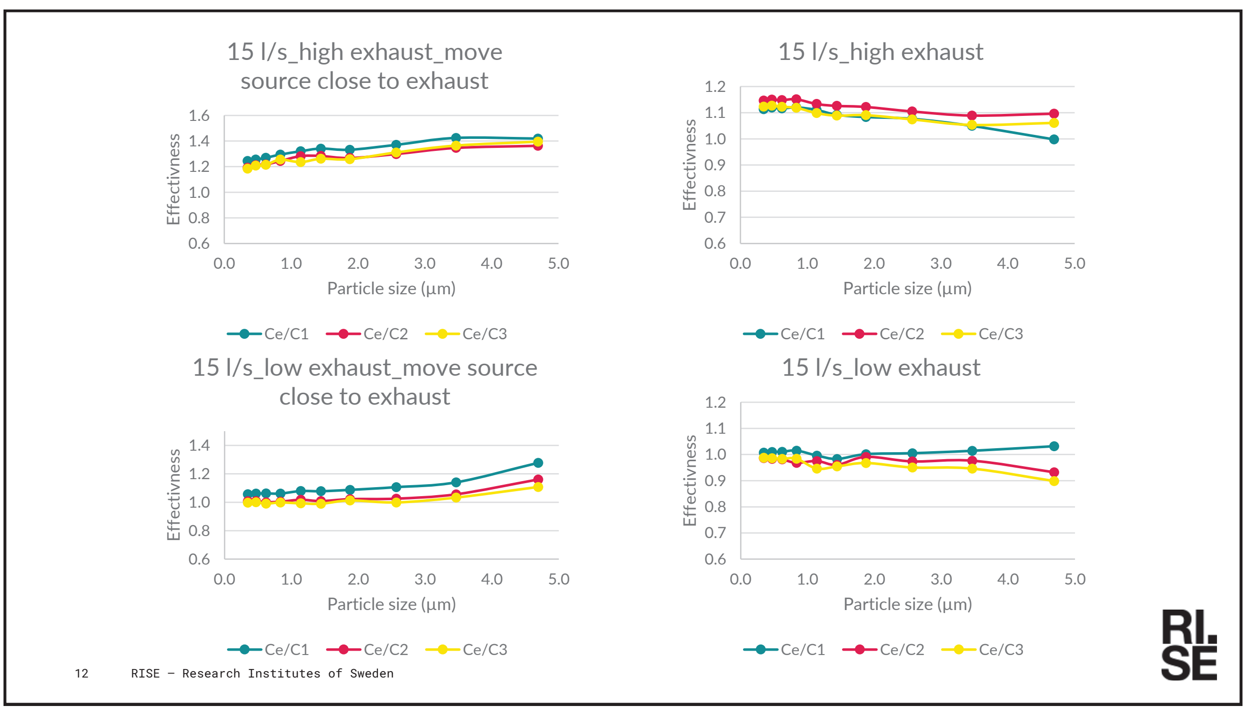









30 l/s_high exhaust
30 l/s_low exhaust
40 l/s_high exhaust
40 l/s_low exhaust
Effectivness
Particle size (µm)
Ce/C1
Ce/C2
Ce/C3
11
RISE – Research Institutes of Sweden
RI.
SE


15 l/s_high exhaust_move source close to exhaust
15 l/s_high exhaust
15 l/s_low exhaust_move source close to exhaust
15 l/s_low exhaust
Effectivness
Effectiveness
Particle size (µm)
Ce/C1
Ce/C2
Ce/C3
12
RISE – Research Institutes of Sweden
RI.
SE

Conclusions

- High exhaust provides better ventilation effectiveness than that with low exhaust.
- 8 and 15l/s, provide slightly better effectiveness which is due to displacement effect.
  - Not as bad as we thought, compensated by higher effectiveness.
- 30 l/s shows typical effectiveness for mixing ventilation (about 1 for smallest particles), while 40l/s shows less effectiveness due to short circuit.
  - Not as good as we believed due to risk of short circuit.
  - Better dilution effect.
- Balance between the contaminant dilution and removal should be considered when increasing the flow rates to enable sufficient and effective ventilation.
- Re-arranging room layout considering potential source locations could be a measure to reduce airborne transmission.

Thank you for your attention!

Huijuan Chen

Huijuan.chen@ri.se

NRC·CNRC

NRC.CANADA.CA

Impact and benefits of the air cleaning measures in two Canadian schools

Prepared by: Liang Grace Zhou, Chang Shu, Justin Berquist, Greg Nilsson, and Janet Gaskin

Construction Research Centre, National Research Council Canada

Prepared for: AIVC 2023 Topical Session "The role of carbon dioxide and particulate matter for assessing ventilation and respiratory disease transmission in buildings"

October 5, 2023

National Research Council Canada | Conseil national de recherches Canada

Canada

Overview of the Controlled Intervention Study

A collaboration between the NRC and a Provincial Government

Two elementary schools were selected: each school has ~30 rooms and ~300 students and staff (Grade 1-8); one section with mechanical ventilation and one without; originally built in late 1950s.

Population: The students and staff.

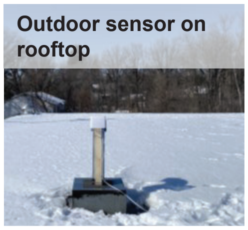
Intervention: Portable air cleaners (PACs) with HEPA filters in each classroom and certain common areas (i.e. library).

Control: Baseline ventilation functioning as in the control school (without PACs).

Outcomes: PM1.0 and PM2.5 concentration; CO_2 level; power consumed by PACs; and filter efficiency; aggregated number of sick days.

Time: 14 weeks April-June 2023 (Control-14 weeks with baseline ventilation; Intervention – 6 weeks with baseline ventilation, followed by 8 weeks with PACs).

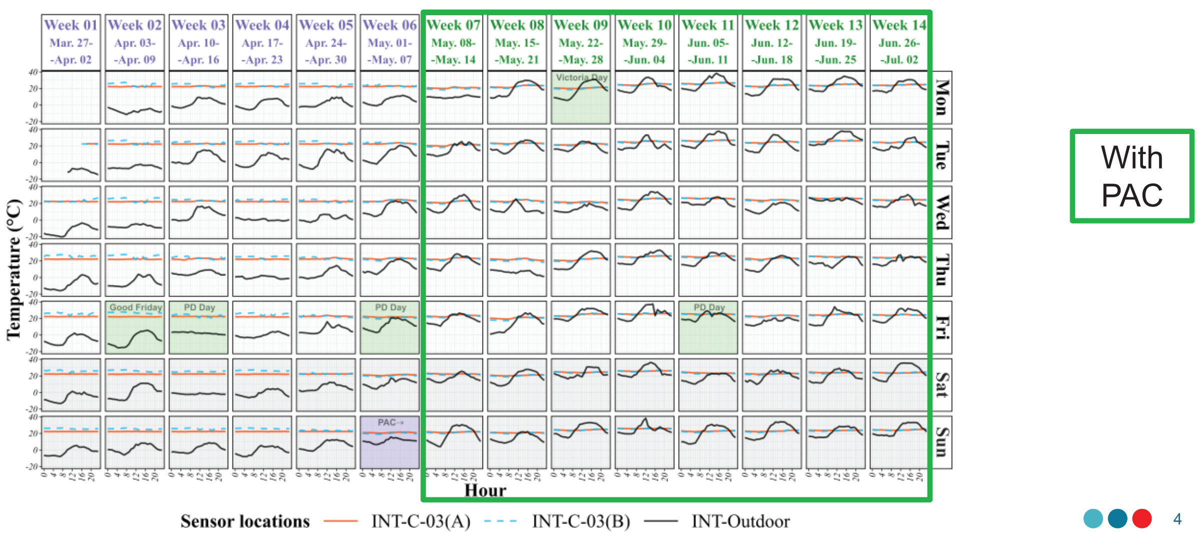
Equipment Installation



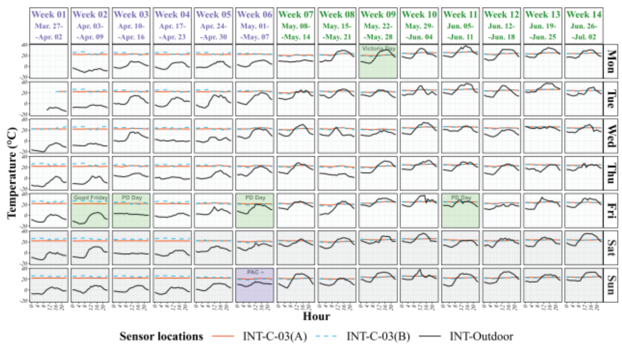
AQ sensors in classrooms, library, staff rooms, band rooms, hallways, and outdoors.

- Sound level with PAC on <54 dBA for all classrooms.
- Airflow rates of PACs were measured in each room (~2.5 ACH).
- 11 PACs were installed with a timer (08:00-17:00), 11 PACs were not controlled by a timer, on 24/7.
- Airflow rates from centralized HVAC system supply/return grills were measured.
- Plug power consumption, indoor/outdoor CO_2, PM1, PM2.5, PM10, RH, and T are continuously monitored.

Temperature: a Classroom in Intervention School

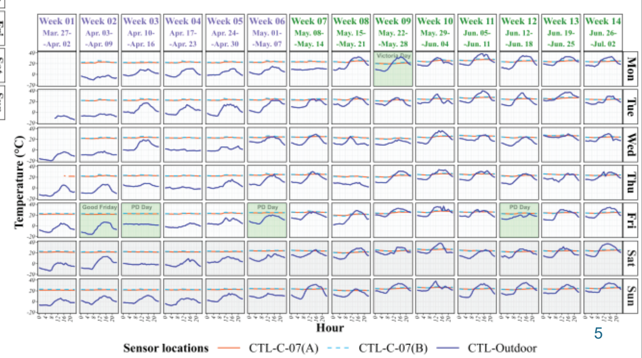


Temperature: Intervention vs. Control



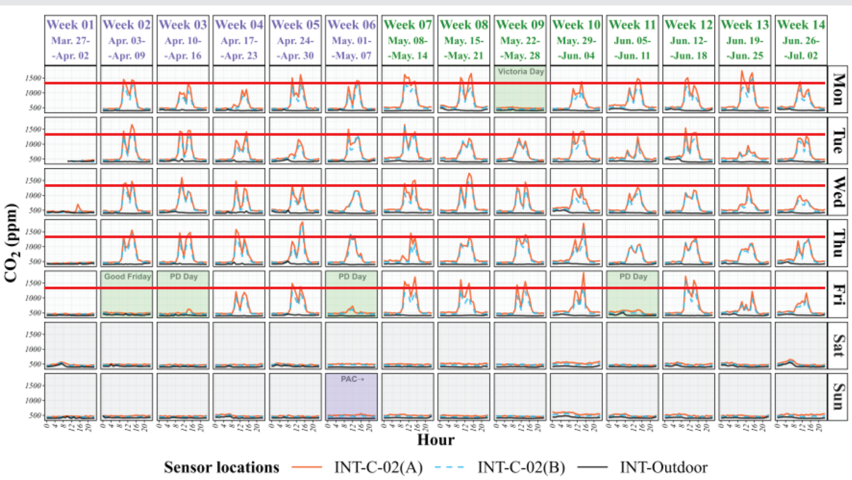
Intervention School INT-C-03

Control School CTL-C-07



5

CO_2 Concentration: Intervention School Original Section, a Classroom with Windows



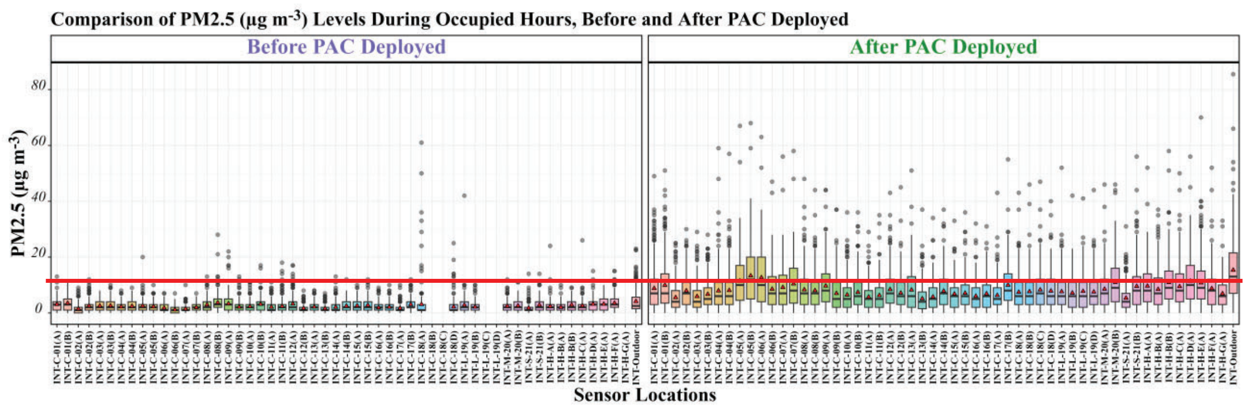
Space type	CO_2 concentration above outdoors (ppm)	Time after occupancy (hr)
Classroom (> 9 years)	900	1

Potential CO_2 concentration metrics based on ASHRAE 62.1 ventilation requirements (Persily, 2022)
Outdoor CO_2 ~450 ppm

This classroom has 29 students, ages 11 to 12, 13 males and 16 females.

6

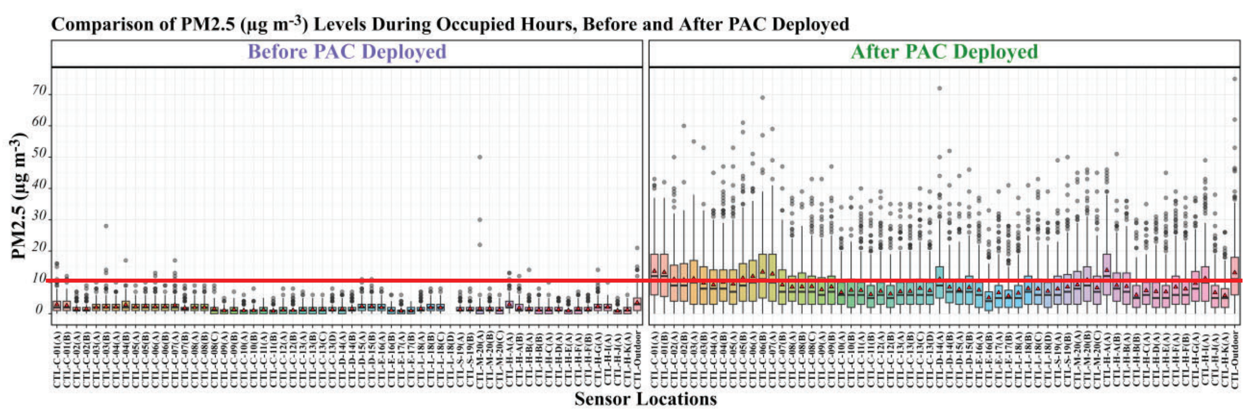
PM2.5 Concentration: Intervention School



Design limits of PM2.5 – 12 µg/m^3 in ASHRAE 62.1

7

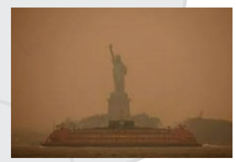
PM2.5 Concentration: Control School



Design limits of PM2.5 – 12 µg/m^3 in ASHRAE 62.1

8

PM Concentration: Outdoor Sources

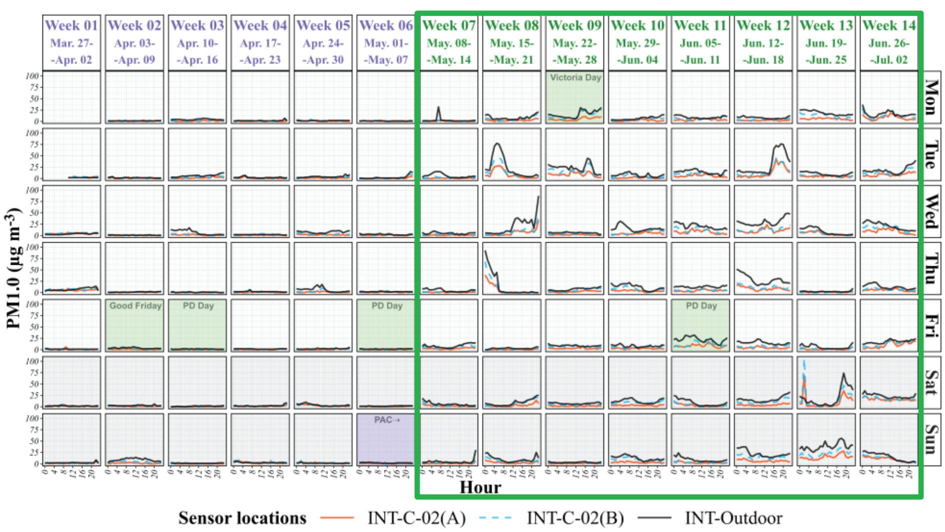


Wildfires May – June 2023

★ Location of the schools

Occupants in the schools didn't smell or see any smoke!

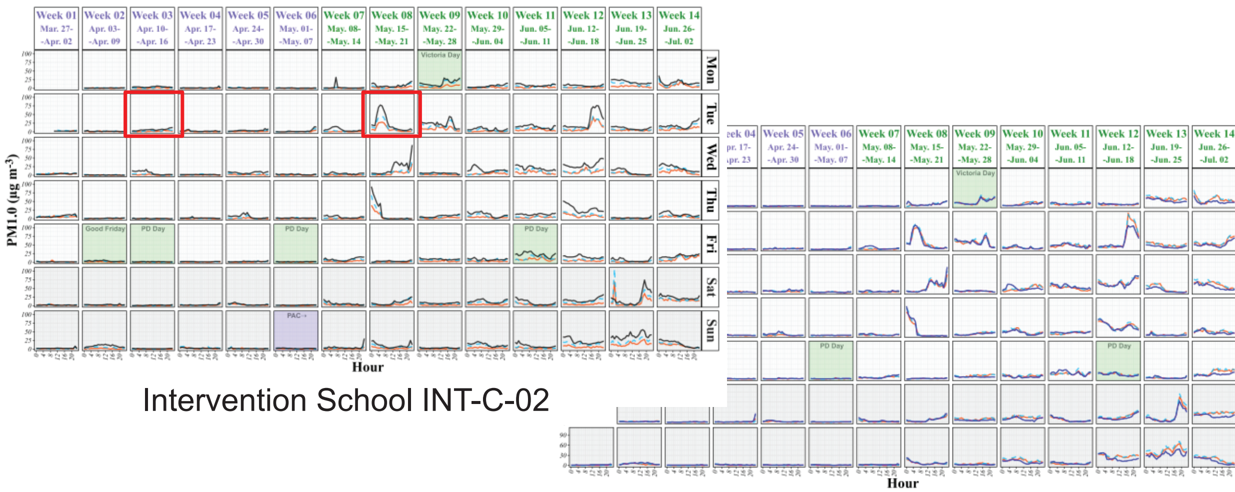
PM1 Concentration: a Classroom with Windows in the Intervention School



Approximate Equivalent Ratings for Filters Tested Under ASHRAE Standard 52.2 (MERV) and ISO 16890	
ASHRAE MERV* (Standard 52.2)	ISO 16890 Rating
1-6	ISO Coarse
7-8	ISO Coarse >95%
9-10	ePM_{10}
11-12	$ePM_{2.5}$
13-16	ePM_1

With PAC

PM1 Concentration: Intervention vs. Control

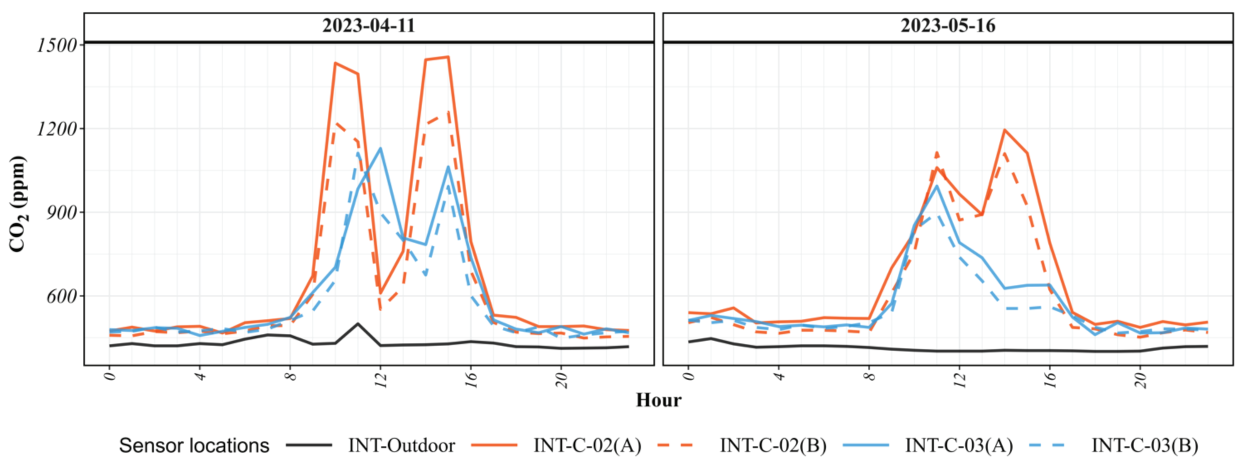


Intervention School INT-C-02

Control School CTL-C-06

11

Impact of Occupancy on Indoor CO_2 Concentration

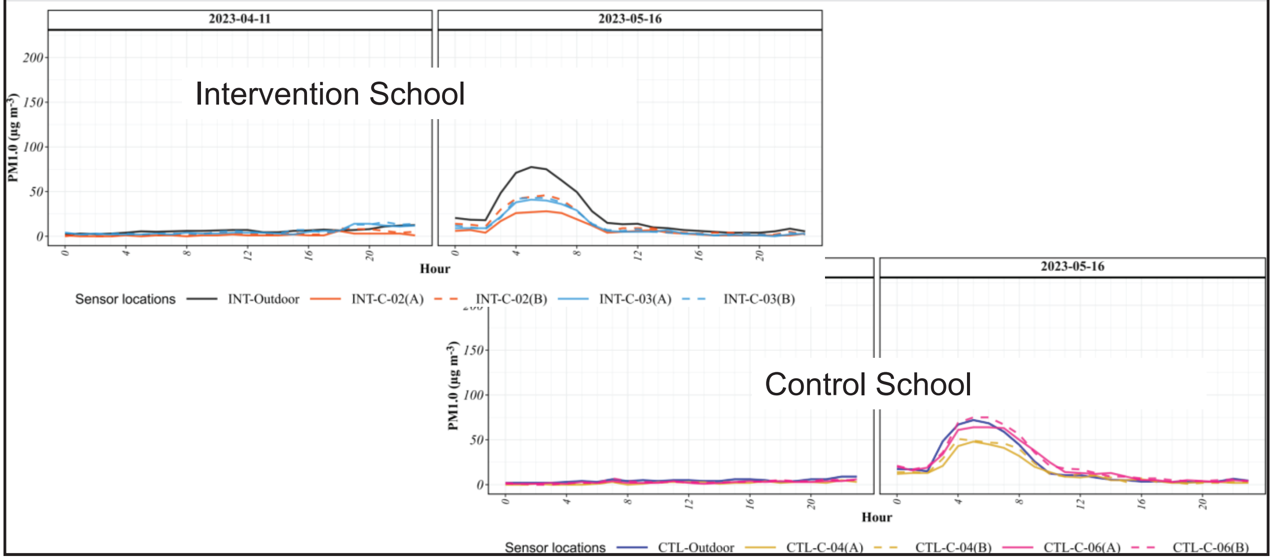


INT-02: exterior walls/windows, 29 students (ages 11 to 12), PAC ON 24/7

INT-03: exterior walls/windows, 20 students (ages 13 to 14), PAC ON 8 AM – 5 PM

12

PAC’s Ability to Reduce Indoor PM1 Concentration



13

PAC’s Ability to Reduce Indoor PM1 Concentration

$$PM_{removal\ efficiency} = 1 - \frac{PM_{indoor}}{PM_{outdoor}}$$

School	Date	PAC (Y/N)	Outdoor PM1 conc (µg/m³)	Indoor PM1 conc (µg/m³)	Outdoor PM2.5 conc (µg/m³)	Indoor PM2.5 conc (µg/m³)	PM1 removal efficiency	PM2.5 removal efficiency
Control	April 11	N	4.53	1.54	6.70	1.70	0.66	0.74
Control	May 16	N	**22.07**	**14.97**	**32.11**	**15.55**	**0.29** ↓	**0.48** ↓

PAC's Ability to Reduce Indoor PM1 and PM 2.5 Concentrations

$$PM_{removal\ efficiency} = 1 - \frac{PM_{indoor}}{PM_{outdoor}}$$

School	Date	PAC (Y/N)	Outdoor PM1 conc (µg/m³)	Indoor PM1 conc (µg/m³)	Outdoor PM2.5 conc (µg/m³)	Indoor PM2.5 conc (µg/m³)	PM1 removal efficiency	PM2.5 removal efficiency
Control	April 11	N	4.53	1.54	6.70	1.70	0.66	0.74
Control	May 16	N	**22.07**	**14.97**	**32.11**	**15.55**	**0.29**	**0.48**
Intervention	April 11	N	6.22	2.16	8.81	2.31	0.65	0.74
Intervention	May 16	Y	**24.65**	**9.26**	**34.07**	**9.69**	**0.61**	**0.70**

PM1 removal efficiency in control school decrease from 0.66 on April 11 to 0.29 on May 16
PM1 removal efficiency in intervention school decrease from 0.65 on April 11 to 0.61 on May 16

15

Observations

- The indoor CO_2 concentrations were dependent on the presence of occupants. The higher the occupant densities, the higher are the CO_2 concentrations.
- The CO_2 concentrations in both schools agreed with the predictions based on occupant characteristics and ASHRAE 62.1 ventilation requirements.
- The outdoor particle sources played the most significant role in deciding the indoor particle concentrations. The presence of exterior walls and windows in a space also affected the indoor particle concentrations.
- The measured PM1 and PM2.5 data with PAC units ON and OFF demonstrates the PAC units in the intervention school were able to remove some of the particles entered indoors.

16

Future Work

Efforts will be made to verify the cost and benefit of air cleaning and ventilation measures on IAQ and occupants' health in these schools:

- Sick days reported in both schools between April and June 2023 and feedbacks from staff and students (pleasant draft, perceived improvement in IAQ, and white noise)
- Long-term comparative tests: respiratory infection peak seasons and stable outdoor PM levels
- Power consumed by PACs
- PAC filter efficiency
- CO_2 decay after occupants leave the buildings
- Building envelope airtightness
- HVAC system's operating schedule and ventilation rate, in-duct filter efficiency
- Provide PAC manufacturer with feedback re. product improvement

17

NRC·CNRC

NRC.CANADA.CA

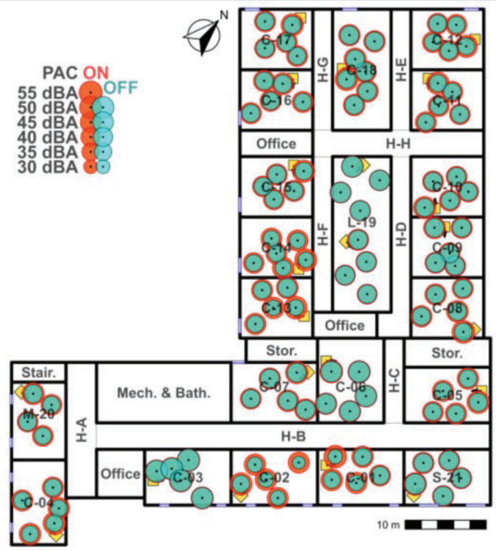
THANK YOU

Grace Liang Zhou, Ph.D.
R&D Director - Building Performance and Quality
Senior Research Officer
Liang.zhou@nrc-cnrc.gc.ca

National Research Council Canada | Conseil national de recherches Canada

Canada

Location of PACs, IAQ Sensors, Sound Level in Intervention School



19

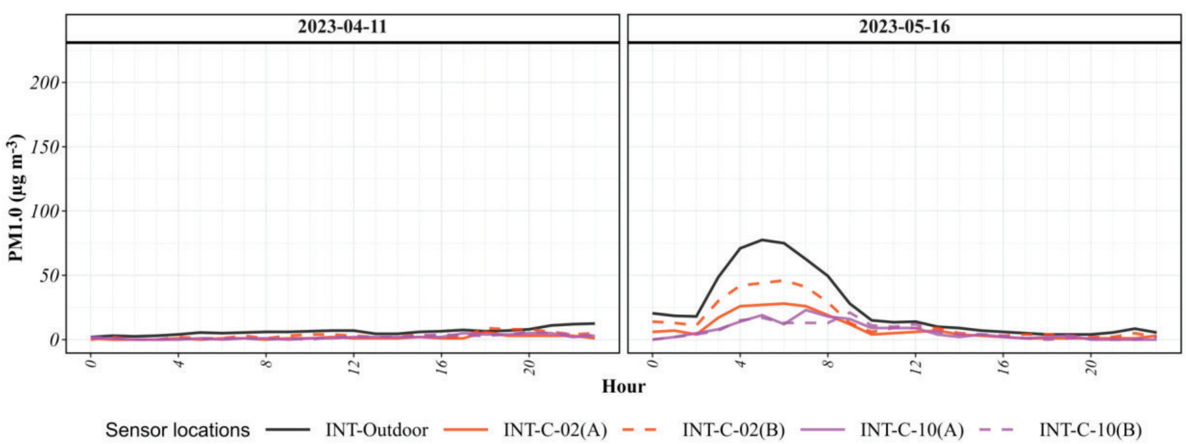
Location of Sensors in Control School

20

Parameters Considered for Data Analysis

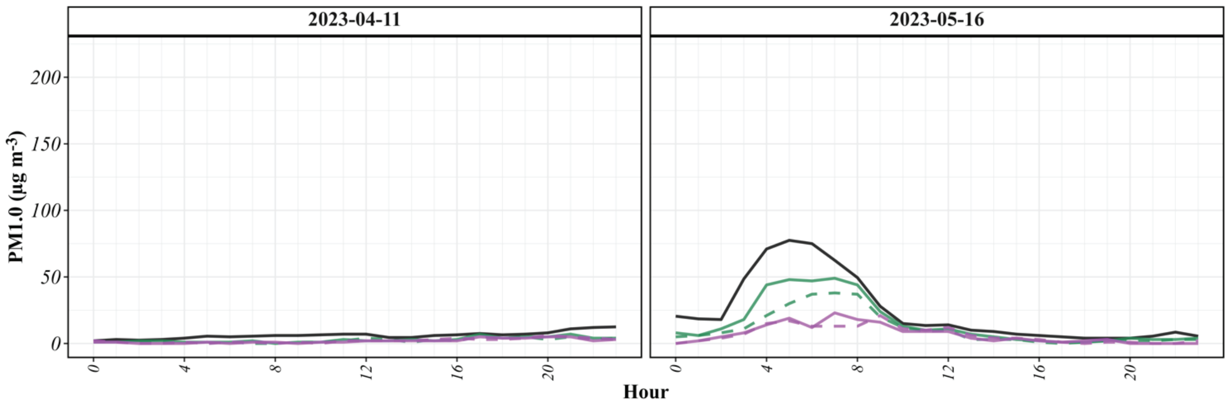
- Day and time: minimize the opportunity for opening window and capture events with high outdoor particle concentrations
- Classroom occupant densities
- Classroom with and without exterior walls and windows: impact of leaks/openings through the building envelope on indoor air quality
- PACs controlled by timers (ON 8 AM – 5 PM) or not
- Define and use an index to minimize the impact of outdoor particle concentration on PAC's particle removal efficiency

Impact of Exterior Walls and Windows on Indoor PM1



INT-C-02: exterior walls/windows, 29 students (ages 11 to 12), PAC ON 24/7
INT-C-10: no exterior walls/windows, 22 students (ages 6 to 7), PAC ON 24/7

Impact of PAC on Indoor PM1 Concentration



INT-C-09: no exterior walls/windows, PAC ON 8 AM – 5 PM (timer)

INT-C-10: no exterior walls/windows, PAC ON 24/7 (no timer)

23

PAC's Ability to Reduce Indoor PM1

- Hourly PM1 data from the intervention and the control schools without PACs: weeks 2-6, hours 0:00-24:00

School and PAC Operation	A. Mean / G. Mean (μg/m³)	Min - Max (μg/m³)
INT NO PAC	1.3 / 0.18	0.0 - 16.0
CTL NO PAC	1.2 / 0.16	0.0 - 20.0

- Hourly PM1 data from the intervention school PACs ON vs. OFF: weeks 7-14, hours 18:00-7:00

INT PAC Operation	A. Mean / G. Mean (μg/m³)	Min - Max (μg/m³)
PACs ON	4.2 / 1.4	0.0 - 106.0
PACs OFF	8.9 / 3.7	0.0 - 101.0

- Hourly PM1 data from the intervention (PACs ON) and the control (PACs OFF) schools : weeks 7-14, hours 0:00-24:00

School and PAC Operation	A. Mean / G. Mean (μg/m³)	Min - Max (μg/m³)
INT PACs ON	4.9 / 1.4	0.0 – 106.0
CTL PACs OFF	10.0 / 4.2 ± 10.3	0.0 – 108.0

24

Critical reflections on indoor-environmental quality constructs

Univ. Prof. Dr. **Ardeshir Mahdavi**
Institute of Building Physics, Services, and Construction
Faculty of Civil Engineering Sciences
Graz University of Technology, Graz, Austria

Assistant Prof. Dr. **Christiane Berger**
Department of Architecture, Design and Media Technology
Aalborg University, Aalborg, Denmark

43rd AIVC -11th TightVent & 9th venticool Conference – October 4-5, 2023 – Aalborg University, Copenhagen, Denmark

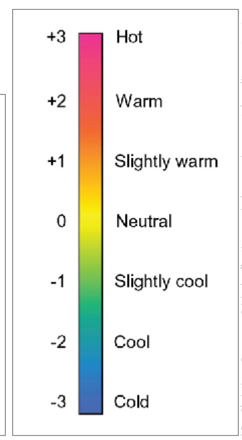
1

Constructs

... hypothetical variables used in experimental research to capture participants' experience of various aspects of IEQ (e.g., thermal comfort).

https://cbe.berkeley.edu/wp-content/uploads/2018/09/ankle-draft-chamber-subjects-768x468.jpg

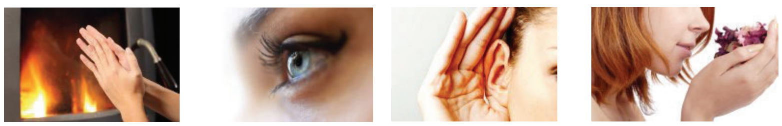
- Independent variables
- Proxies
- Indicators
- Metrics
- ...



Prof. Ardeshir Mahdavi and Dr. Christiane Berger – Critical reflections on indoor-environmental quality constructs

2

Constructs in IEQ research and standardisation

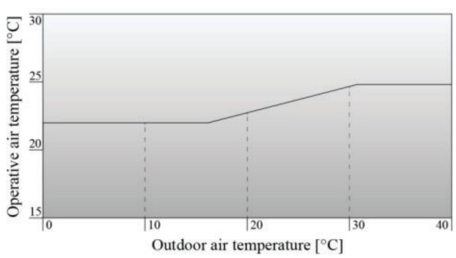


	Thermal	Visual	Auditory	Air Quality
Independent variables	Air and radiant temperatures, water vapor content, air velocity	Illuminance, luminance, contrast, colour temperature	Sound pressure level, reverberation time, frequency (spectrum)	CO_2 and VOC concentration, Air change rate, Age of air
Constructs	Thermal sensation, thermal comfort	Visual comfort, glare rating	Loudness, annoyance	Air freshness

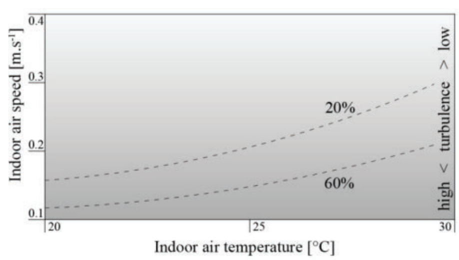
Prof. Ardeshir Mahdavi and Dr. Christiane Berger – Critical reflections on indoor-environmental quality constructs

3

Constructs in IEQ research and standardisation



Operative air temperature and its value as a function of the outdoor air temperature (DIN EN 15251, DIN EN ISO 7730)



Maximum permissible indoor air speed as a function of indoor air temperature for two turbulence intensity levels (DIN EN 15251, DIN EN ISO 7730)

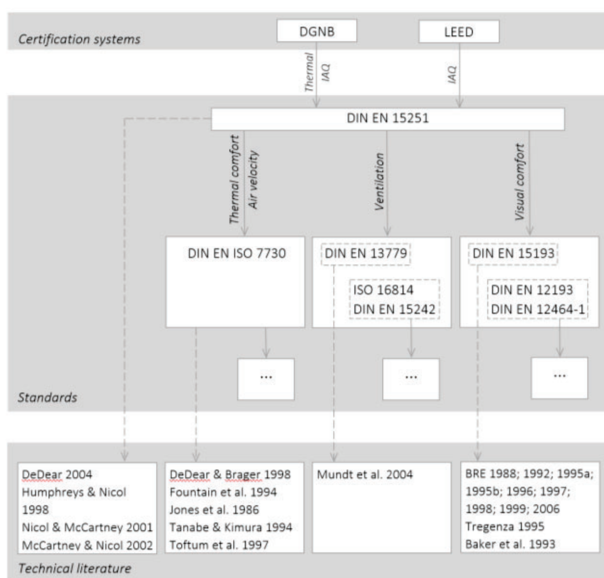
Prof. Ardeshir Mahdavi and Dr. Christiane Berger – Critical reflections on indoor-environmental quality constructs

4

Constructs in IEQ research and standardisation

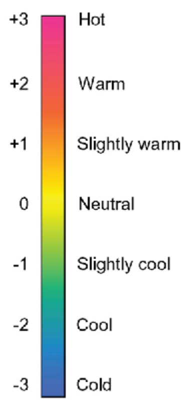
1. Berger, C., Mahdavi, A., et al. (2023). The role of user controls with respect to indoor environmental quality: From evidence to standards. Journal of Building Engineering, 76, 107196. https://doi.org/10.1016/j.jobe.2023.107196
2. Berger, C., Mahdavi, A., et al. (2023). Thermal Conditions in Indoor Environments: Exploring the Reasoning behind Standard-Based Recommendations. *Energies, 16*(4). https://doi.org/https://10.3390/en16041587
3. Berger, C., Mahdavi, A., et al. (2022). Reflections on the Evidentiary Basis of Indoor Air Quality Standards. *Energies, 15*(20). https://doi.org/https://10.3390/en1520772
4. Chinazzo, G., Berger, C., Mahdavi, A. (2022). Quality criteria for multi-domain studies in the indoor environment: Critical review towards research guidelines and recommendations. *BUILDING AND ENVIRONMENT, 226*, 109719. https://doi.org/https://doi.org/10.1016/j.buildenv.2022.109719
5. Mahdavi, A., Cappelletti, F., & Berger, C. (2023). Reflections on the scientific basis of building-related acoustic standards. Journal of Building Engineering, 74, 106847. https://doi.org/https://doi.org/10.1016/j.jobe.2023.106847
6. Mahdavi, A., Berger, C., et al. (2020). Necessary Conditions for Multi-Domain Indoor Environmental Quality Standards. *SUSTAINABILITY, 12*(20). https://doi.org/10.3390/su12208439
7. Schweiker, M., Berger, C., Mahdavi, A. (2020). Review of multi-domain approaches to indoor environmental perception and behaviour. *BUILDING AND ENVIRONMENT*, 106804-106804. https://doi.org/https://doi.org/10.1016/j.buildenv.2020.106804

In pursuit of evidence…



Prof. Ardeshir Mahdavi and Dr. Christiane Berger – Critical reflections on indoor-environmental quality constructs

Multi-domain comfort and behavior studies



"... At times, a **different number of points and different labels** were used, even though the same assessment category was involved. This, as well as the **inconsistent use of dimensions in analogue scales**, disables the comparison of results from different studies and poses a **problem for conducting large-scale meta-analyses**."

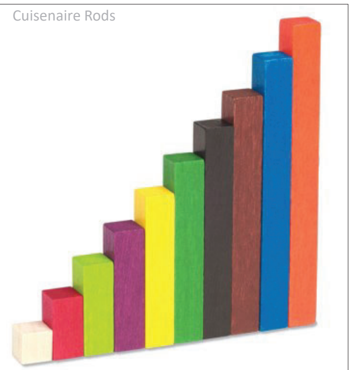
Chinazzo et al. 2022

7

A fundamental conceptual challenge: Two kinds of measurements

- Representational measurements
- Pragmatic measurements

Cuisenaire Rods



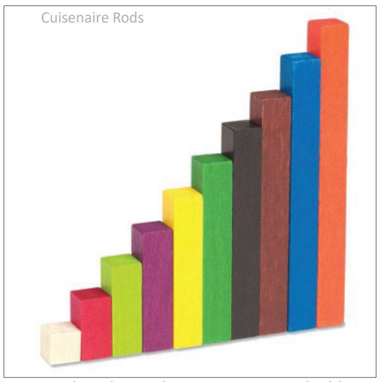
D. J. Hand: End to end concatenation and addition

Bill Hettler 1976

8

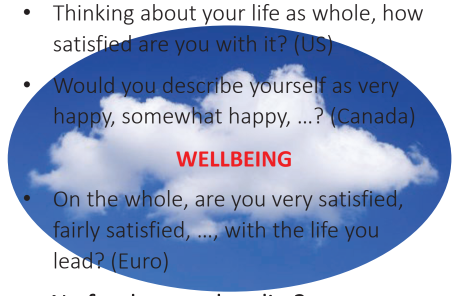
A fundamental conceptual challenge: Two kinds of measurements

- Representational measurements



D. J. Hand: End to end concatenation and addition

- Pragmatic measurements



- Thinking about your life as whole, how satisfied are you with it? (US)
- Would you describe yourself as very happy, somewhat happy, …? (Canada)
- On the whole, are you very satisfied, fairly satisfied, …, with the life you lead? (Euro)

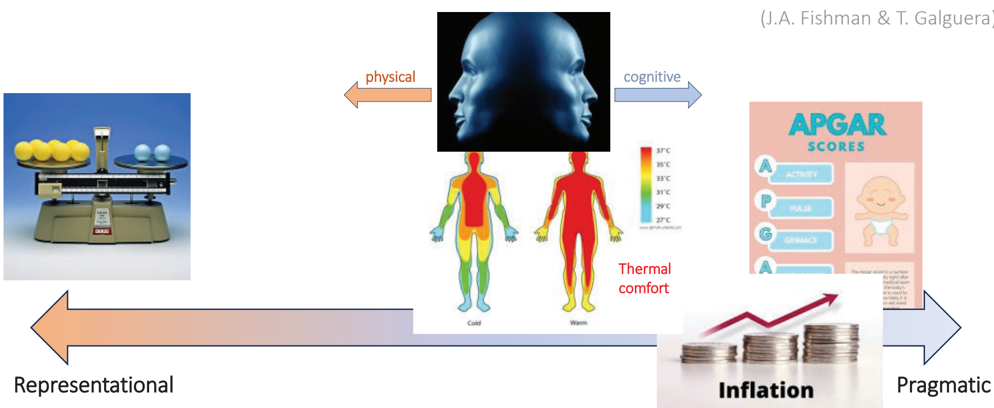
No fundamental reality?

Prof. Ardeshir Mahdavi and Dr. Christiane Berger – Critical reflections on indoor-environmental quality constructs

Measurement validity and reliability

… unless one can be sure that an instrument will produce the same results on different applications, one cannot know whether it measures what it purports to measure.

(J.A. Fishman & T. Galguera)



Prof. Ardeshir Mahdavi and Dr. Christiane Berger – Critical reflections on indoor-environmental quality constructs

Key takeaways

- Consistency, robustness, accuracy of constructs → reproducibility of findings, possibility of cumulative knowledge, dependability of standards.
- To this end, validation procedures for constructs are essential.

Yet:

- Existing IEQ research barely engages in construct validation:
  An ongoing review of 30 recent peer-reviewed publications on multi-domain studies shows that none of them included a construct validation effort!

Constructs validations methods and procedures

- **Cronbach, L. J. (1990). *Essentials of psychological testing* (5th ed.). New York: HarperCollins.**
- **Fischer, J.A., & Hüttermann, H. (2020). PsySafety-Check (PSC** … **cherheit in Teams. *Zusammenstellung sozialwissenschaftlicher Items un***
- Flynn, J.E., Spencer, T.J., Martyniuk, O., & Hendrick, C. (1973 … ng the Effect of Light on Impression and Behavior. *Journal of the Ill*
- **Fowler, F. J., Jr. (1993). *Survey research methods*. Newbury P**
- Mahdavi, A., & Eissa, H. (2002). Subjective Evaluation of Arc … ered Images. *Journal of the Illuminating Engineering Society, 31*(
- Mahdavi, A., & Gurtekin, B. (2004). Generating the design-p … e learning. *Journal of Architectural and Planning Research.*
- **Patten, M.L. (2000). *Understanding research methods* (2nd e**
- **Peterson, R.A. (1999). *Constructing effective questionnaires*. Thousand Oaks: Sage.**

Critical reflections on indoor-environmental quality constructs

Thank you for your attention!

Univ. Prof. Dr. **Ardeshir Mahdavi**
Institute of Building Physics, Services, and Construction
Faculty of Civil Engineering Sciences
Graz University of Technology, Graz, Austria

Assistant Prof. Dr. **Christiane Berger**
Department of Architecture, Design and Media Technology
Aalborg University, Aalborg, Denmark

Ventilation and sleep quality

Pawel Wargocki (pawar@dtu.dk)
Technical University of Denmark, DTU Sustain

43rd AIVC -11th TightVent & 9th venticool Conference
October 4-5, 2023
Aalborg University, Copenhagen, Denmark

ASHRAE research project 1837-RP on "The effects of ventilation in sleeping environments"

- Summary of standards defining bedroom conditions
- Summary of literature on ventilation and sleep quality
- Cross-sectional studies in bedrooms to characterize ventilation conditioms
- Intervention studies in bedrooms

Specific aim

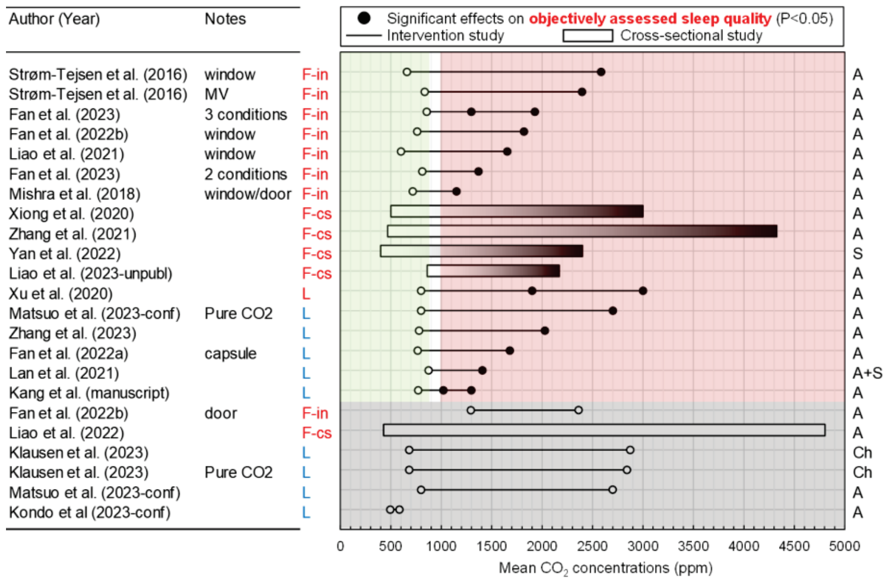
- Amendment to ASHRAE Standard 62.2 " Ventilation and Acceptable Indoor Air Quality in Residential Buildings"

Additional studies (extensions)

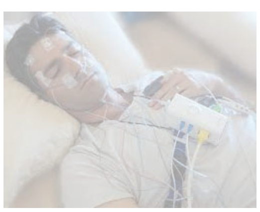
- Survey of bedroom conditions (prior to and after the COVID-19 lockdown)
- Laboratory studies on the effects of ventilation, pure CO_2, temperature and ventilation noise on sleep quality
- Examining bedroom and door opening behavior
- Estimation of CO_2 generation rate for sleeping people (young adults and elderly)
- Estimation of emission rates of bioeffluents from sleeping people using PTR-MS-TOF
- Comparison of performance of different sleep trackers against polysomnograph (PSG)

How much ventilation is needed in bedrooms?

Summary of studies examining the effects of ventilation on sleep quality measured objectively

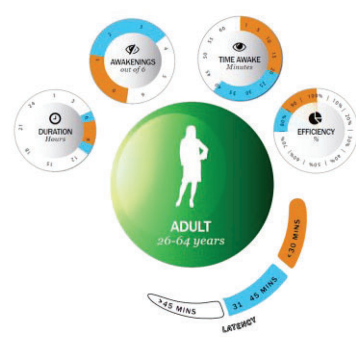


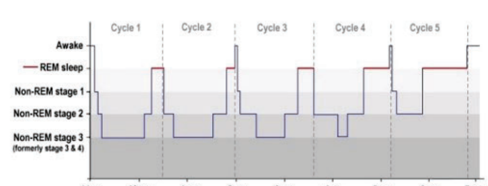
How to objectively measure sleep quality?



Polysomnography

Actigraphy sleep trackers





Source: National Sleep Foundation's sleep quality recommendations (2017)

Study categories

Field measurements
- Actual bedroom

Intervention study
- with window/door opening
- with mechanical ventilation system

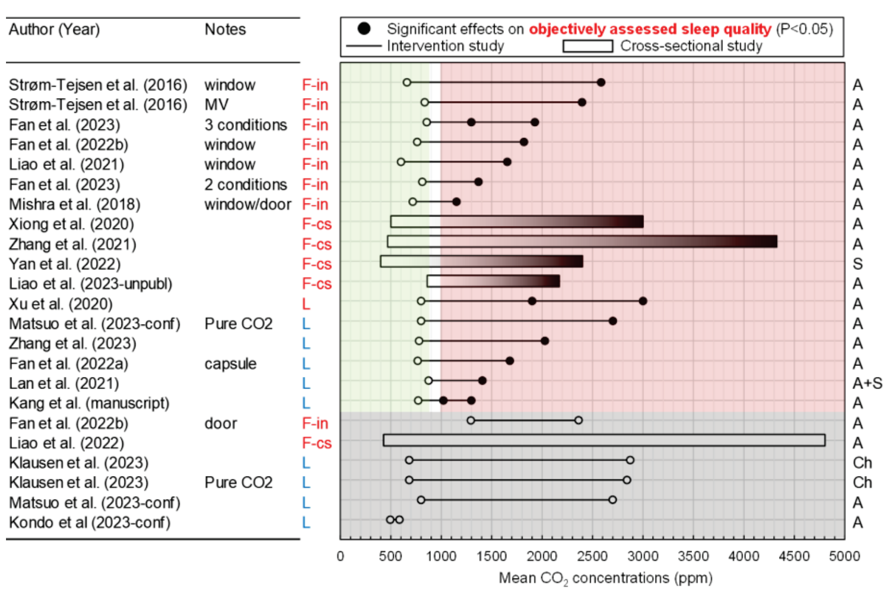
Cross-sectional study

Laboratory experiments
- Climate chamber
- Sleeping laboratory
- Prepared room (dormitory, hotel)

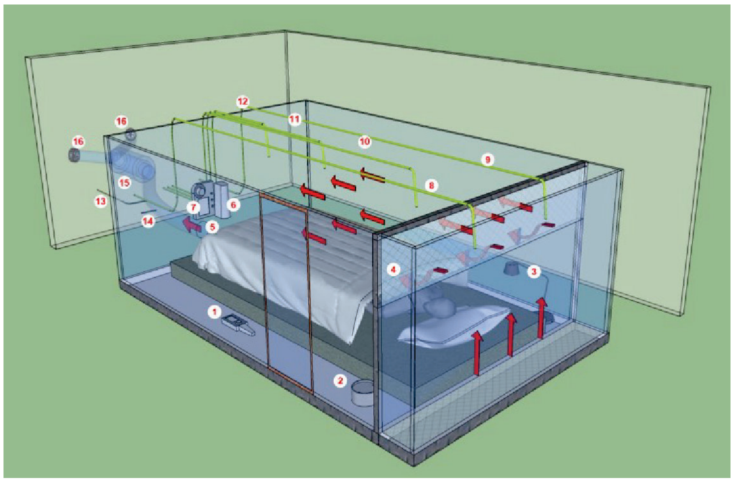
Intervention study
- Focusing on bioeffluent effect
- Focusing on pure CO_2 effect

We use …
- **F-in** : **field intervention study**
- **F-cr** : **field cross-sectional study**
- **L** : **lab study**

Summary of studies examining the effects of ventilation on sleep quality measured objectively

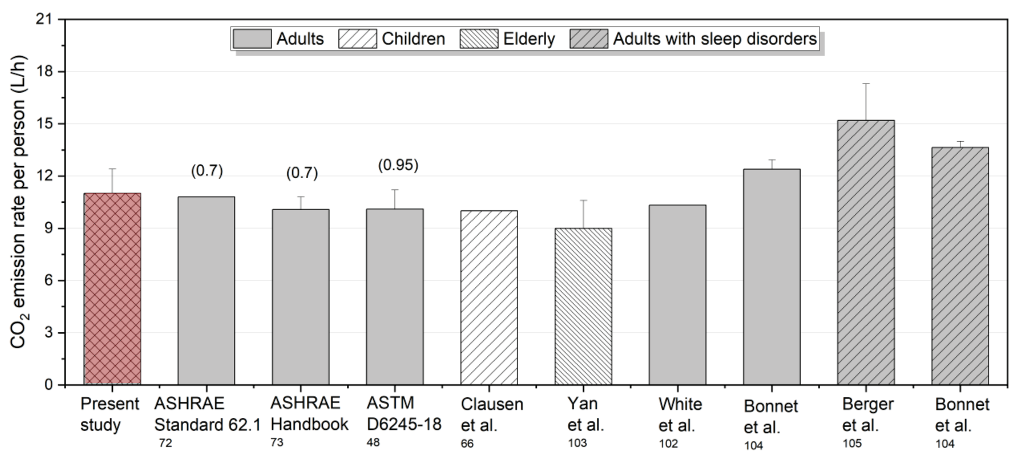


Estimating the emission rate of CO_2



9

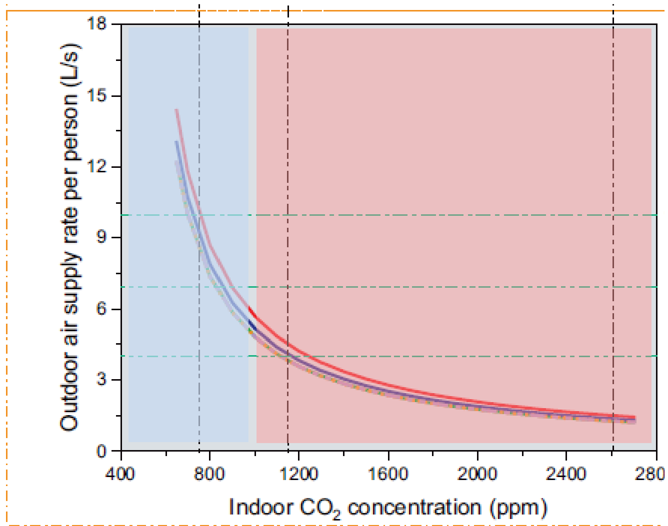
CO_2 emission rates



10

Implications

- Current evidence suggest the rates above 10 L/sp (CO_2 levels below 750-800 ppm) will ensure undisturbed sleep
- This would correspond to about 1 h^{-1}



Bedroom ventilation, standards and measurements: the review

- Wide range of ventilation rates measured in bedrooms using different methods; mostly carbon dioxide concentration and air change rates were measured.
- Reported mean CO2 concentrations ranged from 428 to 2585 ppm.
- Bedrooms with NV during heating season have highest CO2 levels and highest temperatures during cooling season
- Reported mean mean air change rates from 0.2 to 4.9 h^{-1} .
- The lowest observed during heating season and in the naturally ventilated bedrooms
- Most existing ventilation standards do not prescribe specific ventilation requirements for bedrooms - ventilation in bedrooms is merely the result of ventilation requirements for the entire dwelling

Building and Environment 184 (2020) 107229

Contents lists available at ScienceDirect

Building and Environment

journal homepage: http://www.elsevier.com/locate/buildenv

Bedroom ventilation: Review of existing evidence and current standards

Chandra Sekhar [a,b], Mizuho Akimoto [b,c], Xiaojun Fan [b], Mariya Bivolarova [b], Chenxi Liao [b,d], Li Lan [e], Pawel Wargocki [b,*]

[a] Department of Building, School of Design and Environment, National University of Singapore, Singapore
[b] International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Denmark
[c] Department of Architecture, Waseda University, Japan
[d] Department of Architecture and Urban Planning, Ghent University, Belgium
[e] Department of Architecture, School of Design, Shanghai Jiao Tong University, China

ARTICLE INFO

Keywords:
Dwellings
Bedrooms
Ventilation
CO_2
Air exchange rate
Sleep quality
Standards

ABSTRACT

Sleep is essential for our health and well-being. Some research suggests that air quality influences sleep quality in bedrooms, but the evidence is limited. Research, until now, has focused on how indoor air quality affects health, comfort, and cognitive performance during waking hours. Less information is available on the levels of indoor air quality and ventilation in bedrooms, or on their consequences for sleep quality and next-day performance. This paper addresses the former by reviewing research published in peer-reviewed journals in this millennium. Bedroom ventilation has been chosen as a specific focus of this review paper, which also includes a review of selected international standards for bedroom ventilation. Arising out of this review and a comparison of field data with CO_2 and ventilation benchmarks from widely adopted international standards, an attempt is made to generalize the level of bedroom ventilation that exists in practice in residential dwellings and apartments across different seasons and different parts of the world. Based on a limited number of studies dealing with the impact of bedroom ventilation on sleep quality, an attempt is also made to associate measured field data with its potential impact on sleep quality.

RESIDENTIAL VENTILATION REQUIREMENTS DENMARK

- BR18: 0.3 L/sm^2
- DS447 (2021): 0.42 L/sm^2 (Cat. II)
- Typical Danish bedrooms (Bolius, 2020): 5-20 m^2 (85%), of which 9-16 m^2 (61%); average 13.4 m^2; average house size is 109 m^2 with 2 people
- Outdoor air supply rate per bedroom from 2.7 to 4.8 L/s (BR) or 3.8 to 6.7 L/s (DS447, 2021)
- If 0.5 h^{-1}, then (if height 2.5 m) 3.1 to 5.6 L/s

RESIDENTIAL VENTILATION REQUIREMENTS NORDIC COUNTRIES

- Somewhat unclear and inconsistent
- Around 5 L/s per bedroom
- Except Norway 7.2 L/s per person in bedroom
- Estonia defines 10 L/s per bedroom in major renovations
- Finland defines 4-6 L/s per person for the entire dwelling (or bedroom?), unclear
- According to the present data, ventilation rate shall be >6 L/s per person (<1,000 ppm CO_2)

BEDROOM VENTILATION REQUIREMENTS US STANDARD 62.2 (2022)

Floor Area, m^2	Bedrooms 1	2	3	4	5
<47	14	18	21	25	28
47 to 93	21	24	28	31	35
94 to 139	28	31	35	38	42
140 to 186	35	38	42	45	49
187 to 232	42	45	49	52	56
233 to 279	49	52	56	59	63
280 to 325	56	59	63	66	70
326 to 372	63	66	70	73	77
373 to 418	70	73	77	80	84
419 to 465	77	80	84	87	91

US average house: 2273 sq ft. (211 m^2)
(median: 2500 sq ft.=232 m^2)
Wet-rooms ca. 100 sq ft
US average bedroom: 132 sq ft. (12 m^2)
% bedroom floor size (no wet-rooms): 6%

Floor area (m^2)	Bedrooms (L/s/bedroom) 1	2	3	4	5
<47	0,8	1,0	1,2	1,5	1,6
47–93	1,2	1,4	1,6	1,8	2,0
94–139	1,6	1,8	2,0	2,2	2,4
140–186	2,0	2,2	2,4	2,6	2,8
187–232	2,4	2,6	2,8	3,0	3,2
233–279	2,8	3,0	3,2	3,4	3,7
280–325	3,2	3,4	3,7	3,8	4,1
326–372	3,7	3,8	4,1	4,2	4,5
373–418	4,1	4,2	4,5	4,6	4,9
419–465	4,5	4,6	4,9	5,0	5,3

RESIDENTIAL VENTILATION REQUIREMENTS CHINA

- GB50736 (2012), design code: mimimum ACH (h^{-1}) depending on floor size in residential building

Fp - per capita living space (floor area per person)	ACH	L/s
Fp≤10m²	0.70	<4.9
10m²<Fp≤20m²	0.60	4.2-8.3
20m²<Fp≤50m²	0.50	6.9-17.4
Fp>50m²	0.45	>15.6

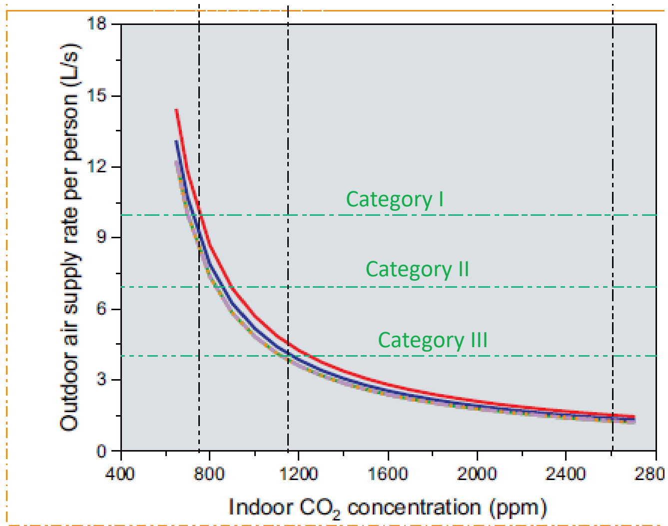
- GB/T 18883 (2022), air quality standard: 30 m^3/hp (8.3 L/sp) and CO_2≤1,000 ppm
- JGJ 134 (2010), design std. or energy efficiency for hot summer and cold winter regions: 1.0 h^{-1} (heating or air conditioning)
- JGJ26 (2018), design std. for energy efficiency in severe cold and hot zones: 0.5 h^{-1}

BEDROOM VENTILATION REQUIREMENTS EUROPEAN STANDARD EN16798-2020

Category	Design ΔCO_2 concentration for living rooms (ppm above outdoors)	Design ΔCO_2 concentration for bedrooms (ppm above outdoors)
I	550	380
II	800	550
III	1 350	950
IV	1 350	950

NOTE 1 The above values in Table B.12 correspond to the equilibrium concentration when the air flow rate is 4, 7, 10 l/s per person for cat. I, II, III respectively and the CO_2 emission is 20 l /h per person and 13,6 l/h per person for living rooms and bedrooms respectively.

NOTE 2 For a 10 m² room (room height 2,5 m, 25 m³) 4; 7 and 10 l/s per person correspond, with two persons in the room, to an air change rate of 1,2; 2,0 and 2,9 ACH.



Take-away messages

- Changes to standards may be necessary
- Only Cat I (EN 16798) may provide sufficient ventilation in bedrooms
- Air change rates may need to be doubled

- Solution: Intelligent air distribution in housing is needed (following occupants)

Acknowledgments (WC team)

Mizuho Akimoto Ph.D. candidate	Mariya P. Bivolarova Asst. Prof.	Xiaojun Fan Ph.D. candidate	Chao Guo Ph.D. candidate	Negin Hosseinpour M.Sc. student	Kazuki Kuga Asst. Prof.	Mengyuan Kang M.Sc. student

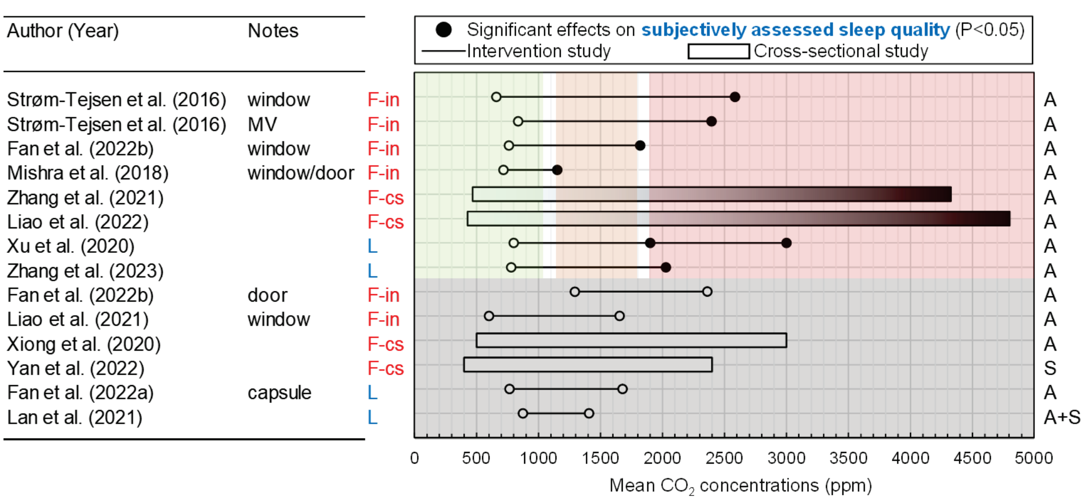
Li Lan Prof.	Zhiwei Lian Prof.	Jelle Laverge Assoc. Prof.	Chenxi Liao Postdoc.	Kazuya Matsuo M.Sc. student	Anna Mainka Asst. Prof.	Chandra Sekhar Prof.

Huiqi Shao Ph.D.	Yuxiang Sun M.Sc. student	Mitsuharu Sakamoto M.Sc. student	Haodong Zhang M.Sc. student	Pawel Wargocki Assoc. Prof.	Xinbo Xu Ph.D. candidate	Yan Yan Ph.D. candidate

QUESTIONS......

21

Summary of studies examining the effects of ventilation on sleep quality measured subjectively



22

How to subjectively measure sleep quality?

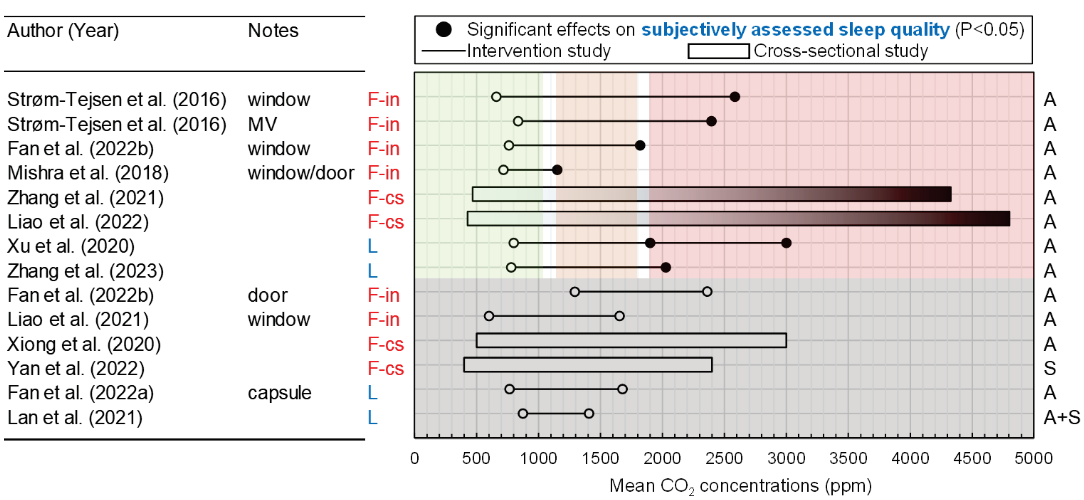
The Groningen Sleep Quality Scale (GSQS)

- Scores range from 0 to 14
- Scores between 0 and 2 indicate normal, refreshing sleep
- Scores ≥6 indicate disturbed sleep

I had a deep sleep last night	True	False
I feel like I slept poorly last night	True	False
It took me more than half an hour to fall asleep last night	True	False
I felt tired after waking up this morning	True	False
I woke up several times last night	True	False
I feel like I didn't get enough sleep last night	True	False
I got up in the middle of the night	True	False
I felt rested after waking up this morning	True	False
I feel like I only had a couple hours of sleep last night	True	False
I feel I slept well last night	True	False
I didn't sleep a wink last night	True	False
I didn't have any trouble falling asleep last night	True	False
After I woke up last night, I had trouble falling asleep again	True	False
I tossed and turned all night last night	True	False
I didn't get more than 5 hours sleep last night	True	False

23

Summary of studies examining the effects of ventilation on sleep quality measured <u>subjectively</u>



24

RESIDENTIAL VENTILATION REQUIREMENTS SWEDEN

- 0.35 L/sm^2 (w/people) and 0.1 L/sm^2 (w/o people): code requirement
- 0.35 L/sm^2 and 0.5 h^{-1}: public health
- Typical bedroom of 13.4 m^2
- Bedroom ventilation will be 4.7 L/s bedroom (based on floor area or air change rate)

RESIDENTIAL VENTILATION REQUIREMENTS NORWAY

- 1.2 m^3/hm^2 (w/people) and 0.7 m^3/hm^2 (w/o people)
- 26 m^3/h per person in bedroom
- Typical bedroom of 13.4 m^2
- Bedroom ventilation will be 4.5 L/s bedroom (based on floor area) or 7.2 L/s per person

RESIDENTIAL VENTILATION REQUIREMENTS FINLAND

- 6 L/sp in new buildings (also 0.35 L/sm^2); also 18 L/s per dwelling and 12 L/s per bedroom
- 6 L/sp in existing buildings but allowed to go to 4 L/sp
- Typical bedroom of 13.4 m^2
- Bedroom ventilation will be 6 L/s per person or 4.7 L/s per bedroom (based on floor area)

27

RESIDENTIAL VENTILATION REQUIREMENTS ESTONIA

- 0.42 L/sm^2 (0.6 h^{-1}) and 7 L/s per person in new residential buildings (EVS-EN 16798)
- 0.42 L/sm^2 for single family and 0.50 L/sm^2 for multifamily apartment buildings (energy performance)
- 10 L/s per living room and bedrooms (major renovations) and estracts 10 L/s toilet, 15 L/s (10 L/s) bathroom and 8 L/s (6 L/s) kitchens

0.42 L/sm^2

- Typical bedroom of 13.4 m^2
- Bedroom ventilation will be 7 L/s per person or 5.6 L/s per bedroom (based on floor area) or 10 L/s per bedroom (major renovation)

28

BEDROOM VENTILATION REQUIREMENTS EUROPEAN STANDARD EN16798-2020

Category	Total ventilation including air infiltration (1)		Supply air flow per. person (2)	Supply air flow based on perceived IAQ for adapted persons (3)	
	l/s,m²	ach	l/s [a] per	q_P l/s*per	q_B l/s,m²
I	0,49	0,7	10	3,5	0,25
II	0,42	0,6	7	2,5	0,15
III	0,35	0,5	4	1,5	0,1
IV	0,23	0,4			

[a] Supply air flow for Method 3 is based on Formula (1) from 6.3.2.2.

Category	Design ΔCO_2 concentration for living rooms (ppm above outdoors)	Design ΔCO_2 concentration for bedrooms (ppm above outdoors)
I	550	380
II	800	550
III	1 350	950
IV	1 350	950

NOTE 1 The above values in Table B.12 correspond to the equilibrium concentration when the air flow rate is 4, 7, 10 l/s per person for cat. I, II, III respectively and the CO_2 emission is 20 l /h per person and 13,6 l/h per person for living rooms and bedrooms respectively.

NOTE 2 For a 10 m² room (room height 2,5 m, 25 m³) 4; 7 and 10 l/s per person correspond, with two persons in the room, to an air change rate of 1,2; 2,0 and 2,9 ACH.

Number of main rooms in the dwelling	Design extract air flow rates in l/s				
	Kitchen	Bathroom or shower with or without toilets	Other wet room	Toilets	
				Single in dwelling	Multiple (2 or more in dwelling)
1	20	10	10	10	10
2	25	10	10	10	10
3	30	15	10	10	10
4	35	15	10	15	10
5 and more	40	15	10	15	10

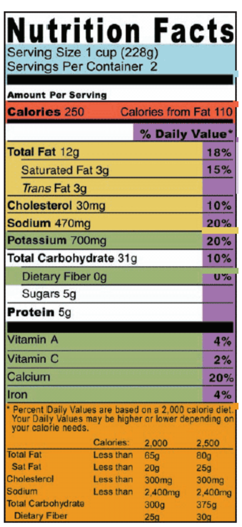
Category	Airflow rates defined in Table B.13 multiplied by
I	1,4
II	1
III	0,7
IV	0,5

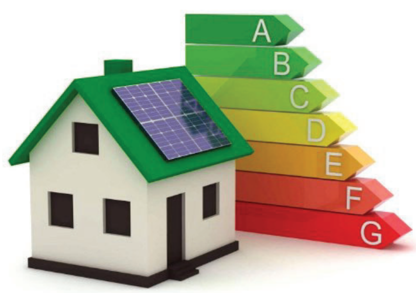
Applicability and sensitivity of the TAIL rating scheme using data from the French national school survey

Pawel Wargocki
pawar@dtu.dk

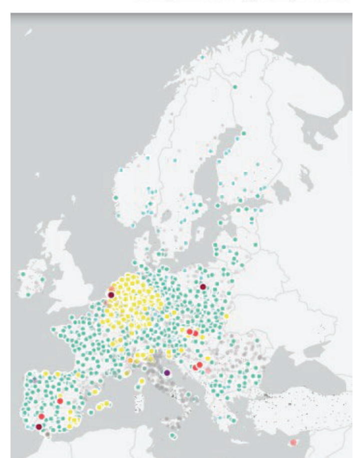
43rd AIVC -11th TightVent & 9th Venticool Conference
October 4-5, 2023
Aalborg University, Copenhagen, Denmark

NO METHOD FOR LABELING INDOOR ENVIRONMENTAL QUALITY





European Air Quality Index



RATING SCHEMES PROVIDE MONITORING AND DOCUMENTATION OF COMPLIANCE

- Useful data for all building stakeholders and additional incentives for improvement of IEQ
- Create benchmark, reference, building data-base
- Monitor performance – compliance and maintenance
- Input to sustainable investments, and technological advancements
- Input to control and AI
- Input to energy simulation and reduce performance gap
- Input to economic calculations
- Demonstrate invisible - occupants feel secure (no risks)
- Raising awareness

3

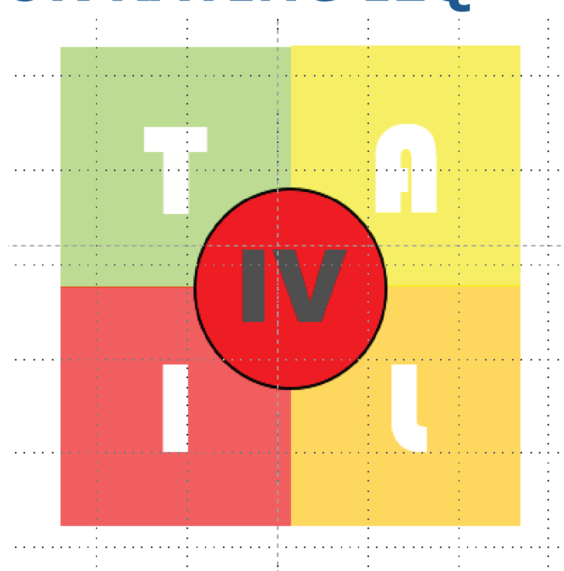
A TAIL SCHEME FOR RATING IEQ

Four components:

- **T**hermal environment
- **A**coustic environment
- **I**ndoor air quality
- **L**ight – Luminous (visual) environment

Overall IEQ:

- I II III IV



Source: Wargocki et al. (2020)

4

WHY IS CLASSIFICATION OF A WIDER BENEFITS THAN ENERGY NECESSARY?

1) To guarantee that IEQ is not degraded during renovation to satisfy the EPBD mandate.
2) To document any improvements in IEQ after renovation.
3) To estimate potential additional benefits from renovation including benefits for health and well-being, as well as the financial benefits from improved productivity and increased value of a building on a market.

Source: EU ALDREN Project

TWELVE IEQ PARAMETERS in TAIL

	IEQ parameter	Measured	Modelled	Visual inspection
T	Indoor temperature (°C)	×		
A	Noise level (dB(A))	×		
I	CO_2 (ppm)	×		
	Ventilation rate (L/s)	×		
	Formaldehyde (µg/m³)	×		
	Benzene (µg/m³)	×		
	$PM_{2.5}$ (µg/m³)	×		
	Radon (Bq/m³)	×		
	Indoor air relative humidity (%)	×		
	Visible mold (cm²)			×
L	Daylight factor (%)		×	
	Illuminance (lux)	×		

RANGES OF PARAMETERS INCLUDED IN TAIL: IAQ

Quality of indoor air quality (I)	Green	Yellow	Orange	Red
Carbon dioxide (concentration above outdoors)[1,2]	≤550 ppm	≤800 ppm	≤1350 ppm	If other quality levels cannot be achieved
Ventilation rate[3,7]	≥(10 L/s/p + 2.0 L/s/m²floor)	≥(7 L/s/p + 1.4 L/s/m²floor) and <(10 L/s/p + 2.0 L/s/m²floor)	≥(4 L/s/p + 0.8 L/s/m²floor) and <(7 L/s/p + 1.4 L/s/m²floor)	If other quality levels cannot be achieved
Relative humidity offices[2,4] hotel rooms[2,4,5]	≥30%≤50%≥30% and ≤50%	≥25%≤60%≥25% and ≤60%	≥20%≤70%≥20% and ≤60%	If other quality levels cannot be achieved
Visible mold[6,7]	No visible mould	Minor moisture damage, minor areas with visible mould (<400 cm²)	Damaged interior structural component, larger areas with visible mould (<2500 cm²)	Large areas with visible mould (≥2500 cm²)
Benzene[7]	<2 μg/m³	≥2 μg/m³	no criteria	≥5 μg/m³
Formaldehyde[7]	<30 μg/m³	≥30 μg/m³	no criteria	≥100 μg/m³
Particles $PM_{2.5}$ (gravimetric)[7]	<10 μg/m³	≥10 μg/m³	no criteria	≥25 μg/m³
Particles $PM_{2.5}$ (optical)[7]	<10 μg/m³	≥10 μg/m³	no criteria	≥25 μg/m³
Radon[7,8]	<100 Bq/m³	≥100 Bq/m³	no criteria	≥300 Bq/m³

7

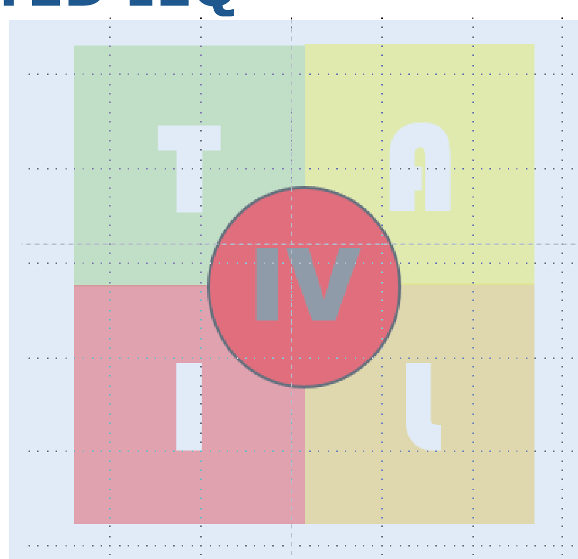
PredicTAIL, the method for rating SIMULATED IEQ

Four components:

- **T**hermal environment
- **A**coustic environment
- **I**ndoor air quality
- **L**ight – Luminous (visual) environment

Overall IEQ:

- I II III IV



Source: Wei et al. (2021)

8

Energy & Buildings 244 (2021) 111029

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enb

TAIL, a new scheme for rating indoor environmental quality in offices and hotels undergoing deep energy renovation (EU ALDREN project)

Pawel Wargocki [a,*], Wenjuan Wei [b], Jana Bendžalová [e], Carlos Espigares-Correa [d], Christophe Gerard [f], Olivier Greslou [b], Mathieu Rivallain [b], Marta Maria Sesana [c], Bjarne W. Olesen [a], Johann Zirngibl [b], Corinne Mandin [b]

[a] International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark (DTU), Denmark
[b] University of Paris-Est, Scientific and Technical Centre for Building (CSTB), Health and Comfort Department, French Indoor Air Quality Observatory (OQAI), France
[c] Politecnico di Milano, Polo Territoriale di Lecco, Italy
[d] Valencia Institute of Building (IVE), Spain
[e] Environment and Building Energy Efficiency (ENBEE), Slovakia
[f] Certivea, Scientific and Technical Direction, France

ARTICLE INFO

Article history:
Received 14 February 2021
Revised 7 April 2021
Accepted 13 April 2021
Available online 19 April 2021

Keywords:
Indoor environmental quality
Measurements
Assessment scheme
Energy renovation
Public buildings

ABSTRACT

To avoid health risks and discomfort, the European Energy Performance for Building Directive (EPBD) mandates that "Member States should support energy performance upgrades of existing buildings that contribute to achieving a healthy indoor environment." There is, however, no widely accepted method for rating the overall level of indoor environmental quality (IEQ), although several different approaches are proposed by standards, guidelines, and certification schemes. To fill this void, a new classification rating scheme called TAIL was developed to rate IEQ in offices and hotels undergoing deep energy renovation during their normal use; the scheme is a part of the energy certification method developed by the EU ALDREN project. The TAIL scheme standardizes rating of the quality of the thermal (T) environment, acoustic (A) environment, indoor air (I), and luminous (L) environment, and by using these ratings, it provides a rating of the overall level of IEQ. Twelve parameters are rated by measurements, modelling, and observation to provide the input to the overall rating of IEQ. Their quality levels are determined primarily using Standard EN-16798-1 and World Health Organization (WHO) air quality guidelines and are expressed by colours and Roman numerals to improve communication. The TAIL rating was shown to discriminate IEQ levels when its feasibility was examined in eleven buildings across Europe to provide support for its applicability and input for further modifications. Opportunities for using the scheme in other types of buildings and for its further development and application are discussed.

1. Introduction

Several policies and actions have been put forward by the European Union (EU) to mitigate and reduce the impact of climate change. One such action is the modernization and renovation of the European building stock, which is responsible for 40% of energy use and 36% of carbon dioxide (CO_2) emissions [14]. The European Commission created instruments to initiate changes in how buildings are constructed, operated, and maintained to achieve significant reductions in energy use. The framework was established by the Energy Performance of Building Directive (EPBD), which was launched in 2003 [13], re-cast in 2010 [14], and amended in 2018 [10]. The main purpose of this Directive is to promote improvements in the energy performance of buildings. This applies both to new construction and existing buildings, of which 25% are commercial buildings, 75% are considered to be inefficient, and about 35% are at least 50 years old.

Despite these high ambitions and good intentions, the implementation of EPBD failed somewhat concerning renovation of the existing building stock. Renovation rates that followed EPBD recommendations have not exceeded 1% to 2% [49], although it is estimated that renovation accounts for 57% of all construction activity, and many renovations do not reach the full amount of energy savings that could be achieved [41]. Renovation rates following EPBD recommendations should reach at least 3% to guarantee that minimum energy reduction goals will be met [41]. One reason for this shortfall could be that renovations, even those leading to reductions in energy

* Corresponding author.
E-mail address: paw@byg.dtu.dk (P. Wargocki).

https://doi.org/10.1016/j.enbuild.2021.111029

Energy & Buildings 258 (2022) 111839

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enb

PredicTAIL, a prediction method for indoor environmental quality in buildings undergoing deep energy renovation based on the TAIL rating scheme

Wenjuan Wei [a,*], Pawel Wargocki [b], Yao Ke [b], Simon Bailhache [a], Thierno Diallo [a], Samuel Carré [a], Pascal Ducruet [a], Marta Maria Sesana [c], Graziano Salvalai [c], Carlos Espigares-Correa [d], Olivier Greslou [a], Johann Zirngibl [a], Corinne Mandin [a]

[a] University of Paris-Est, Scientific and Technical Centre for Building (CSTB), 84 Avenue Jean Jaurès, Champs sur Marne, 77447 Marne la Vallée Cedex 2, France
[b] International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Nils Koppels Alle, Building 402, DK-2800 Kongens Lyngby, Denmark
[c] Politecnico di Milano, ABC Department, via Ponzio 31, 20133, Milan, Italy
[d] Valencia Institute of Building (IVE), Campus de Vera, Vera Road, 46022 Valencia, Spain

ARTICLE INFO

Article history:
Received 20 August 2021
Revised 29 October 2021
Accepted 5 January 2022
Available online 10 January 2022

Keywords:
IEQ
IAQ
Temperature
Modeling
Renovation design
Indicator

ABSTRACT

The recently developed TAIL rating scheme enables assessment of the changes in the indoor environmental quality (IEQ) associated with a building's deep energy renovation (DER) and classification of the resulting quality levels of the thermal (T), acoustic (A), and luminous (visual) (L) environments and indoor air quality (I). Since the TAIL rating is primarily based on measurements, it cannot be determined prior to renovation operations to help design the IEQ. To fill this gap, the PredicTAIL method was developed in the present study to predict the changes in ten of the twelve TAIL parameters as a result of DER. These parameters are indoor air temperature, relative humidity, sound pressure level, daylight factor, illuminance, and concentrations of carbon dioxide, formaldehyde, benzene, radon, and $PM_{2.5}$; no prediction is made for ventilation rate or mold. To examine the feasibility of the PredicTAIL method and the sensitivity of the existing models for quantifying changes in the TAIL parameters corresponding to different renovation strategies, simulations were performed in a hotel and an office building using TRNSYS, IDA ICE, ACOUBAT, MATHIS-QAI, and PHANIE. These modeling tools were first benchmarked against the TAIL parameters measured in the buildings before renovation. Once the agreement between measurements and modeling was considered acceptable, four pragmatic renovation scenarios were applied, and their impact on the IEQ parameters was quantitatively modeled. The simulations showed that the quality levels of the IEQ parameters were improved or unchanged for some parameters but degraded for other parameters after DER. The changes in the IEQ parameters and the TAIL rating depended on the renovation scenarios, suggesting that the PredicTAIL method is sufficiently sensitive to guide renovation design.

1. Introduction

The European Union (EU) put forward a series of directives aimed at developing a sustainable, competitive, secure, and decarbonized energy system, providing objectives for reducing energy consumption by 20% by 2020 and at least 40% by 2030 compared with that in 1990 [1–4]. Given that almost 50% of the EU's final energy consumption is used for heating and cooling, 80% of which is used in buildings [1], performing deep energy renovation (DER) to improve buildings' energy efficiency is a promising way to achieve the EU's energy and climate goals. However, improved insulation may impose risks of higher indoor air humidity, higher indoor pollutant concentrations and overheating, and installing a heating, ventilation and air conditioning (HVAC) system may compromise the indoor acoustic environment [5]. To account for the influence of DER on the indoor environmental quality (IEQ), the latest amendment of the EU Directive on the energy performance of buildings states that "the energy needs for space heating, space cooling, domestic hot water, ventilation, lighting, and other technical building systems shall be calculated in order to optimize health,

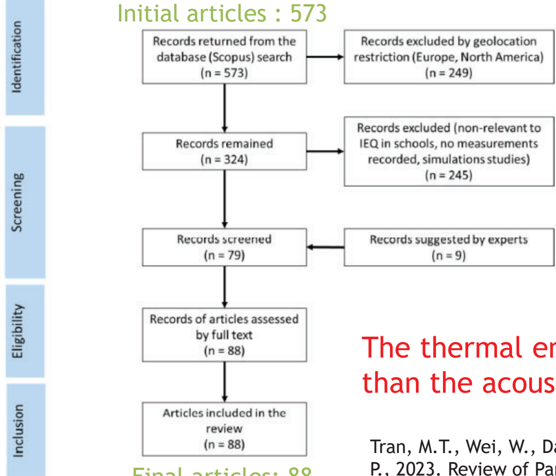
* Corresponding author.
E-mail address: wenjuan.wei@cstb.fr (W. Wei).

https://doi.org/10.1016/j.enbuild.2022.111839

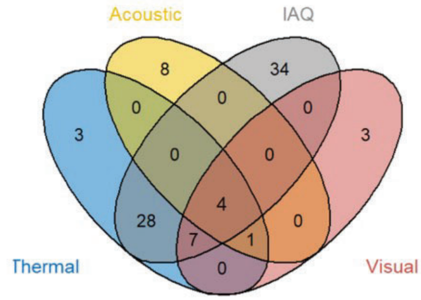
WHAT ABOUT SCHOOLS?

WHAT PARAMETERS HAVE BEEN FREQUENTLY MEASURED IN CLASSROOMS?

Initial articles : 573



Final articles: 88



The thermal environment and IAQ are assessed more frequently than the acoustic and visual environments in schools.

Tran, M.T., Wei, W., Dassonville, C., Martinsons, C., Ducruet, P., Mandin, C., Héquet, V., Wargocki, P., 2023. Review of Parameters Measured to Characterize Classrooms' Indoor Environmental Quality. *Buildings* 2023, *13*(2), 433; https://doi.org/10.3390/buildings13020433

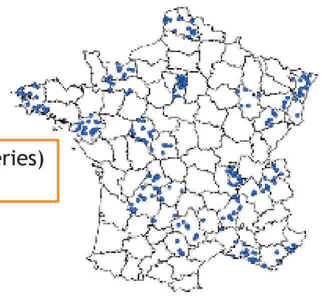
Parameters defining TAIL components for schools

	IEQ parameter	Measured	Modelled	Visual inspection
T	Indoor temperature (°C)	×		
A	Noise level (dB(A))	×		
	Reverberation time (s)	×		
I	CO_2 (ppm)	×		
	Ventilation rate (L/s)	×		
	Formaldehyde (µg/m^3)	×		
	Benzene (µg/m^3)	×		
	$PM_{2.5}$ (µg/m^3)	×		
	Radon (Bq/m^3)	×		
	Indoor air relative humidity (%)	×		
	Visible mold (cm^2)			×
	Nitrogen dioxide (µg/m^3)	×		
L	Daylight factor (%)		×	
	Illuminance (lux)	×		

NATIONAL SCHOOLS IEQ SURVEY IN FRANCE

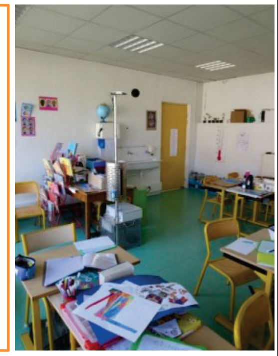
National school survey: (CNE)
OQAI 2013-2017
Measurement during 1 schools week.

- 308 schools (elementary & nurseries)
- 602 classrooms



Measurements values:

- Temperature (°C), relative humidity (%)
- Volatile organic compounds, semi-volatile organic compounds and metals in settled dust, particulate matter 2.5µm, total particles counts, NO_2, CO_2
- Background noise level
- Artificial illuminance
- Building characteristics



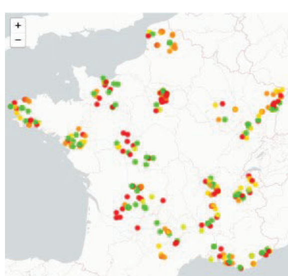
Occupants' perception (Teachers, auto complete survey)

Observatoire de la qualité de l'air intérieur

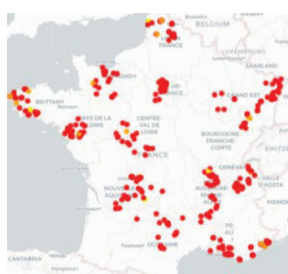
ILLUSTRATE INVISIBLE, TAIL FOR 308 SCHOOLS IN FRANCE, EXAMPLE

High, desired	Medium	Ordinary	Low - undesired

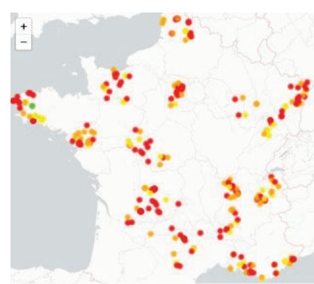
Quality of thermal environment (T)



Quality of acoustic environment (A)



IAQ (I)

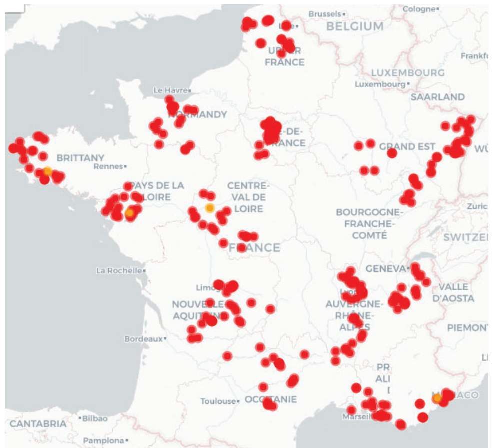


Quality of luminous environment (L)

Source: Tran et al. (2023)

ILLUSTRATE INVISIBLE, TAIL FOR 308 SCHOOLS IN FRANCE, EXAMPLE

High, desired	Medium	Ordinary	Low - undesired



Overall quality of indoor environment (TAIL)

Source: Tran et al. (2023)

VERIFICATION AND VALIDATION PERCEPTIONS OF TEACHES AND TAIL

	Perception of teachers
Thermal comfort 5 questions	Thermal sensation (cold/warm, satisfactory/unsatisfactory)
	Temperature variation during the day
	Presence of drafts and its perception
Olfactif comfort 4 questions	Presence of odors and its perception
Air quality sensation 3 questions	Sensation of air quality (satisfactory/unsatisfactory, dry/wet, confined/renewed)
Acoustic comfort 29 questions	Feeling the noise in the classroom
	Noise from outside and inside
	Feedback on the furniture layout
Lighting comfort 23 questions	Sensation of the quality of light in the classroom
	Use of solar protection
	Use of artificial lighting

CONCLUDING REMARKS

17

SUMMARY

- TAIL and PredicTAIL provide a complete tool allowing characterization of IEQ in buildings.
- They are expected to become a standard method of benchmarking IEQ in buildings when applied.
- They are expected to stimulate actions leading to the general improvement of the IEQ in buildings.

18

ACKNOWLEDGMENTS

Minh-Tien Tran[ǂ,δ], Valérie Héquet[δ], Pawel Wargocki[⸙], Corinne Mandin[ǂǂ], Claire Dassonville[ǂ], Wenjuan Wei[ǂ]

ǂFrench Indoor Air Quality Observatory (OQAI), Health and Comfort Department, Scientific and Technical Center for Building (CSTB), Marne-la-Vallée, France

ǂǂ Institute for Radiological Protection and Nuclear Safety - IRSN- Paris, France

δ: GEPEA, UMR 6144, CNRS, IMT Atlantique, Nantes, France

⸙: Department of Civil Engineering Indoor Environment, Technical University of Denmark

Questions

Pawel Wargocki
pawar@dtu.dk

43rd AIVC -11th TightVent & 9th Venticool Conference
October 4-5, 2023
Aalborg University, Copenhagen, Denmark

An investigation of MVHR system performance based on health and comfort criteria in bedrooms of low-carbon social housing in Wales

Faisal Farooq
Welsh School of Architecture, Cardiff University
Simon Lannon, Colin Biggs, Phil Jones

1

Aim

Investigate MVHR system performance in low-carbon housing in the UK based on a health and comfort criteria and propose design solutions.

Motivation

- MVHR has a critical role in the success of low-carbon housing.
- Resolve recurring issues with the performance gap.

2

Background

- Carried systematic literature review on in-situ performance evaluation of different ventilation technologies in low-carbon housing in the UK.
- Selection criteria was dwellings with an airtightness of 5-6 m^3/m^2h @ 50 Pa or below.
- Meta-analysis showed high concentration of CO_2 in bedrooms without MVHR.
- CO_2 is used as a surrogate for human emitted bio-effluents and commonly forms the basis for ventilation design.

Results of meta-analysis

Reference	Sample size & ventilation strategy	Monitoring period	Avg. airtightness (m3/h m2 @ 50 Pa)	Occupied time weighted average CO_2 level (ppm) in bedrooms	ΔCO_2 level (ppm) in bedrooms above ambient
Howieson (2014b)	20 (trickle vents)	5 months	4-5	1834	1404
Sharpe et al. (2015)	40 (trickle vents)	3 months	<4	1847	1417
Sharpe et al. (2019)	41 (dMEV)	1 week	4-5	1922 (separate bathroom), 1204 (en-suite)	1492 (separate bathroom), 774 (en-suite)
Sharpe et al. (2014)	21 (trickle vents), 5 (MVHR)	7 months	5.33 (trickle vents), 2.13 (MVHR)	1292 (trickle vents), 858 (MVHR)	862 (trickle vents), 428 (MVHR)*
McGill (2015c)	4 (trickle vents), 4 (MVHR)	24 hrs	4.6 (trickle vents), 2.06 (MVHR)	1710 (trickle vents), 875 (MVHR)	1280 (trickle vents), 445 (MVHR)*
Sharpe et al. (2016)	20 (trickle vents), 23 (MVHR)	3 months	3.2	1118 (trickle vents), 762 (MVHR)	688 (trickle vents), 332 (MVHR)*

* CO_2 values for MVHR are under 550 ppm above ambient which represents a ventilation rate of 7l/s per person.

Common MVHR shortcomings in UK housing

- Design specification
- Installation
- Commissioning
- Project management
- Occupant knowledge
- Occupant feedback

Common MVHR shortcomings in UK housing
Health and Comfort perspective

- Design specification
  - Supply vent close to bedroom door (Sharpe and Charles, 2015).
- Occupant knowledge
- Occupant feedback
  - Perceived **draught** from supply vent above beds (Sharpe et al., 2018; Gupta et al., 2018; Gupta and Kapsali, 2016; Gupta, 2016).
  - Perceived **noise** when trying to fall asleep (ZCH, 2015; Sharpe et al.,2018; Gupta, 2016).

Research questions

- What is the relationship of supply/door undercut arrangement with ventilation effectiveness?
- Do sound levels from an MVHR lie within comfortable range in low-carbon dwellings?
- Under what conditions and circumstances can air from an MVHR supply vent cause thermal (dis)comfort for occupants at night?

Case study A

Case study B

Case study details

- Systems were commissioned to meet the minimum ventilation rates prescribed under UK Building Regulations.
- Rigid ducting was used throughout with minimum bends.
- MVHR unit was located in the thermal envelope for Case Study A.
- Ducting was insulated throughout for Case Study B.

Methodology

- **Tracer gas experiments**
  - Ventilation effectiveness & Age of Air (Fisk and Faulkner, 1992).
- **Sound and frequency measurements**
  - Part F of UK Building Regulations
- **Thermal comfort**
  - Predicted Mean Vote experiment (ISO 7730:2005)
  - Continuous Temperature/RH monitoring

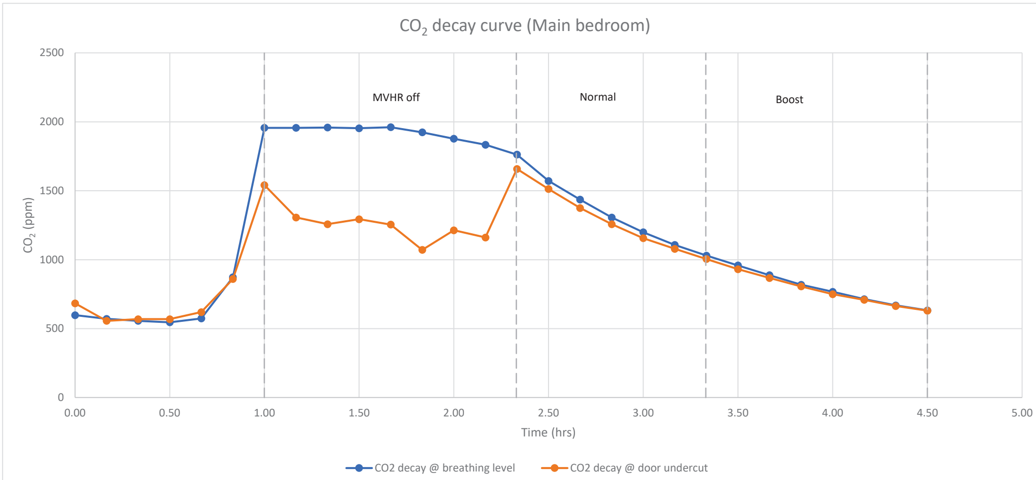
11

Tracer gas experiment



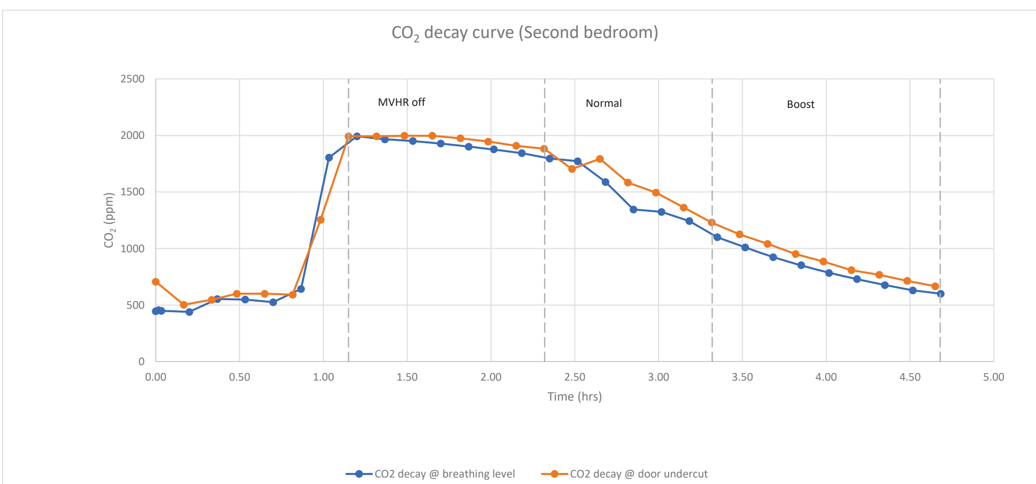
12

Decay curve for main bedroom



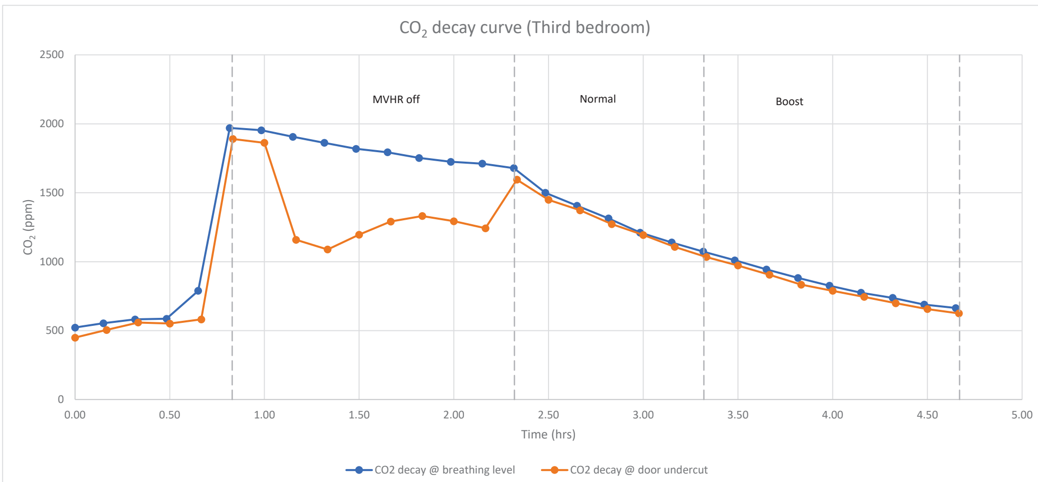
13

Decay curve for second bedroom



14

Decay curve for third bedroom



15

Tracer gas experiment results

	τ_{DU^*} (hr)	$\tau_{BL^{**}}$ (hr)	$E_{ADE^{***}}$
Main bedroom	0.78	0.76	1.02
Second bedroom	0.84	0.81	1.04
Third bedroom	0.81	0.79	1.02

τ_{DU^*} is age of air at Door Undercut
$\tau_{BL^{**}}$ is age of air at Breathing Level
$E_{ADE^{***}}$ is Air Diffusion Effectiveness

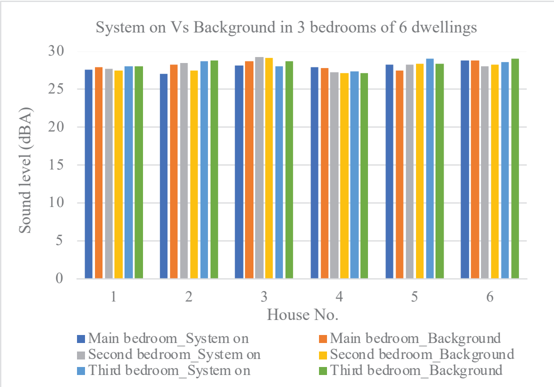
$E_{ADE} > 1$ is displacement flow pattern
$E_{ADE} = 1$ is perfect mixing
$E_{ADE} < 1$ is short-circuiting

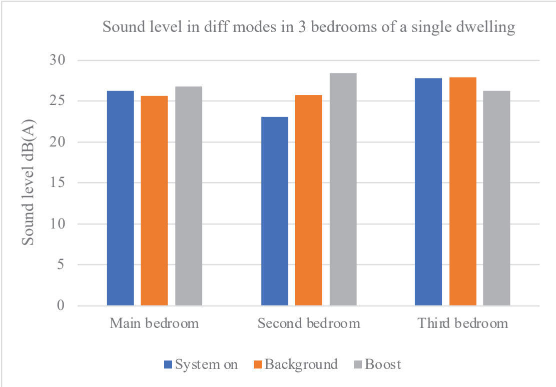
16

Sound measurements

17

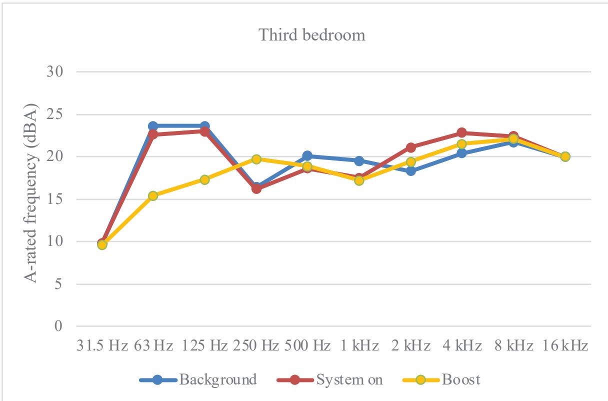
Sound measurements results in dB(A)





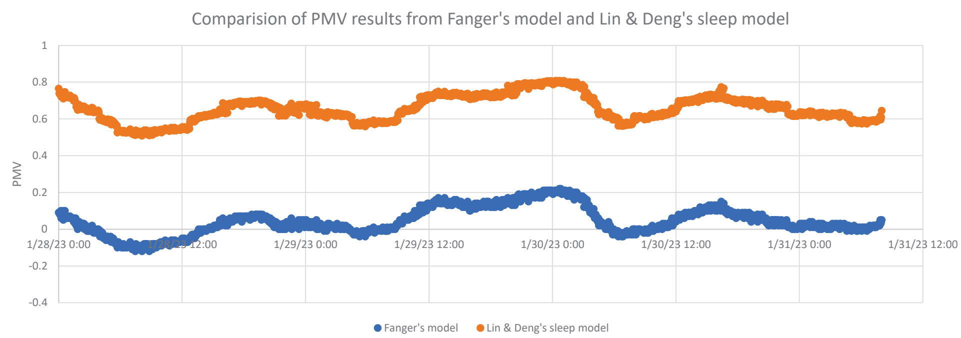
18

Frequency measurement in one bedroom

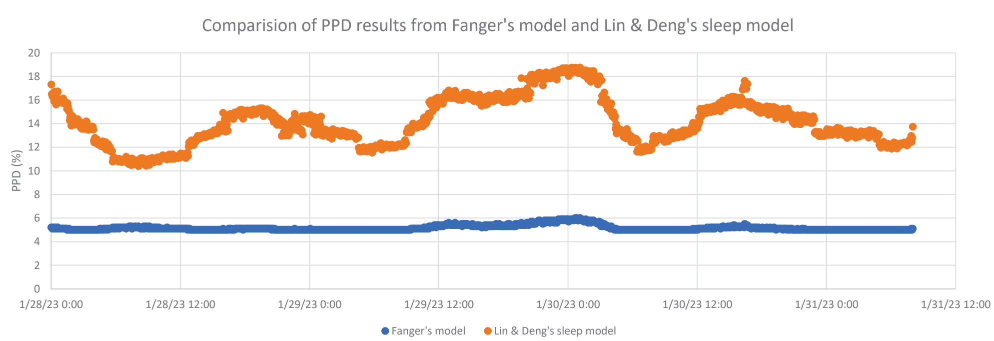


Thermal Comfort experiment

Predicted Mean Vote results



Predicted Percentage Dissatisfied results



Conclusions

- In terms of ventilation effectiveness, displacement flow pattern was observed, despite the proximity of the vent to the door.
- This is attributed to low velocities and shape of supply vent.
- Noise levels were under 30dB(A) in all modes of operation.
- A rumble in the low frequency range (50-500Hz) was observed in one of the bedrooms under boost mode.
- From the PMV experiment, 80% of occupants are predicted to be thermally satisfied under these environmental conditions.
- This is attributed to proper installation and commissioning practice at the two case study sites.

Further work – CFD modelling

- Vent closer to the door
- Different seasons
  - Continuous monitoring data
- Unbalanced system
- Door undercut
- Furniture/bed

Thank you! ☺

Contact: farooqf@cardiff.ac.uk

Impact of optimized residential ventilation with energy recovery on health and well-being

Martin Kremer, Kai Rewitz, Dirk Müller

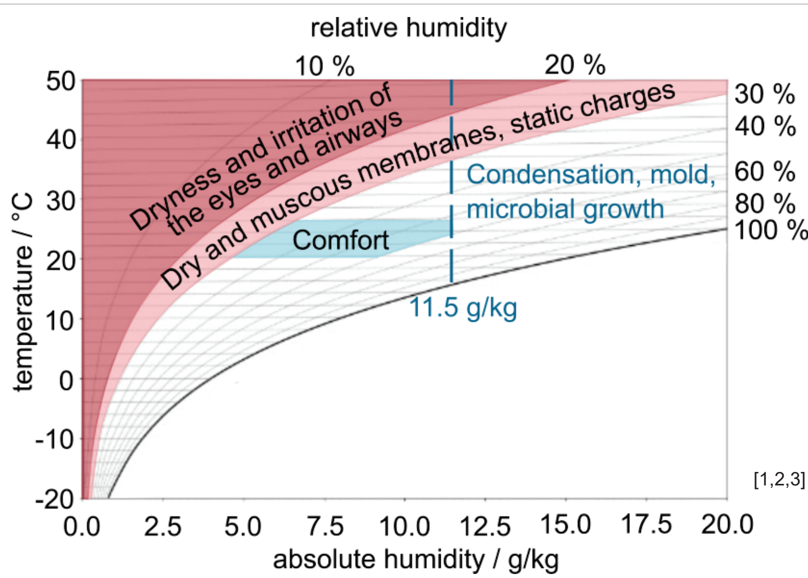
RWTH Aachen University, E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate

EBC | Institute for Energy Efficient Buildings and Indoor Climate | E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

1

Motivation

Why optimization of energy recovery is necessary?



[1,2,3]

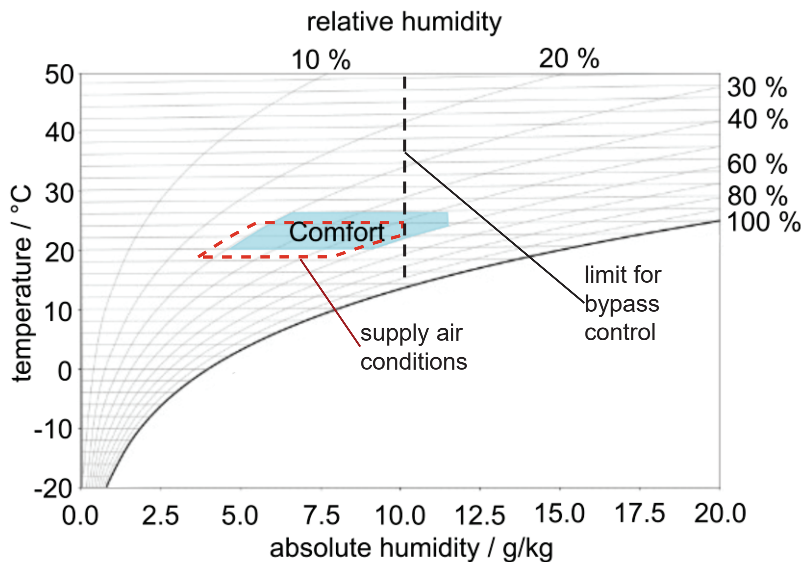
humidification necessary, but energy intensive

solution: enthalpy recovery

E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

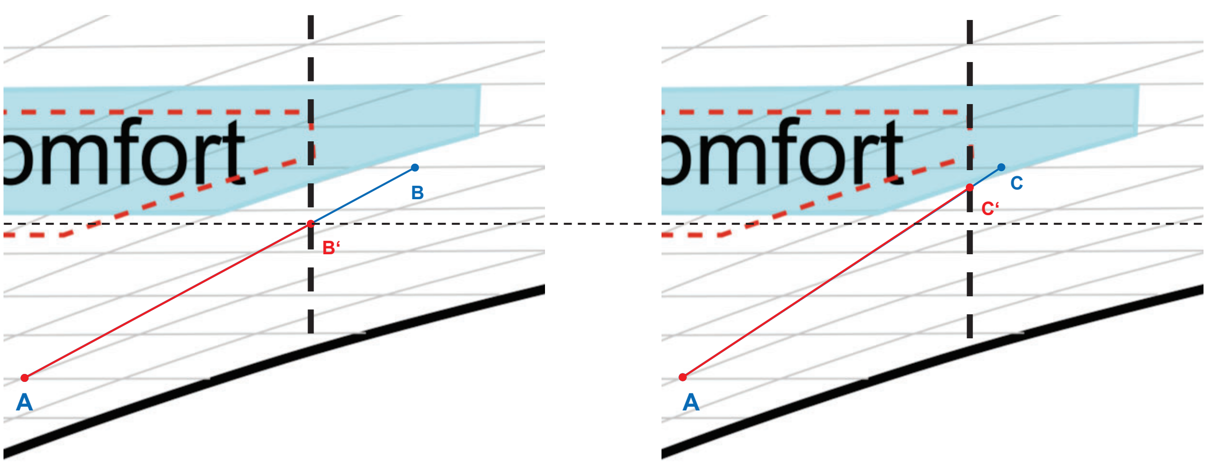
2

Motivation
Why optimization of energy recovery is necessary?



3

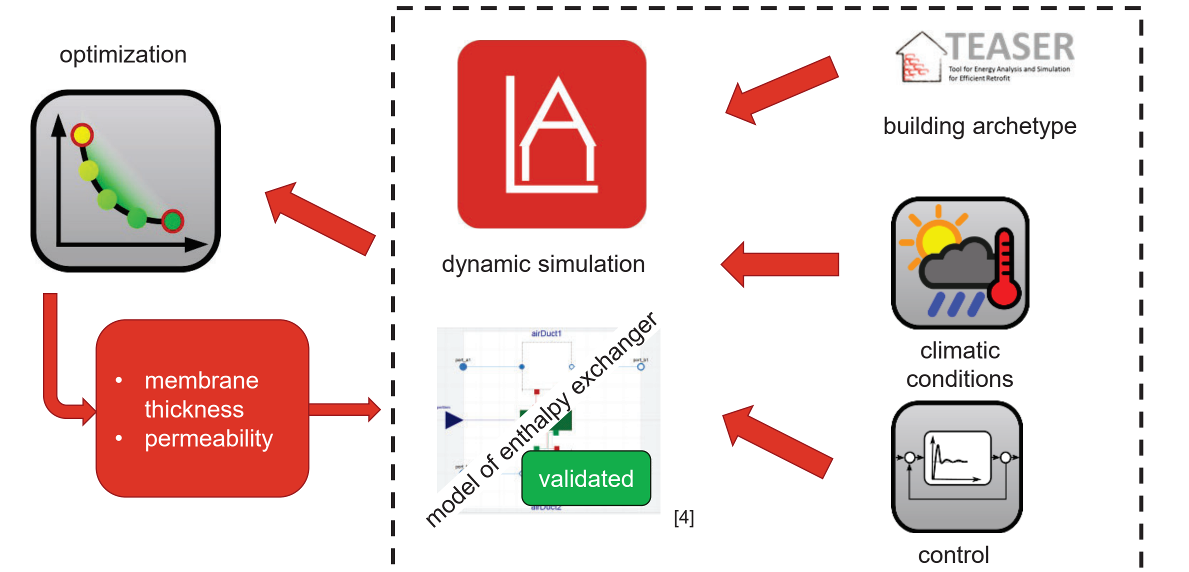
Motivation
Why optimization of energy recovery is necessary?



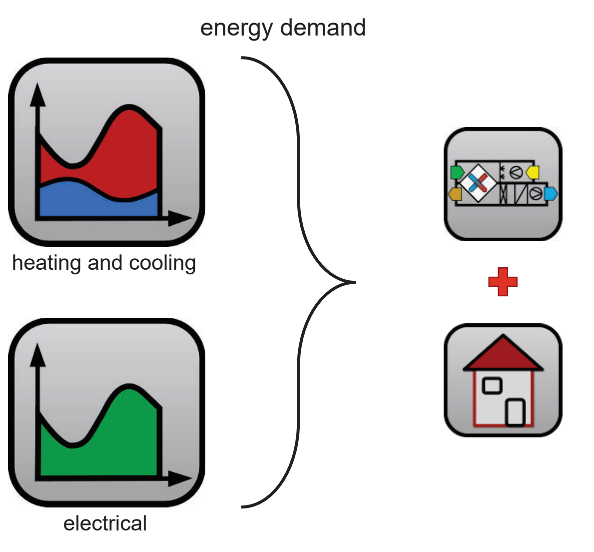
Optimization of latent effectiveness saves energy

4

Methodology
Design optimization with dynamic simulation models

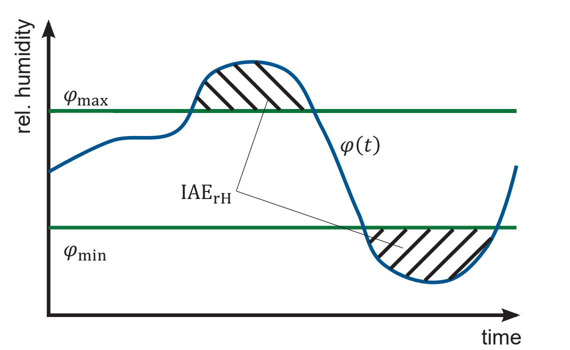


Methodology
Multicriterial optimization regarding energy demand and comfort

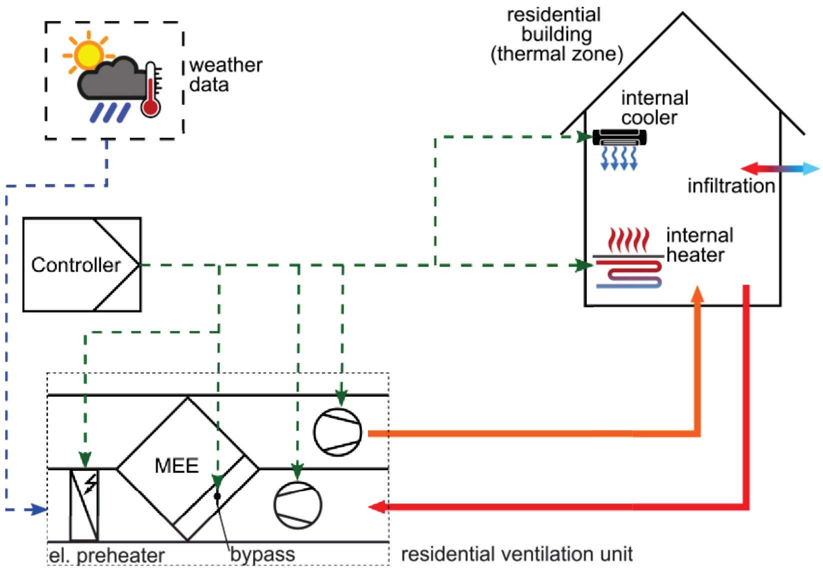


indoor air comfort violation

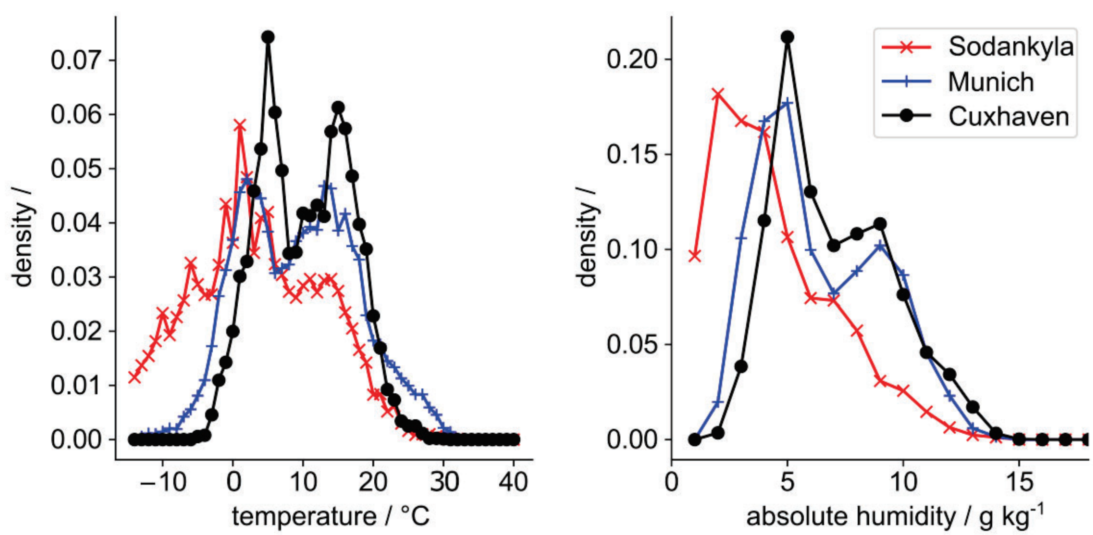
$$\mathrm{IAE}_{\mathrm{rH}} = \int \max(\varphi(t) - \varphi_{\max}, 0) + \max(\varphi_{\min} - \varphi(t), 0)\ dt$$



Case Study
Simulation model of residential building with central ventilation unit

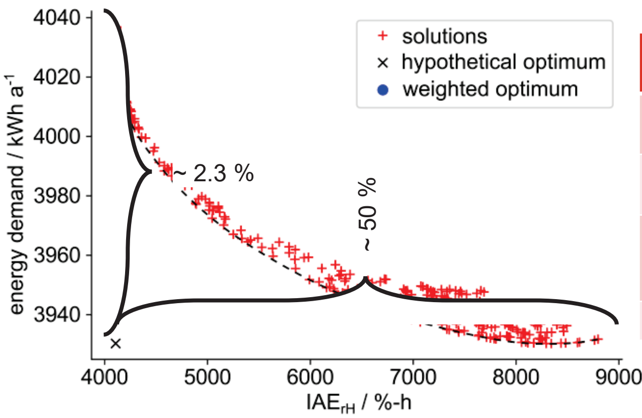


Case study
Investigated locations – differences in temperature and humidity



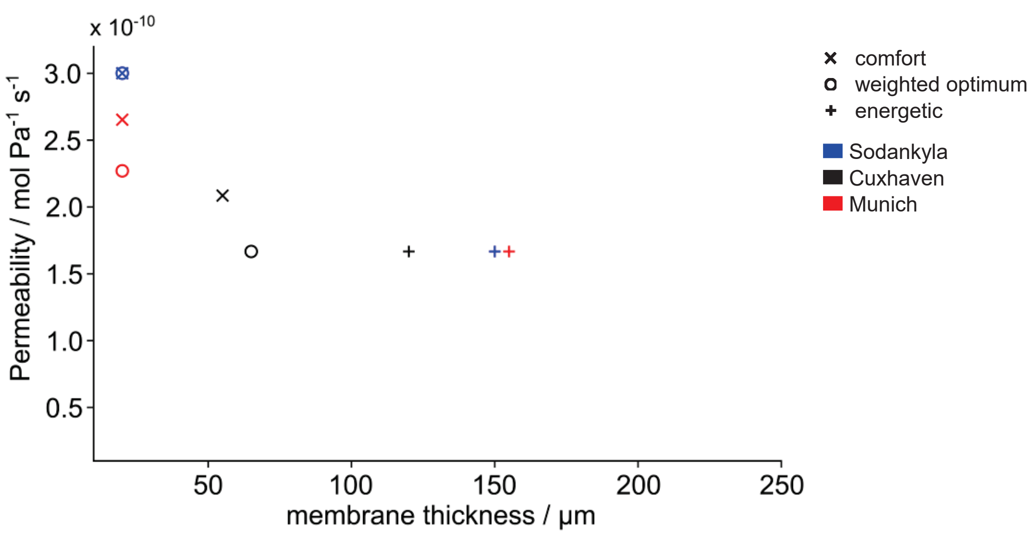
Results
Energetic and comfort optimum differ: weighting necessary

Munich



	energetic optimum	comfort optimum	weighted optimum
membrane thickness / µm	155	20	20
permeability / mol m^{-1} s^{-1} Pa^{-1}	$1{,}67 \cdot 10^{-10}$	$2{,}65 \cdot 10^{-10}$	$2{,}27 \cdot 10^{-10}$
energy demand / kWh a^{-1}	3930	4030	4021
IAE_{rH} / %-h	8343	4107	4124

Results
Influence of the location: moderate climates need lower latent effectiveness

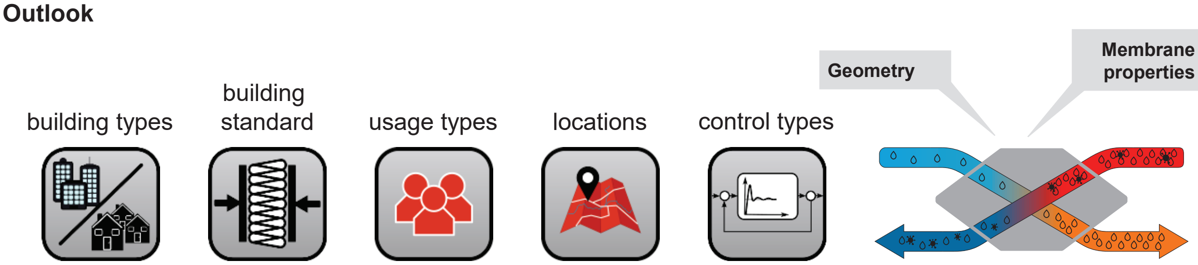


Conclusion and Outlook
Comfort increase with optimal enthalpy exchanger design depending on location

Conclusion

- Energetic Optimum: thicker and less permeable membranes
- Comfort Optimum: thinner and more permeable membranes
- Relative impact
  - Energy demand: 0.5 – 2.3 %
  - Comfort: 34 – 50 %

Outlook



Martin Kremer, M. Sc.
Team Leader, Team Ventilation Systems

T +49 241 80-49898
F +49 241 80-49769
mkremer@eonerc.rwth-aachen.de

RWTH Aachen University
E.ON Energy Research Center · Institute for Energy Efficient Buildings and Indoor Climate

Mathieustraße 10
52074 Aachen
Germany
www.eonerc.rwth-aachen.de/ebc

References

[1]: DIN EN 16798 – Part 1 (2023): *Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6; German version EN 16798-1:2019*

[2]: Sterling, E.M.; Arundel, A.; Sterling, T.D. (1985): *Criteria for human exposure to humidity in occupied buildings*. In: ASHRAE transactions91.1, S. 611-622

[3]:Sunwoo, Y.; Chou, C.; Takeshita, J.; Murakami, M.; Tochihara, Y. (2006): *Physiological and subjective Responses to low relative humidity*. In: Journal of physiological anthropology 25 (1), S. 7-14

[4]: Kremer, Martin; Mathis, Paul; Müller, Dirk (2019): *Moisture Recovery - A Dynamic Modelling Approach.* In: CLIMA 2019 Congress : Bucharest, Romania, May 26-29, 2019 / S.I Tanabe, H. Zhang, J. Kurnitski, M.C. Gameiro da Silva, I. Nastase, P. Wargocki, G. Cao, L. Mazzarela and C. Inard (Eds.). https://doi.org/10.1051/e3sconf/201911101099

A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices

Dr Magdalena Hajdukiewicz
Dr Marcel G.L.C. Loomans

m.hajdukiewicz@tue.nl
m.g.l.c.Loomans@tue.nl

5th October 2023

Built Environment Department, Building Performance Group

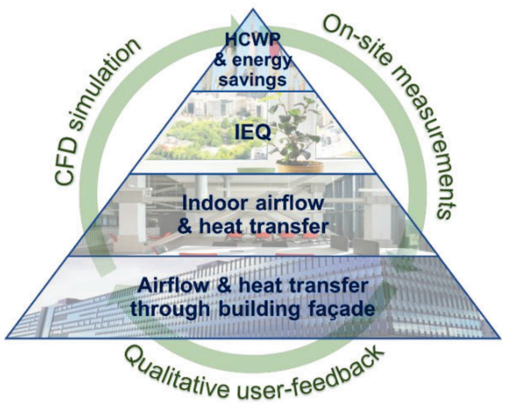
EINDHOVEN UNIVERSITY OF TECHNOLOGY

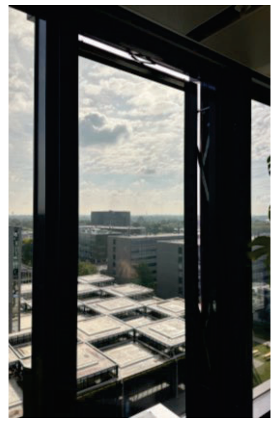
Outline

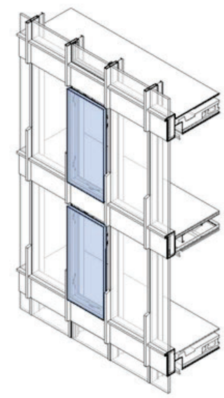
- ✓ FaceINQ project
- ✓ Research objectives
- ✓ Methodology
- ✓ Results
- ✓ Summary & conclusions

FaceINQ project

Innovative dynamic Façade systems for INdoor environmental Quality







Sources: https://www.archdaily.com/
Zhijian Wang

Research objectives

Develop **new operational strategies and designs** for innovative building façade systems that:

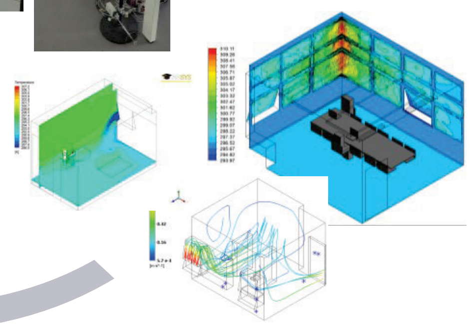
- Ensure IEQ appropriate to users,
- Limit building related health risks and
- Reduce energy consumption.

FaceINQ

- Provide detailed IEQ parameters in offices,
- Capture user's perception of the indoor environment,
- Provide data for development of validated CFD/BES models.

Methodology

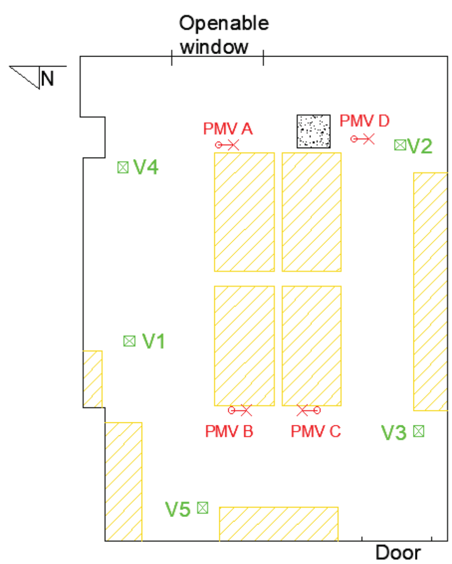
Source: Bart van Overbeeke



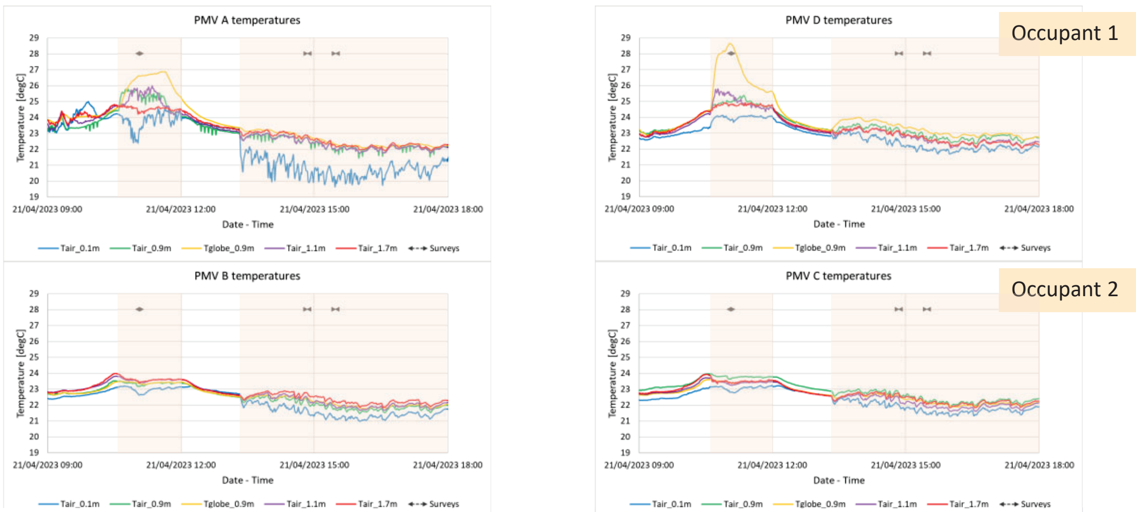
Measurements & surveys

Air temperature	Air velocity
RH	CO_2 concentration
Boundary air temperature	Boundary air velocity
Weather conditions	

- Background questions
- Thermal comfort
- Air quality
- General comfort



Results – Indoor air temperatures



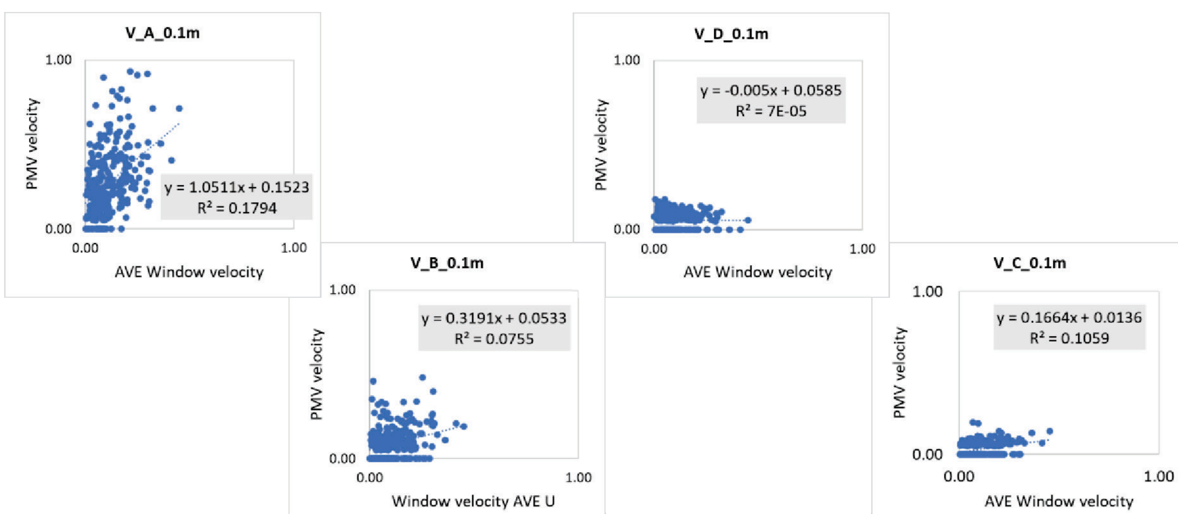
Results – Draught risks

		PMV A		PMV B		PMV C		PMV D	
		V_0.1m	V_1.1m	V_0.1m	V_1.1m	V_0.1m	V_1.1m	V_0.1m	V_1.1m
Window closed (9:00-10:35)	*MEAN*	0.07	0.15	0.08	0.08	0.09	0.08	0.08	0.08
	Tu	*16*	34	56	38	60	37	*28*	*23*
	DR	***3***	***13***	6	6	8	6	5	4
Window open (10:36-12:00)	*MEAN*	0.17	0.16	0.09	0.09	0.08	0.08	0.11	0.10
	Tu	74	41	56	36	32	27	31	28
	DR	***24***	***15***	8	7	5	5	9	7
Window closed (12:01-1:19)	*MEAN*	0.10	0.10	0.06	0.09	0.08	0.07	0.10	0.08
	Tu	*21*	40	*18*	*22*	*24*	*21*	*23*	*26*
	DR	7	8	3	6	5	4	7	4
Window open (1:20-6:00)	*MEAN*	0.30	0.20	0.14	0.09	0.08	0.08	0.09	0.09
	Tu	64	34	59	*29*	32	43	33	*28*
	DR	***50***	***19***	***16***	6	5	6	6	6

Results – Occupants' perception

Survey	Morning		Afternoon	
	Occupant 1	Occupant 2	Occupant 1	Occupant 2
How are you feeling now?	*Slightly warm*	*Slightly warm*	Neutral	Neutral
How do you find this thermal environment?	**Comfortable**	**Comfortable**	**Comfortable**	**Comfortable**
Please state how you would prefer to be now.	A little colder	Neutral	Neutral	A little colder
Do you feel local heat or cold on some parts of your body?	No	No	No	No
Do you experience draught on some parts of your body?	No	No	No	No
I am satisfied with the air quality in this room.	Neutral	Agree	Agree	*Slightly agree*
The air in this room is not stale.	*Slightly agree*	Agree	Agree	Agree
There is a lot of fresh air in the room.	*Slightly disagree*	Strongly agree	Agree	Agree
The room is properly ventilated.	Neutral	Strongly agree	Agree	Strongly agree
The room has a pleasant smell.	Slightly agree	Neutral	Agree	Agree
The scent of the air in the room does not distract me.	Agree	Agree	Agree	Strongly agree
The air is not dry in the room.	Agree	Agree	Agree	Strongly agree
The air is not dusty in the room.	Agree	Agree	Agree	Strongly agree
Is the window open at this moment?	Yes	Yes	Yes	Yes
At this moment, do you prefer the window open or closed?	**I prefer it open**	**I prefer it open**	**I prefer it open**	**I prefer it open**
Are there any other factors in the room that bother you?	No	No	No	No
Are you currently experiencing any other symptoms?	No	No	No	No
How are you feeling at the moment?	Neither alert nor sleepy	Alert	Very alert	Some signs of sleepiness

Results – Air velocity correlation

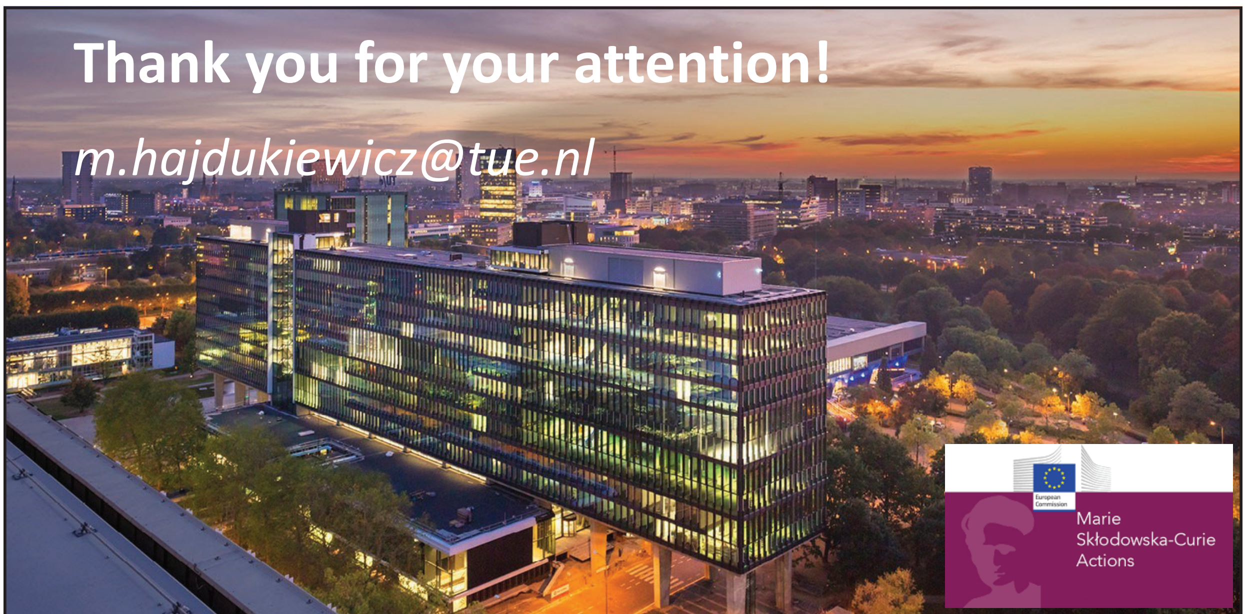


Summary & conclusions

- Research objectives, measurement protocol and the initial results of the IEQ investigation in an office room.
- Point-in-time characterisation of the façade operation and its impact on the occupants.
- Measured data to support validation of CFD and building energy models.
- Leading to optimised design and operation of adaptive façade systems.

Thank you for your attention!

m.hajdukiewicz@tue.nl



M. Hajdukiewicz & M.G.L.C. Loomans
'A detailed investigation of the impact of an innovative dynamic façade system on indoor environmental quality in offices'

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

eurac research

Methodology for evaluating the ventilative cooling potential in early-stage building design

43rd AIVC Conference "Ventilation, IEQ and health in sustainable buildings"

Valentina Radice Fossati, Annamaria Belleri, Dick van Dijk

4-5th October 2023

Outline

- Context
- Methodology for evaluating ventilative cooling potential (VC)
- Validation of the methodology
- Results
- Conclusions and next steps

Context

What's ventilative cooling?

Ventilation used to **reduce the cooling loads and limit the use of mechanical cooling** in buildings by **utilizing differences between indoor and outdoor temperatures for airborne cooling**

Ventilative cooling potential methodology

Calculation method that allows **engineers/designers/experts** to assess the potential of ventilative cooling in early-stage design

Version 1 developed within the **IEA - EBC Annex 62 - "Ventilative Cooling"**

Version 2 involved the **CEN/TC 156/WG21 - "Ventilative Cooling Systems - Design"**

Calculation Methodology

Ventilative Cooling Potential (VCP) Methodology

Calculation method **to evaluate VCP** based on a **single-zone thermal model** applied to user-input climatic data on hourly basis

From EN ISO 52016, the **detailed thermal balance calculation was reduced to essential (lumped) parameters** and applied to calculate:

- Free-floating room temperature
- Heating/cooling loads (with and without VC contribution)

1 RC Lumped parameter model

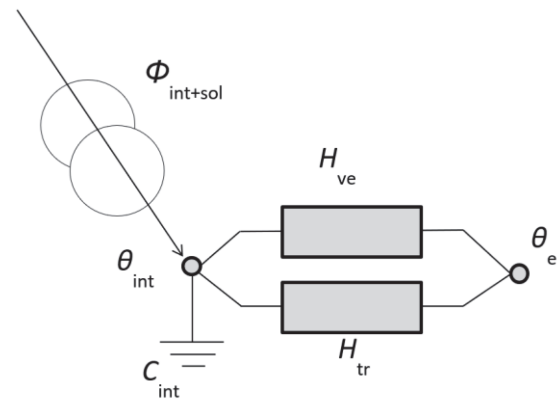


Fig. 1 RC model selected as the most suited model for the early design phase

Overall Energy Balance Equation

At each time interval the heat balance of the building according to the 1 RC model is calculated

$$\left[\frac{C_{int}}{\Delta t} + H_{ve;t} + H_{tr}\right] \theta_{int;t} = \frac{C_{int}}{\Delta t} \cdot \theta_{int;t-1} + \left[H_{ve;t} + H_{tr}\right] \cdot \theta_{e;a;t} + \Phi_{int;t} + \Phi_{sol;t} + \Phi_{HC;t}$$

(lumped) internal thermal capacity

overall heat transfer coefficient by ventilation

Internal air temperature at previous time interval

internal gains

heating/cooling loads

timestep

internal air temperature

overall heat transfer coefficient by transmission

external air temperature

solar gains

$$\rightarrow \boxed{A_t \ \theta_{int;t} = B_t + \Phi_{HC;t}}$$

Input and Output

Input

- **Climatic conditions**
- **Building data (building typology and geometry)**
- **Technical specifications**
  - U-value of opaque and transparent envelope
  - g-value of glazing system
  - Shading control setpoint
  - Minimum required ventilation rate
  - Gains
  - Time control

Output

- Hourly distribution of **ventilative cooling modes over the year**
- Frequency of **ACH required to provide potential comfort** (VC-mode[2])
- **Monthly and annual sensible energy needs of heating/cooling with and without VC**

Evaluation Criteria for VCP

Equations based on heating and/or cooling loads

- **VC-mode [0]** – ventilative cooling is not required

  IF $\theta_{int;0;t} < \theta_{int;set;H}$ THEN $q_{V;t} = q_{V;min}$

- **VC-mode [1]** – potential comfort achieved with minimum airflow rate

  IF $\theta_{int;set;H} < \theta_{int;0;t} < \theta_{int;set;C}$ THEN $q_{V;t} = q_{V;min}$

- **VC-mode [2]** – potential comfort achieved with increased airflow rate

  IF $\theta_{int;0;t} > \theta_{int;set;C}$ AND $\theta_{e;a;t} \leq (\theta_{int;set;C} - \Delta\theta_{crit})$ AND $\Phi_{HU;e;a;t} \leq \Phi_{HU;max}$
  THEN $q_{V;t} = q_{V;VCS}$

- **VC-mode [3]** – residual discomfort hours

Methodology Validation

Methodology

Comparison of the results of the methodology with those indicated in EN ISO 52016-1:2017

2 test cases consisting of a **single thermal zone with different thermal capacity** were analysed in the climate of **Denver, USA**

- **Lightweight case (BESTEST 640)** ⟶ wood-based construction system
- **Heavyweight case (BESTEST 940)** ⟶ concrete-based construction system

Alignment of the input* according to EN ISO 52016-1:2017

Calculation of statistical error (CV(RMSE)) to assess uncertainty degree of the methodology

Validation output:

- **Monthly and annual** sensible energy needs for **heating** ($Q_{H;nd}$) and **cooling** ($Q_{C;nd}$)
- **Monthly** average values of **operative temperature** ($\theta_{op;av}$)

* for further details see the paper

Statistical error

CV(RMSE) (Coefficient of Variation of the Root Mean Square Error)

Errors that allows to delete cancellation errors and measure the model uncertainty degree

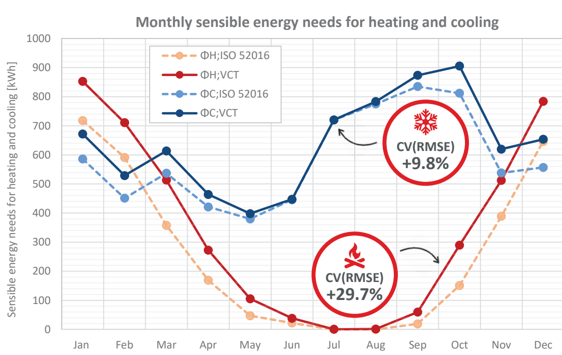
$$CV(RMSE) = \frac{RMSE}{a} 100[\%] \qquad RMSE = \sqrt{\frac{\sum_{i=1}^{n}(s_i - m_i)^2}{n}}$$

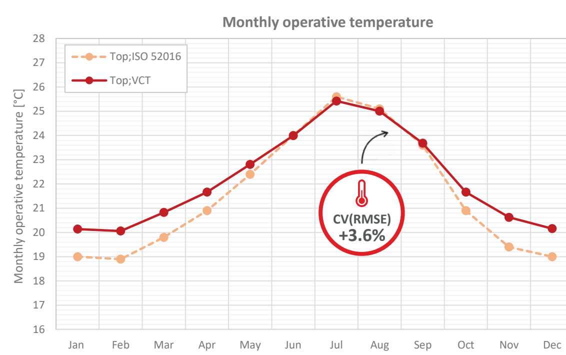
- Acceptable limits according to ASHRAE Guideline 14:

	Monthly criteria	Hourly criteria
CV(RMSE)	15%	30%

** The mentioned statistical errors are generally used to calibrate and validate dynamic simulation software. Since the tested methodology refers to early stage design phase, these errors are just taken as reference.*

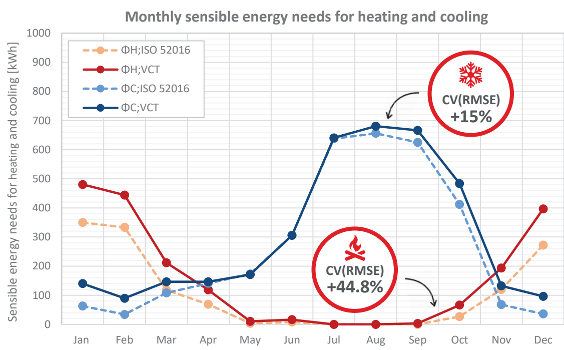
Results - BESTEST 640 (Lightweight)

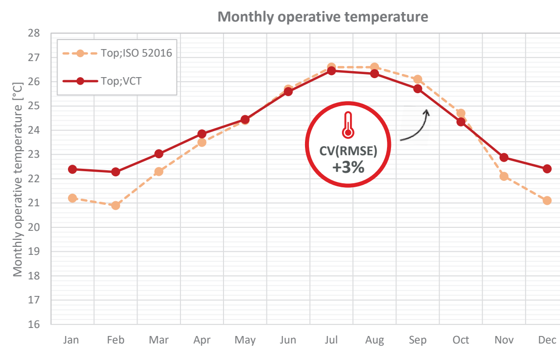




- $\Phi_{H;annual;VCT}$ = 4141 kWh **vs** $\Phi_{H;annual;bestest}$ = 3110 kWh
- $\Phi_{C;annual;VCT}$ = 7680 kWh **vs** $\Phi_{C;annual;bestest}$ = 7058 kWh

Results - BESTEST 940 (Heavyweight)



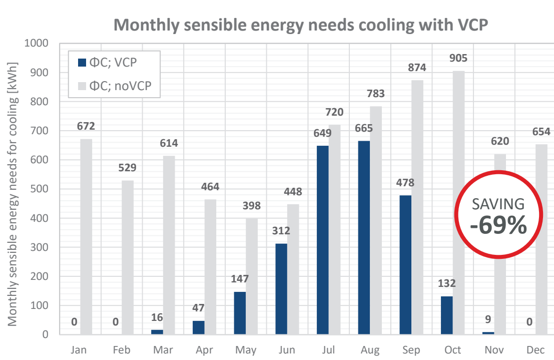


- $\Phi_{H;annual;VCT}$ = 1941 kWh **vs** $\Phi_{H;annual;bestest}$ = 1301 kWh
- $\Phi_{C;annual;VCT}$ = 3699 kWh **vs** $\Phi_{C;annual;bestest}$ = 3260 kWh

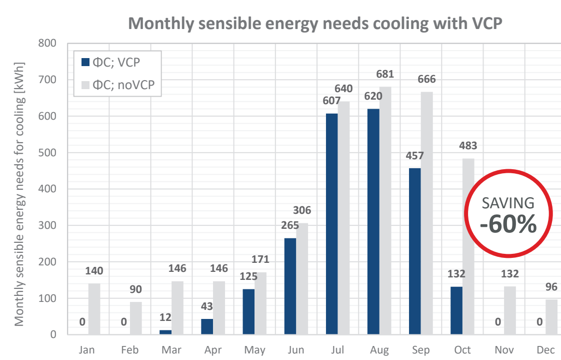
Results - Ventilative cooling potential

- **Cooling loads comparison considering the potential of ventilative cooling**

BESTEST 640 (Lightweight)



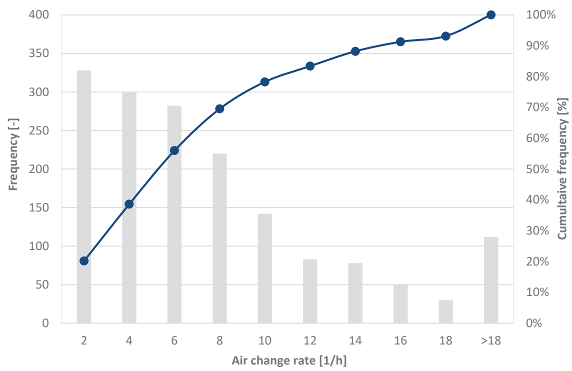
BESTEST 940 (Heavyweight)



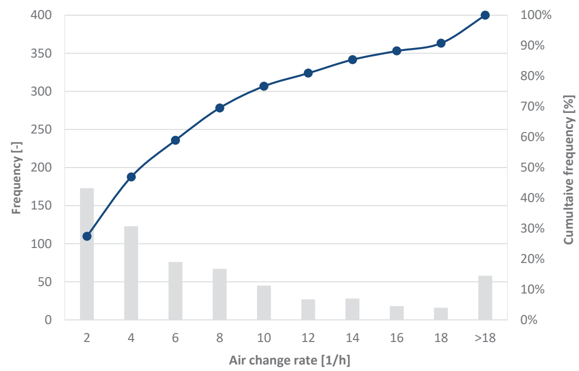
Results - ACH required for comfort

- Frequency of ACH required to provide potential comfort (VC-mode[2])

BESTEST 640 (Lightweight)



BESTEST 940 (Heavyweight)



Conclusions and next steps

Conclusions and next steps

Conclusions

- **Validation results are promising** since **the level of detail of input data** required for the 1RC model is **very low**
- Ventilative cooling tool is useful to **compare the ventilative cooling capacity for different building typologies and thermal capacities**
- The methodology enables to **analyse the effect of other energy efficiency measures on ventilative cooling effectiveness**, such as internal gains reduction, solar gains control and envelope performance

Next steps

- Modelling a shoebox and **compare software and methodology results**
- Implement the **calculation method in Python and release on GitHub**
- Implement **resilience check**

eurac research

Thank you!

Valentina Radice Fossati, Annamaria Belleri, Dick van Dijk

The authors would like to thank the CEN/TC 156/WG21 TG on *"Ventilative Cooling Systems - Design"* experts for their contributions to the concept development and the interesting discussions.

4-5th October 2023

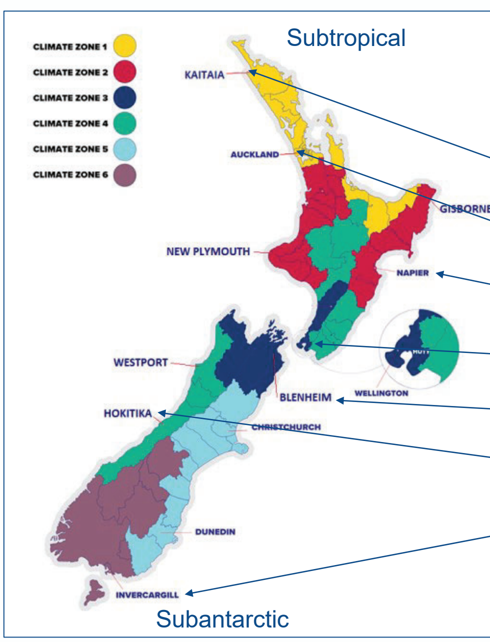
www.eurac.edu

Ventilation reliability: A pilot study on window opening behaviour in a primary school

L Tookey

M Boulic, B McDonald, W Page, P Wargocki, H van Heerden

N Z CONTEXT

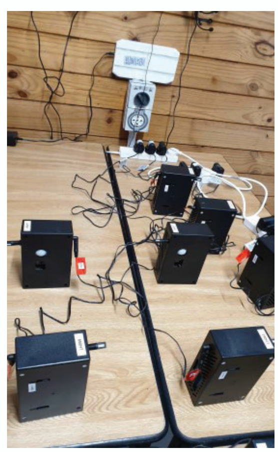


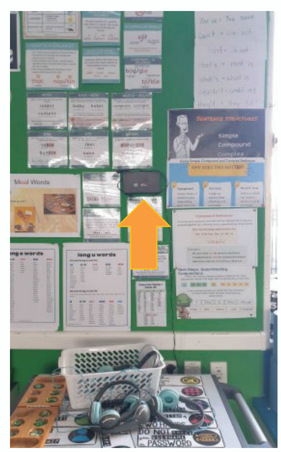
NZ Climate zones

Rainfall (mm)	T_{max} (°C)	T_{min} (°C)	Wind (km/h)
1334	30.2	0.9	15
1240	30.5	-2.5	17
803	35.8	-3.9	29
1249	31.1	-1.9	22
655	36	-8.8	13
2875	30	-3.4	11
1112	32.2	-9.0	18

METHODS

- Built in 1965
- Six classrooms in one pilot study primary school located in Auckland (Zone 1),
- Data collected in NZ Autumn (March 2023), over three days,
- Visual observation forms completed,
- Discussions with teachers clarifying reasons for window operations,...

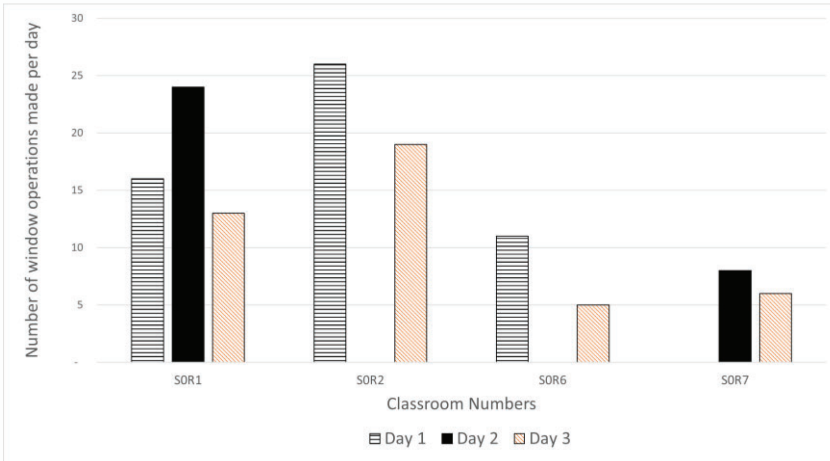




- Windows opening monitored using magnetic sensors,
- Carbon dioxide (CO_2), temperature and relative humidity monitored,
- Ambient measurements from local met station.

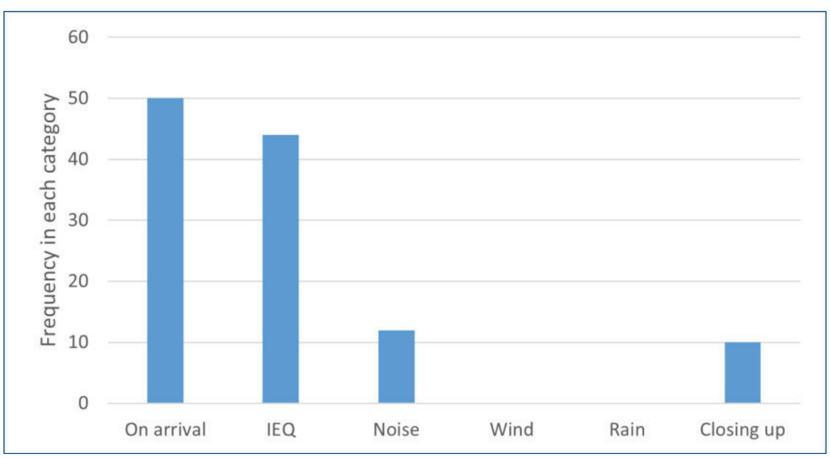
Number of daily window operations

RESULTS



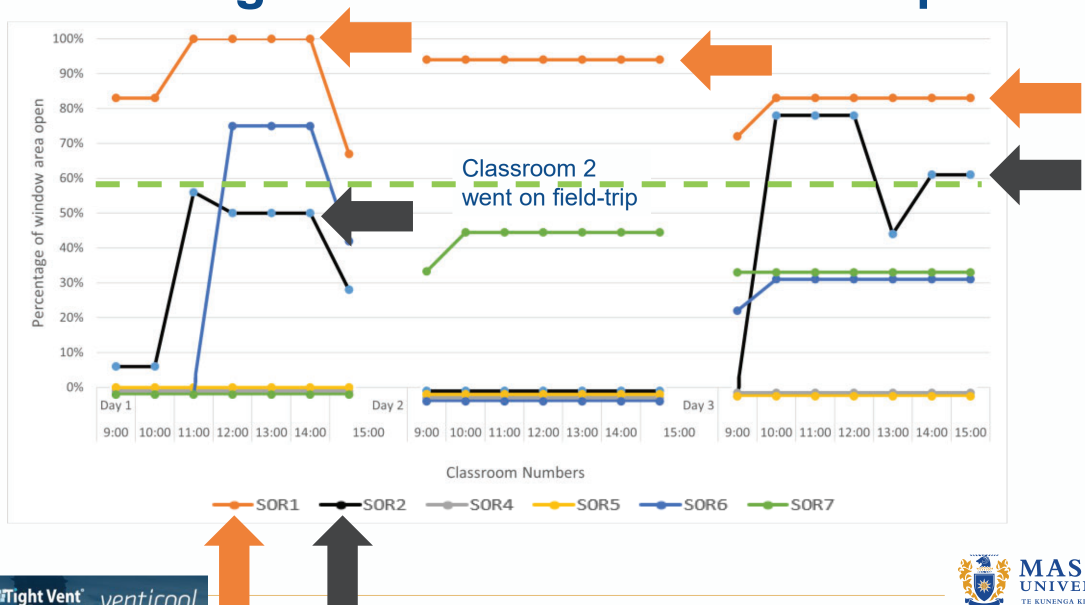
Reasons for window operations

RESULTS



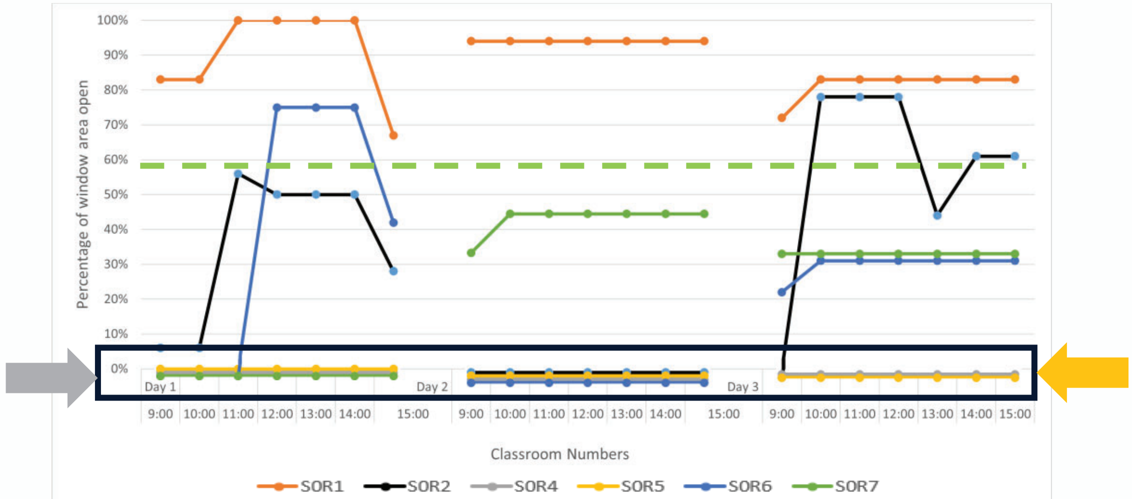
Percentage of window area that is open

R E S U L T S



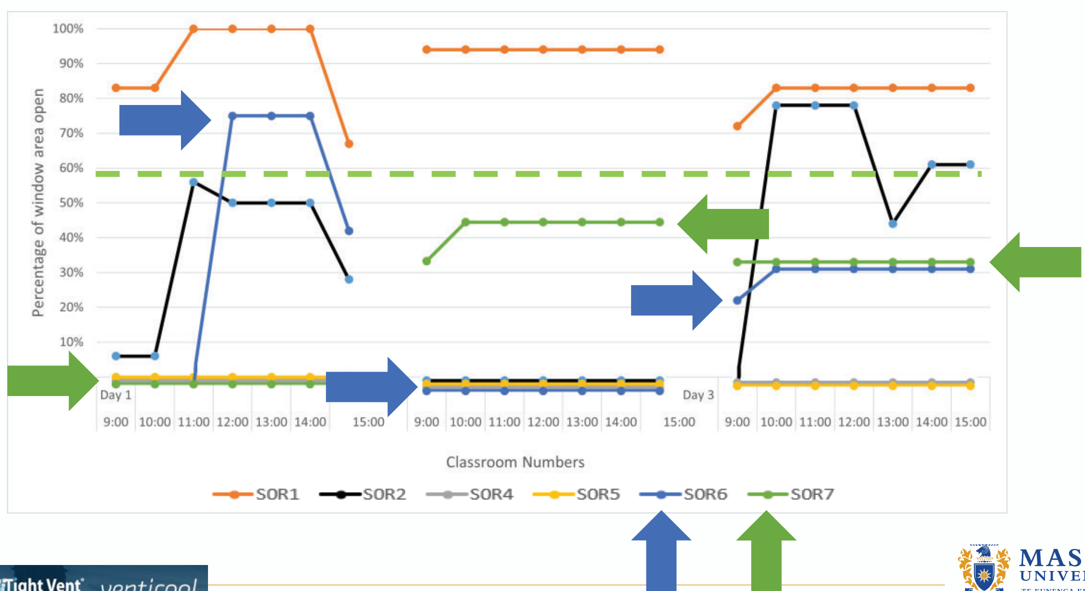
Percentage of window area that is open

RESULTS



Percentage of window area that is open

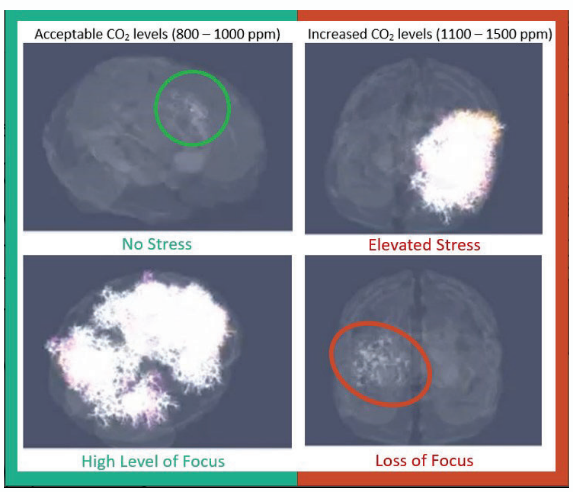
RESULTS



CONCLUSIONS

- Extreme difference between six teachers in one school.
- Behaviour difference continues after receiving ventilation best practice notes.
- Observed correlations support changes
  - likely to impact variations in indoor temperature & CO_2 levels.
- Preliminary results good agreement
  - between observations & data from window sensors.
- Next
  - evaluate how indoor temperature & CO_2 levels change based on window opening behaviour.

Next Steps



MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Ventilation reliability: A pilot study on window opening behaviour in a primary school

QUESTIONS

l.tookey@massey.ac.nz
https://orcid.org/0000-0001-9965-1716

"A survey of building design practitioner perceptions of ventilative cooling in their building design processes"

Maha Sohail*[1,2], Adam O'Donovan[1,2], Christopher Plesner[3] and Paul D. O'Sullivan*[1,2]

3rd Year PhD Student, EPSRC-SFI CDT for Energy Resilience in the Built Environment, Munster Technological University, Cork, Ireland

1. *Department of Process, Energy and Transport Engineering, Munster Technological University, Cork, Ireland*
2. *MaREI SFI Centre for Marine, Climate and Energy, University College Cork, Ringaskiddy, Co. Cork, Ireland*
3. *VELUX, Ådalsvej 99 DK-2970, Hørsholm, Denmark*

*Corresponding authors email addresses: maha.sohail@mycit.ie; paul.osullivan@mtu.ie

1

Contents

- Background
- Overview of the Survey
- Results
- Conclusion
- Future Work and Discussion
- Q/A
- References

2

RBE

Background: Definition of Ventilative Cooling

International Energy Agency's Energy in Buildings and Communities Annex 62 State of the Art Review report (2018) recently defined Ventilative Cooling (VC) as, *'The application of ventilation flow rates to reduce the cooling loads in buildings. VC utilizes the cooling and thermal perception potential of outdoor air. The air driving force can be natural, mechanical or a combination '*.

(https://venticool.eu/)

RBE

Background

Critical Review of Design Processes

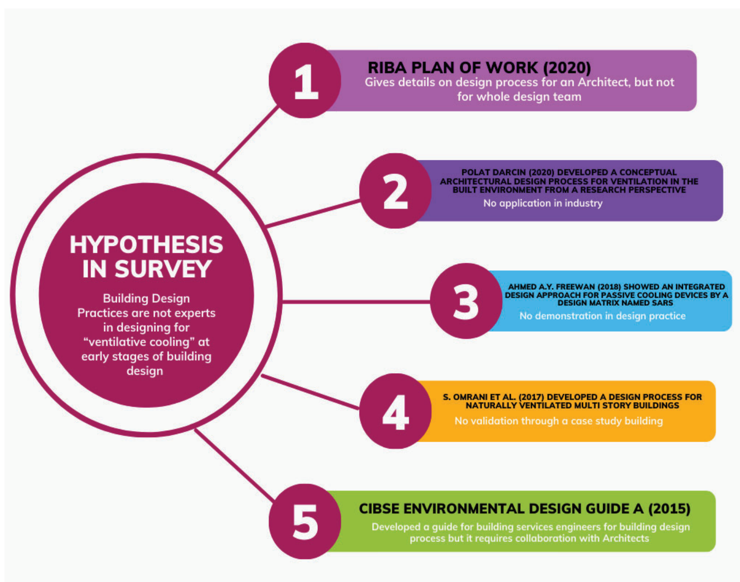


Fig 1: A critical review of a few design processes developed in literature pertaining to ventilation

Overview of the Survey

- **Title:** "Perception of ventilative cooling in building design practices"
- **Tool:** Survey Monkey
- **Estimated Completion Time:** 17-35 minutes
- **Results Presented in Conference Paper:** 14 completed responses out of 32 in first three weeks (15 March to 7th April 2023)
- **Target Location:** UK and Ireland
- **Time Run:** March 15th to 30th September 2023
- **Question Types:** A mix of open ended and closed ended questions, only closed ended responses are presented in this paper.

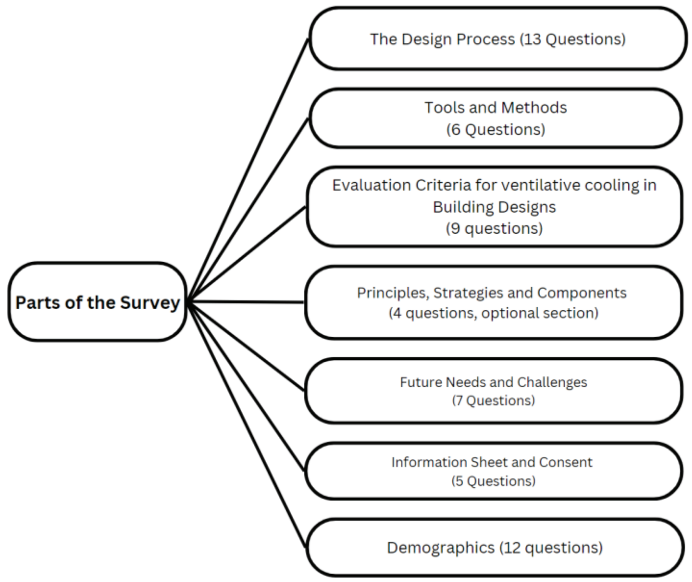


Figure 2: Summary of 57 questions used in the survey

ERBE

Results: Demographics of Survey Respondents

Table 1: Demographics of Survey Respondents

Demographic	Architect	Engineer	Architectural Technologist	Other	Total
Gender					
Male	7	2	1	1	11 (78%)
Female	2	0	0	0	2 (14.3%)
Prefer Not to Say	1	0	0	0	1 (7%)
Age					
35-44	2	0	0	0	2 (14%)
45-54	4	1	0	1	6 (43%)
55-64 65+	4	1	1	0	6 (43%)
Highest Qualification					
PhD	0	0	0	1	1 (7%)
Masters or Postgraduate	7	1	0	0	8 (57%)
Bachelors	2	1	0	0	3 (21%)
Diploma	0	0	1	0	1(7%)
Other	1	0	0	0	1(7%)

MeSSO MECHANICAL ENERGY SYSTEM SIMULATION OPTIMISATION · MaREI · ROYAL ACADEMY OF ENGINEERING · EPSRC · SFI

Results: The Design Process

Reasons of not agreeing:

- "Design is an iterative process, not a single process can be standardized.."
- "The diagram seems biased towards a commercial building".
- "additional stages are involved e.g., tender, building regulations etc."

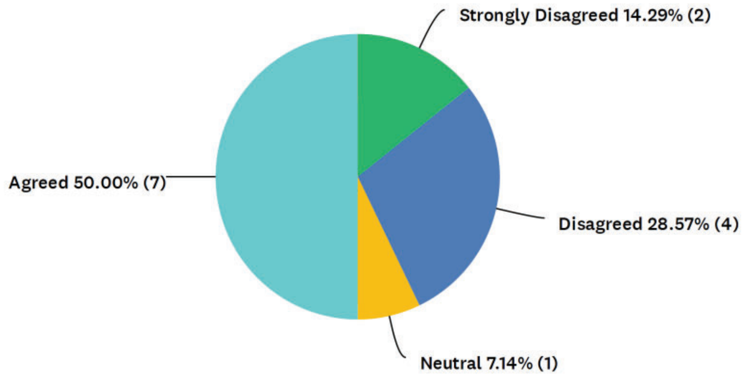


Figure 3: The extent to which respondents agreed or disagreed with the building design process diagram presented to them.

Scan the QR code to see the design process diagram presented in the survey

10/9/2023 7

7

Results: Tools and Methods

- Around **21%** of the respondents do not use any design tools, **50%** sometimes do and **29%** use a tool normally
- The most popular software used by the respondents is **Passive House Planning package (PHPP)** with around **50%** of the respondents using it, and the second most popular tool is **Integrated Environmental Solutions (IES)** with around **33%** of the respondents using it in their design practices
- **54%** of the respondents are not satisfied with the tools for taking ventilative cooling decision (this is one of the results, that is changed now)
- Other than the tools, around **64%** of the respondents rely on their **professional experience**, and 28% rely on other ways to take a ventilative cooling decision

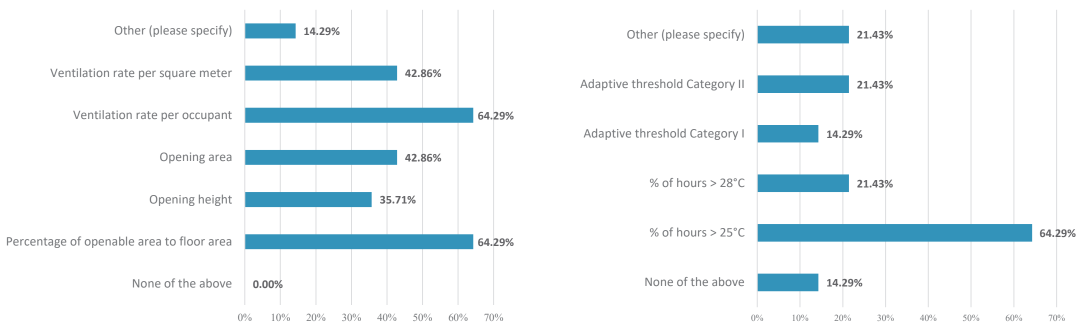
Scan the QR code to see the list of tools presented in the survey

09/10/2023 8

8

Results: Evaluation Criteria for Ventilative Cooling in Building Designs

Figure 4: Results of the questions, *"Which of the following metrics or variables do you consider at the early design stage for ventilative cooling systems?"* and *"When evaluating comfort performance in your designs, what upper temperature thresholds do you consider?"* from left to right respectively



Results: Future Needs and Challenges

Table 2: Responses of Questions related to Future Needs and Challenges of Ventilative cooling in Building Designs in the Survey

Questions	Answer Option 1	Answer Option 2
Do you think that the built environment design professionals are prepared for accounting for extreme future climate events, such as heat waves, while designing buildings today that will be used many years from now?	Yes (28.57%)	No (71.43%)
In your experience does Natural Ventilation work satisfactorily as a cooling solution against future climate change?	Yes (42.86%)	No (57.14%)
Can Ventilative Cooling play a role in delivering a carbon neutral built environment?	Yes (92.86%)	No (7.14%)

Conclusion of the Survey

- Lack of collaboration at early stages by core design team can lead to poor Ventilative Cooling decisions
- Building design is an iterative process and good ventilative cooling design practices require time, expert advice and often cost in non-domestic buildings at early stages
- Post Occupancy Evaluation or site monitoring is critical in ensuring good ventilative cooling performance after building hand over

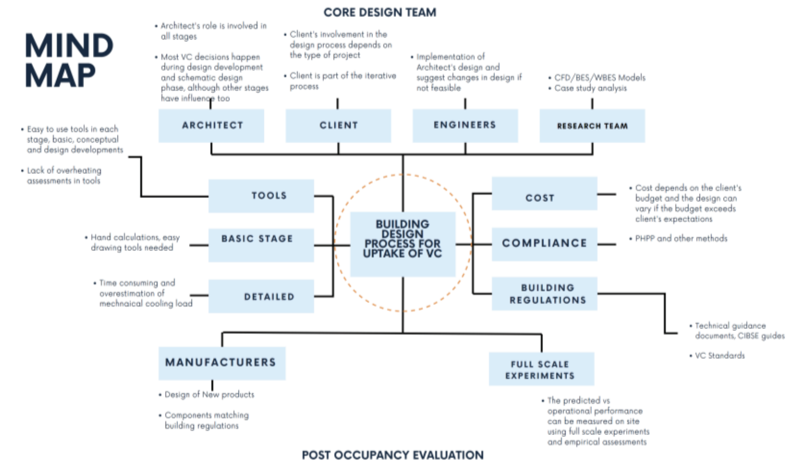


Figure 5: Visualization of the survey responses of how information flows in the design process

Future Work and Discussion

- Many results have changed in the survey (**40/71** complete responses received by far)
- Survey was too long for many practitioners to complete
- **10** interviews have been completed by far (6 Architects, 4 Engineers)
- Analyse the survey and interview data collectively
- Propose an improved design process diagram and demonstrate it through case studies by numerical modelling

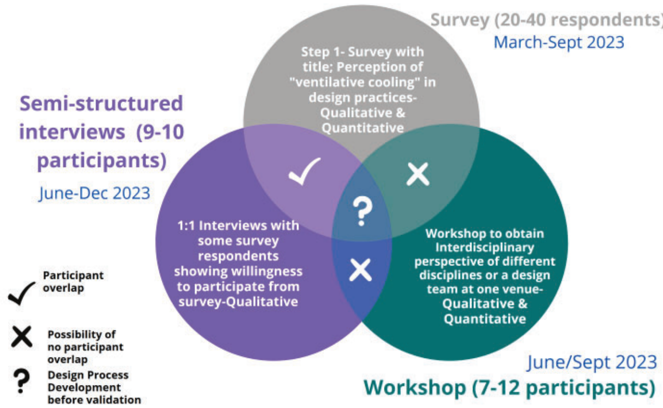


Figure 6: Planned methodology for the study for participatory action research

ERBE

The End
Any Questions?

Maha Sohail

3rd Year PhD Student at Munster Technological University, Cork, Ireland

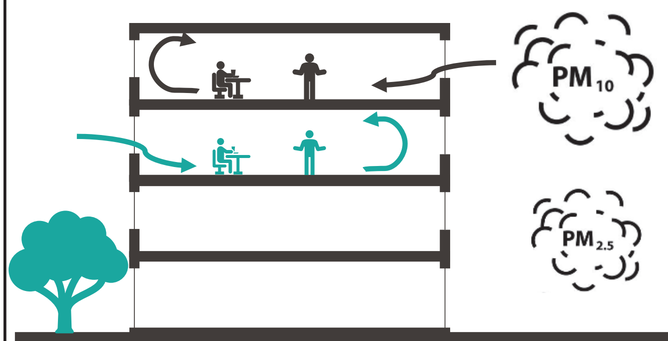
5th October 2023

ERBE

References

1. A. A. Y. Freewan, "Advances in Passive Cooling Design: An Integrated Design Approach," Zero and Net Zero Energy, Sep. 2019, doi: 10.5772/INTECHOPEN.87123.
2. P. B. Purup and S. Petersen, "Requirement analysis for building performance simulation tools conformed to fit design practice," *Autom Constr*, vol. 116, Aug. 2020, doi: 10.1016/J.AUTCON.2020.103226.
3. P. B. Purup and S. Petersen, "Research framework for development of building performance simulation tools for early design stages," *Autom Constr*, vol. 109, Jan. 2020, doi: 10.1016/J.AUTCON.2019.102966.
4. P. B. Purup and S. Petersen, "Characteristic traits of visualizations for decision-making in the early stages of building design," *J Build Perform Simul*, vol. 14, no. 4, pp. 403–419, 2021, doi: 10.1080/19401493.2021.1961864.
5. M. Kolokotroni and P. Heiselberg, "IEA-EBC Programme-Annex 62 Ventilative Cooling Ventilative Cooling STATE-OF-THE-ART REVIEW".
6. "RIBA Plan of Work." https://www.architecture.com/knowledge-and-resources/resources-landing-page/riba-plan-of-work (accessed Sep. 21, 2022).
7. S. Halperin and O. Heath, "Political research : methods and practical skills," p. 506, Accessed: Oct. 15, 2022. [Online]. Available: https://global.oup.com/academic/product/political-research-9780198820628
8. S. Omrani, V. Garcia-Hansen, B. Capra, and R. Drogemuller, "Natural ventilation in multi-storey buildings: Design process and review of evaluation tools," Build Environ, vol. 116, pp. 182–194, May 2017, doi: 10.1016/J.BUILDENV.2017.02.012.
9. C. McGrath, P. J. Palmgren, and M. Liljedahl, "Twelve tips for conducting qualitative research interviews," *https://doi.org/10.1080/0142159X.2018.1497149*, vol. 41, no. 9, pp. 1002–1006, 2018, doi: 10.1080/0142159X.2018.1497149.
10. CIBSE, "Environmental Design - CIBSE Guide A (8th Edition)," Environmental design CIBSE Guide A, vol. 552, no. F-14, pp. 1–10, 2015, Accessed: Apr. 29, 2022. [Online]. Available: www.cibse.org
11. Darçın, P. (2020). A Conceptual Architectural Design Process For Ventilation In Built Environment. MEGARON / Yıldız Technical University, Faculty of Architecture E-Journal. https://doi.org/10.14744/megaron.2020.84756

EPFL



Can naturally ventilated office buildings cope with dusty outdoor air?

Evangelos Belias[1,2], Flourentzos Flourentzou[2], Dusan Licina[1]

1 Human-Oriented Built Environment Lab, EPFL

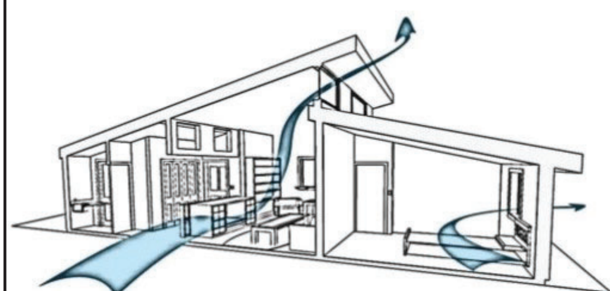
2 Estia SA, Lausanne, Switzerland

École polytechnique fédérale de Lausanne

AIVC 2023
05.10.2023

EPFL

Natural ventilation advantages

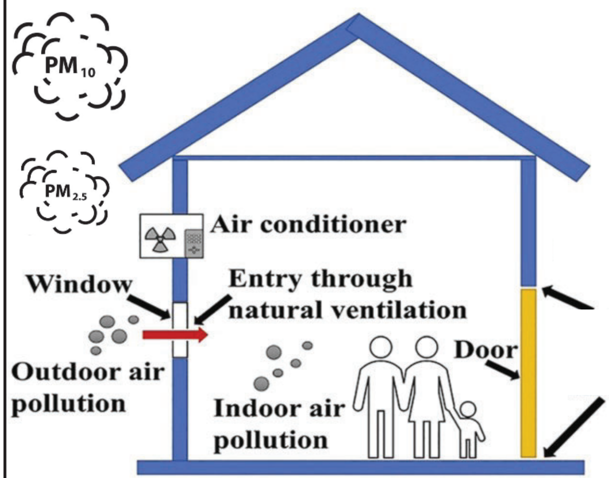


- Comfort
- Indoor air quality (IAQ)
- Save energy
- Low operational and grey energy demand

(Flourentzou et al., 2017)

Evangelos BELIAS

Natural ventilation and outdoor air pollution



(Hossain et al. 2021)

- The use of NV increase the penetration of outdoor air pollutants
  (Stabile et al., 2017)
- Particulate matter (PM) provokes severe health impacts
  (Logue et al., 2012)
- Lack of studies that examine the resilience of NV in polluted areas

3

Evangelos BELIAS

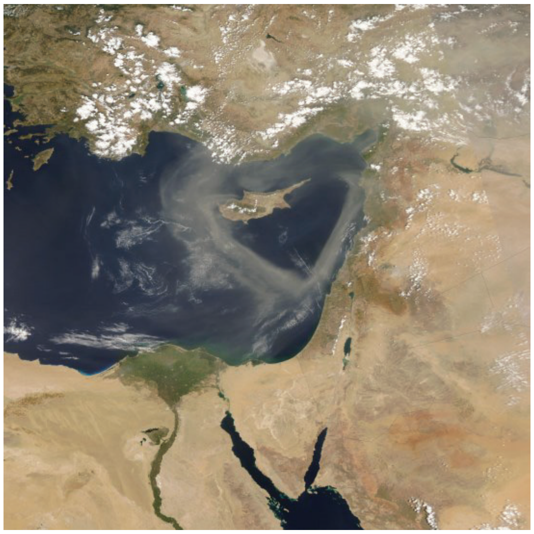
Dust episodes, arid areas and climate change

- ~40% of the planet's surface
- 2.1 billion people
  (Katra & Krasnov, 2020)
- Need to examine the resilience of NV in such environments

4

Can naturally ventilated buildings cope with dusty environments?

Evangelos BELIAS

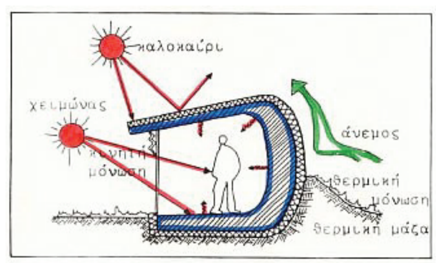


https://earthobservatory.nasa.gov/

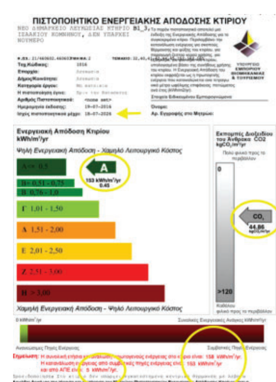
Investigated building

Evangelos BELIAS

- Bioclimatic principles
  - High thermal mass/insulation
  - NV – many window opening positions
  - Ceiling fans
  - Solar protection
- AC units for heating/cooling
- Occupant-centered control
- Measurements
  - Energy consumption
  - IEQ – Subjective + Objective



Technical Chamber of Greece, 20702-5/2010


ΠΙΣΤΟΠΟΙΗΤΙΚΟ ΕΝΕΡΓΕΙΑΚΗΣ ΑΠΟΔΟΣΗΣ ΚΤΙΡΙΟΥ

EPFL

Investigated building – IEQ monitoring plan

Evangelos BELIAS

Indoor PM sensor

Outdoor PM sensor

Indoor T, RH, CO_2, and Pressure sensor

Outdoor T, RH, and Pressure sensor

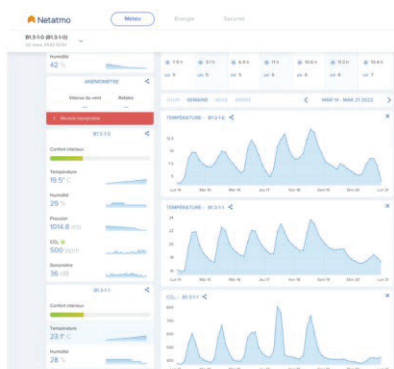
AIVC 2023

EPFL

Used sensors

Evangelos BELIAS

OPC-R2 sensor



https://www.alphasense.com/

https://www.netatmo.com/

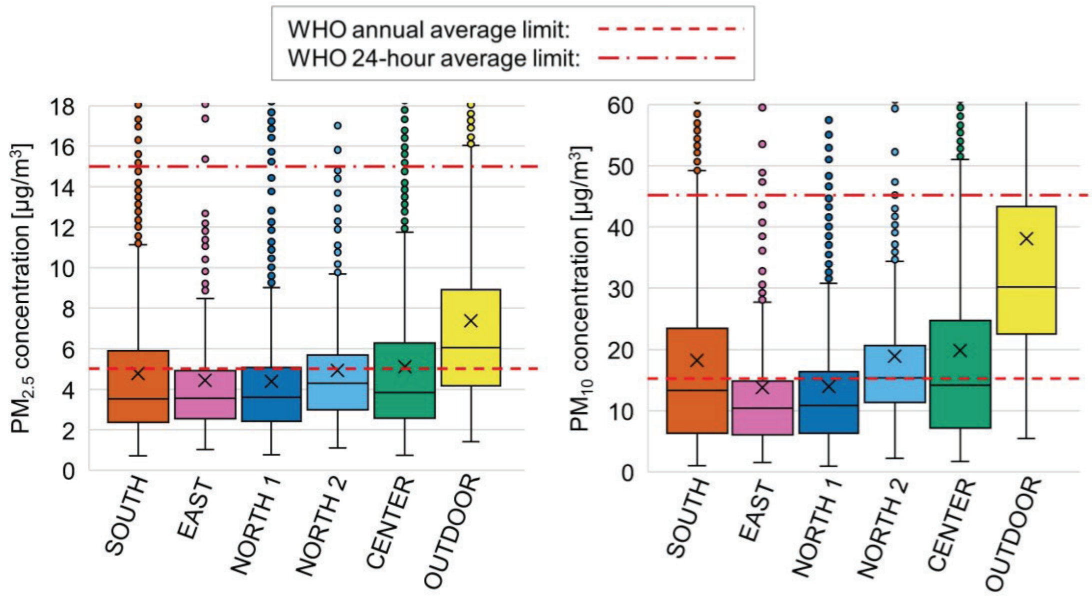
Sufficient accuracy compared to high grade sensors

(Demanega et al., 2021)

AIVC 2023

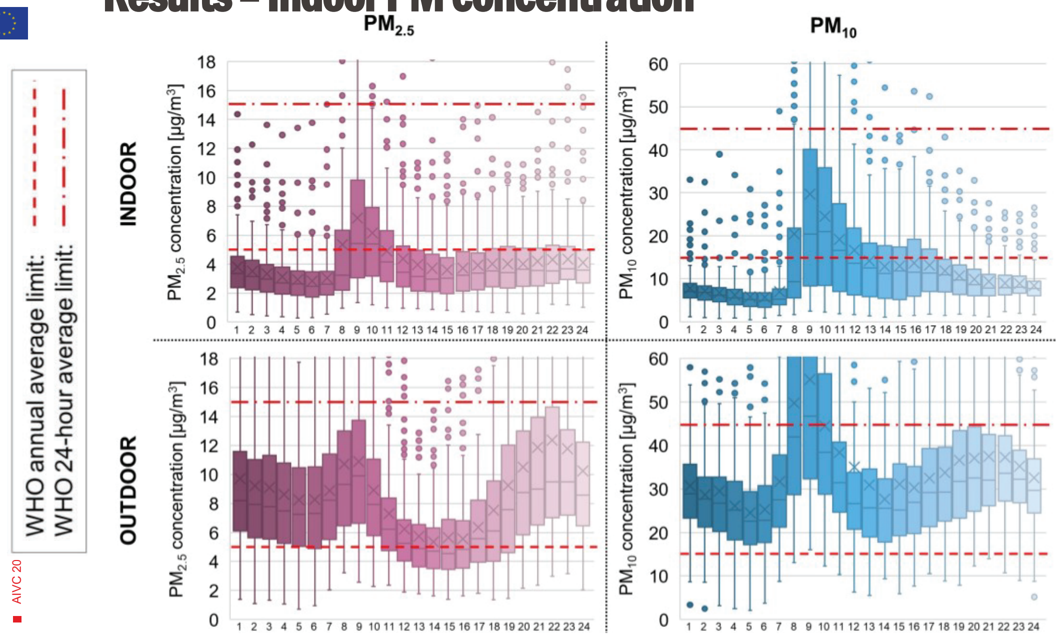
EPFL

Results – Indoor PM concentration



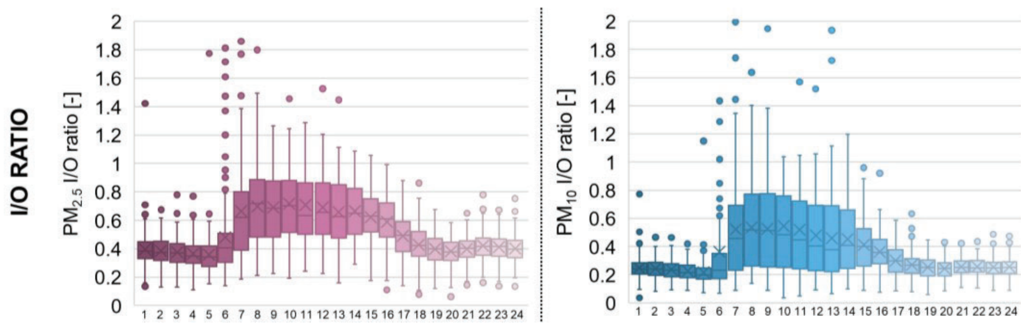
EPFL

Results – Indoor PM concentration



Results – Indoor to outdoor PM ratio

Evangelos BELIAS

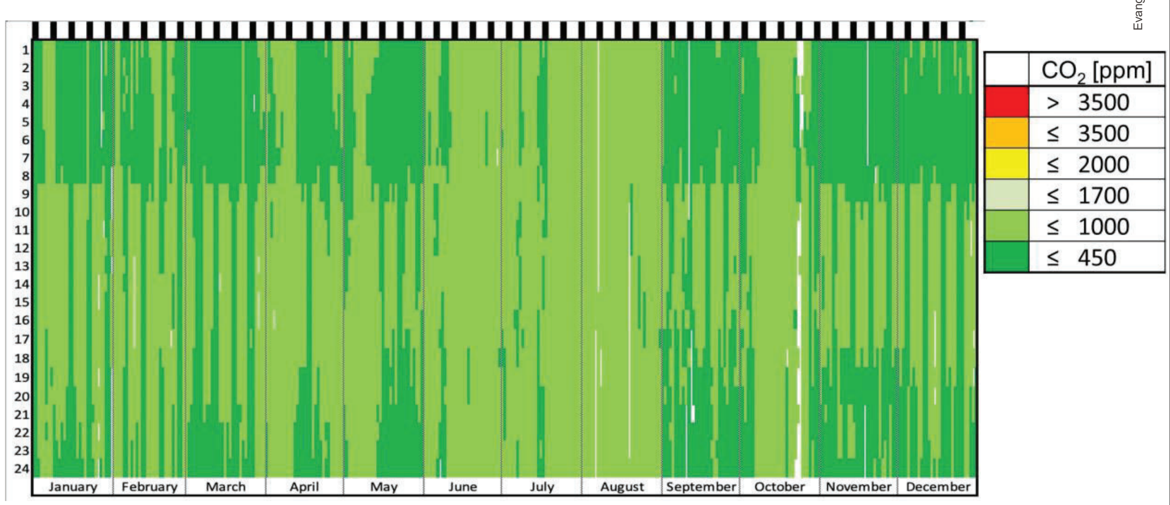


- Outdoor air is the main PM source
- During occupied hours higher I/O due to ventilation and indoor sources

AIVC 2023

Results – Indoor CO_2

Evangelos BELIAS



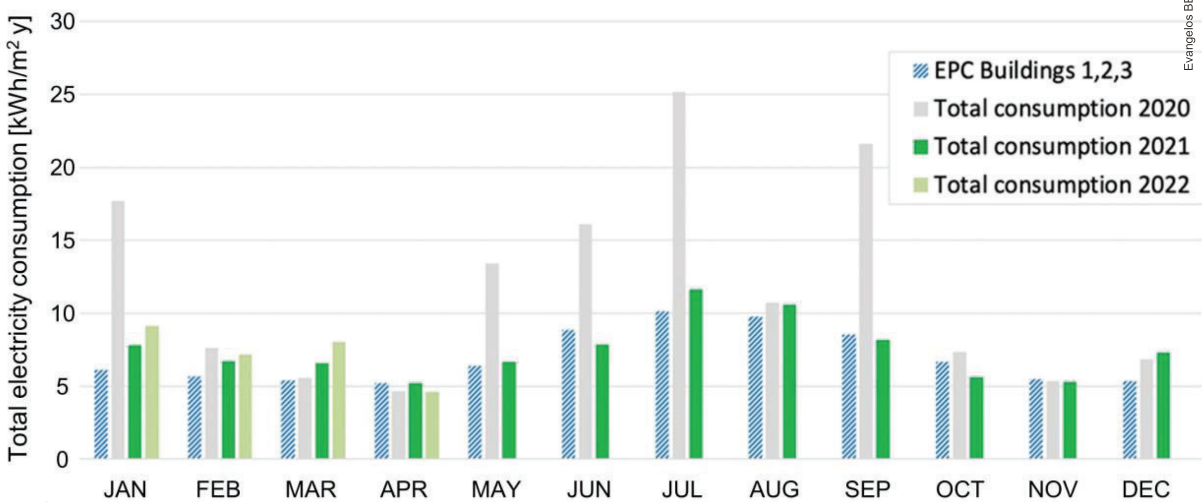
AIVC 2023

EPFL

Results – Predicted and real energy consumption

13

Evangelos BELIAS



AIVC 2023

EPFL

Summary – Conclusions

14

Evangelos BELIAS

- Indoor $PM_{2.5}$ levels complied with the WHO air quality guidelines in 4 out of 5 monitored spaces
- PM_{10} levels respected these limits in 2 out of 5 monitored spaces
- Indoor CO_2 concentrations remained below the 1000 ppm limit for more than 90% of the time
- More than 90% of the interviewed occupants evaluated the IEQ as exceptional or very good
- **NV buildings can offer high IEQ with low energy usage even in dusty environments**

Merci. Questions?

AIVC 2023

43rd AIVC 11th TightVent & 9th venticool Conference

DAIKIN

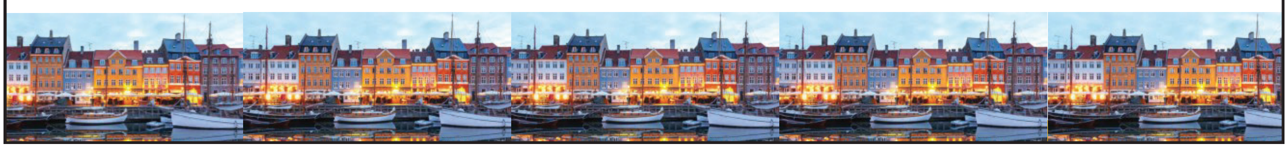
Osaka University

Distribution of Particulate Matter Concentration and Temperature Stratification Examined by Zonal Model and Experimental Measurements in Room with A Novel Portable Displacement Ventilation Cooling Unit

DAIKIN

Session 6C
(Ventilative cooling & Natural Ventilation)
11:00-12:30

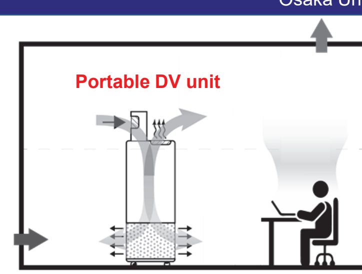
OSAKA UNIVERSITY
Toshio YAMANAKA

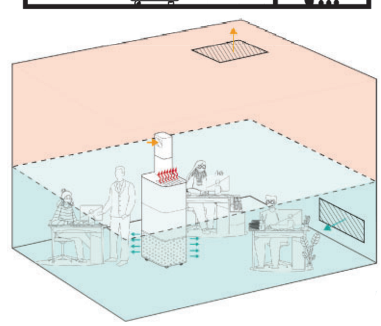


Objectives

Osaka University

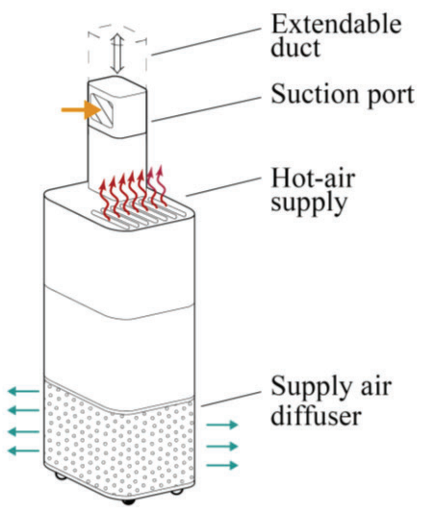
- **Objective:**
  - To investigate the improvement effect of ventilation effectiveness by a novel **portable DV unit** (PDV unit) in the room with displacement ventilation
- **Evaluation:**
  - Vertical temperature distribution
  - Vertical distribution of concentration of particle concentration
- **Method:**
  - Zonal Model
  - Full-scale experiment





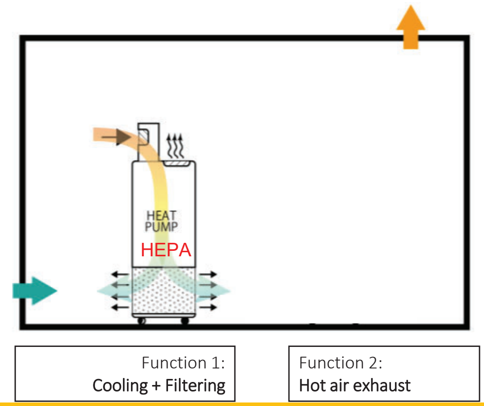
Portable DV unit : Conceptual Design

Osaka University



Prototype design of PDV unit

- PDV unit has two functions:
- The first function is cooling and filtering, that is, air cooler and HEPA filter.
- The second function is that exchanged heat is exhausted in the upper zone to boost the temperature stratification.



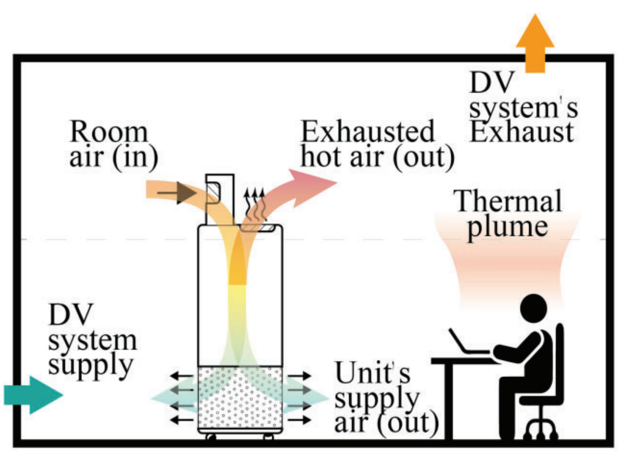
Combination of DV and PDV unit

Osaka University

PDV unit is ….

“Portable air purifier with air cooling and heating function for displacement ventilation”

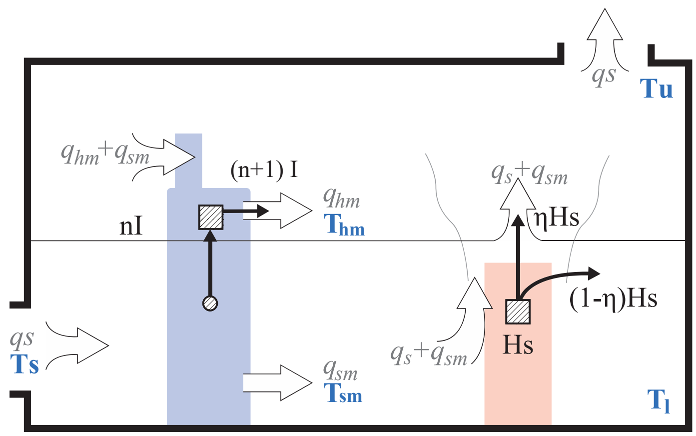
- Basically, PDV unit is supposed to be placed in the room with DV (Displacement Ventilation).



Zonal Model

Osaka University

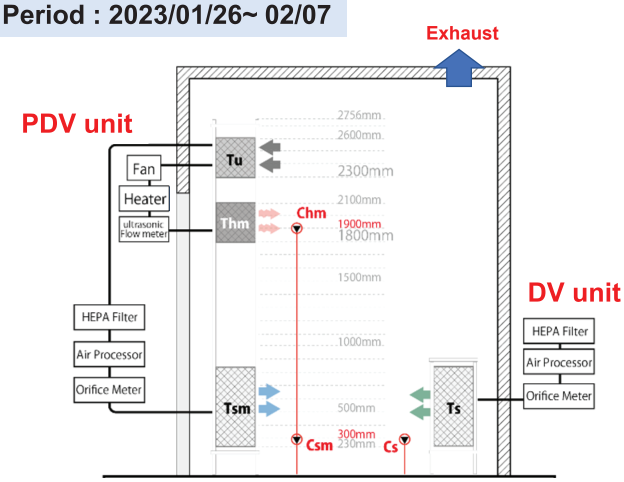
- Basically, this model is based on two zones, that is, the upper zone and the lower zone.
- The model consists of heat balance equations and airflow balance equations.
- This model is used to determine the conditions of parameters for experiment.



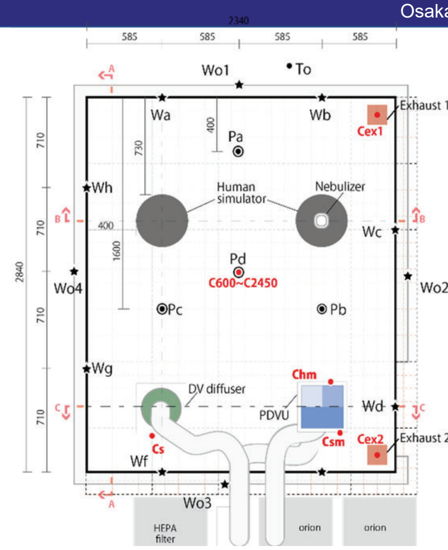
Experimental chamber for full-scale experiment

Osaka University

- **Period : 2023/01/26~ 02/07**



Section of experimental chamber

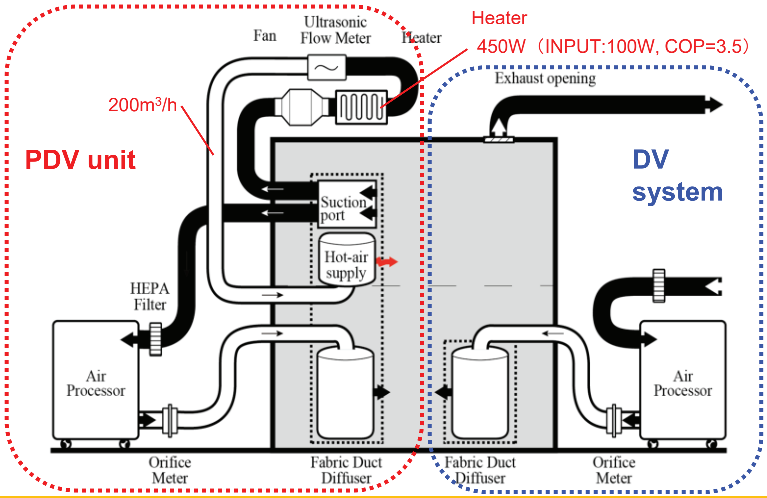


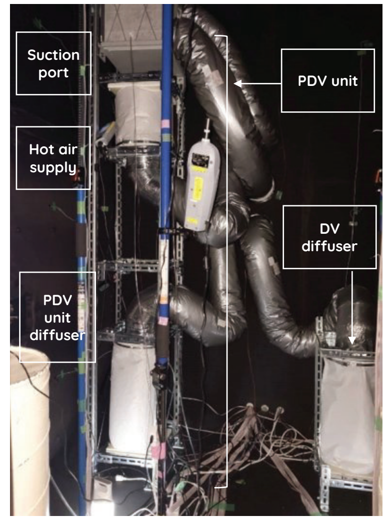
Plan of experimental chamber

Experiment equipments

Osaka University

- In fact, the PDV unit is not an all-in-one unit, but composed of separate components in the experiment,



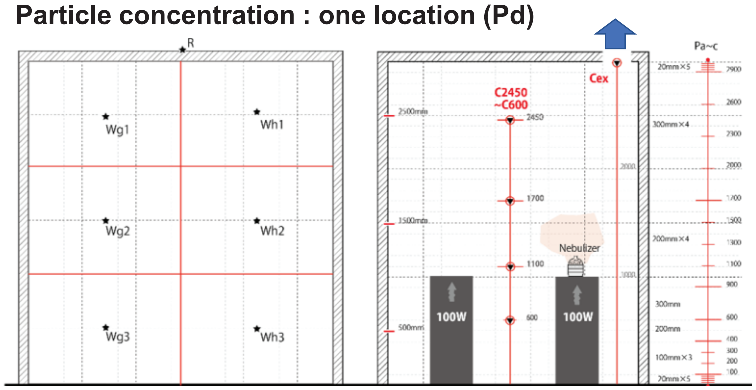


Inside view of the chamber

Measurement points of temperature and PM

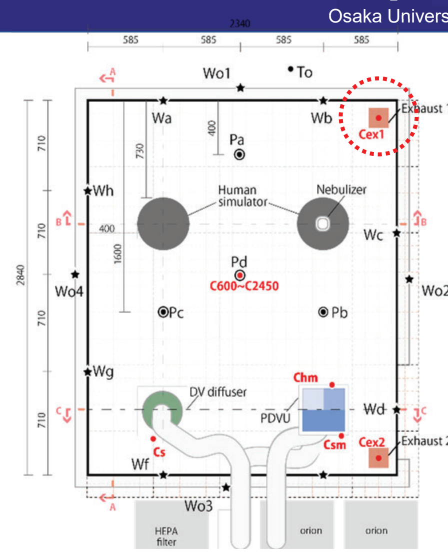
Osaka University

- Temperature gradient : three locations (Pa, Pb, Pc)
- Particle concentration : one location (Pd)



Wall temperature PM concentration Air temp.

Section of experimental chamber

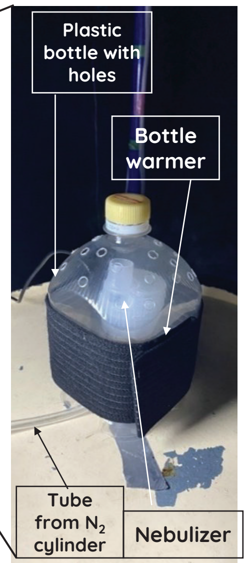


Plan of experimental chamber

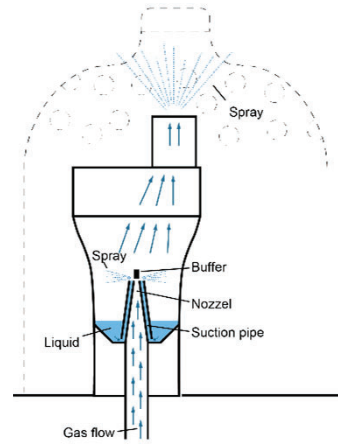
Two person simulators and nebulizer

Osaka University

Person simulator with 100W heat emission



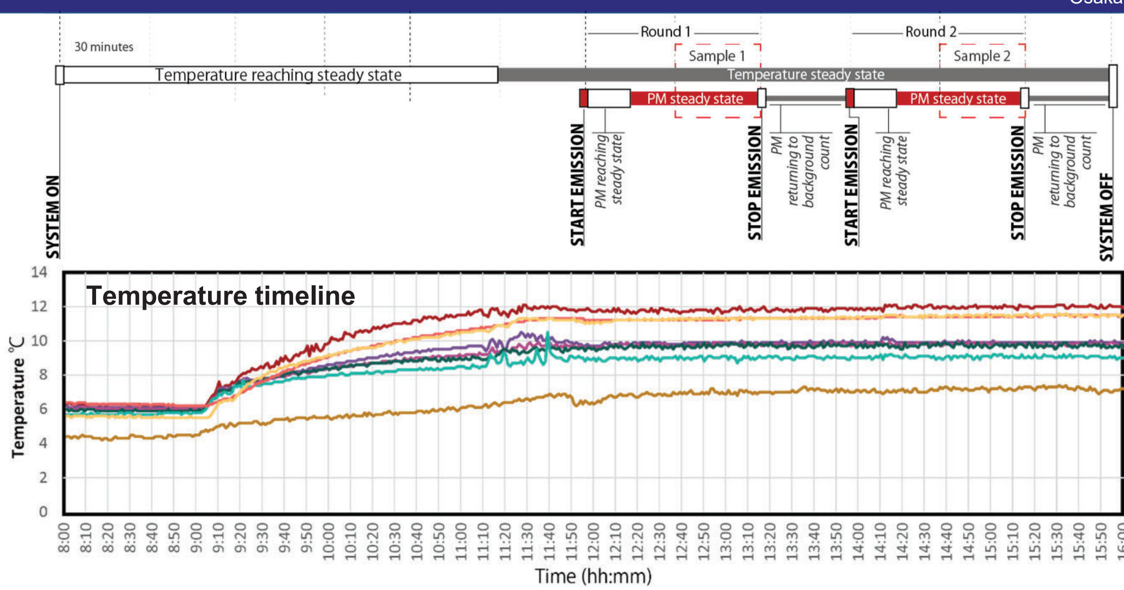
Artificial saliva was used with 12 g salt (NaCl) and 76 g glycerine for 1 L of distilled water.



Section of nebulizer

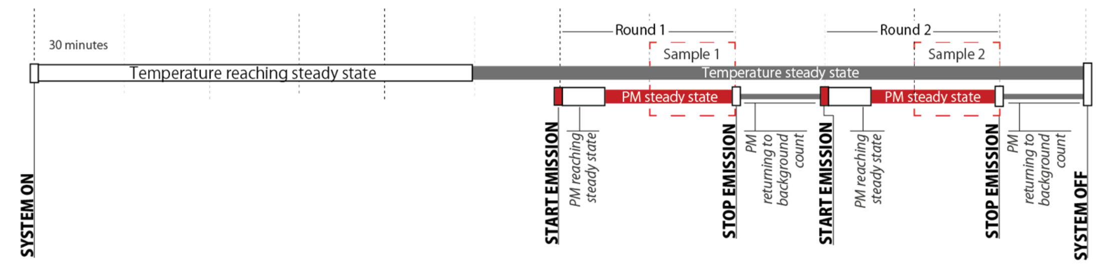
Time schedule of experiment

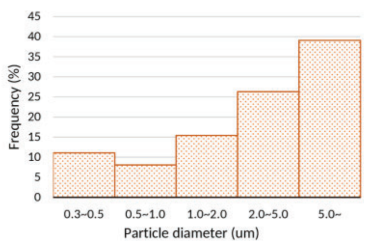
Osaka University



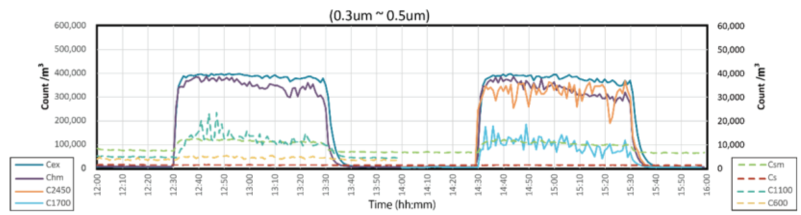
Experiment timeline and PM concentration

Osaka University





Particle size distribution at outlet of nebulizer



Timeline of particle concentration (Example of 0.3~0.5μm)

Experimental cases

Osaka University

Case		Flow rate (m3/h) qsm	qs
1	DV200	0	200
2	DV200_PU100	100	200
3	DV200_PU200	200	200
4	DV200_PU300	300	200
5	DV100_PU200	200	100
6	DV100_PU100	100	100
7	PU200_Ex1	200	0

Airflow rate of PDV unit (qsm)

Airflow rate of DV (qs)

- Base case of DV 100m³/h only (case 1)
- DV200 +PDV unit 100~300 m³/h (cases 2–4)
- DV100 +PDV unit 100~200 m³/h (cases 5–6)
- Special case of PDV 200m³/h only without any ventilation (case 7)

Experimental results and investigations

Osaka University

- **Three groups for investigation**:

➢**Group 1** : Changing PDV unit's supply flowrate (q_{sm}) with the same DV flowrate

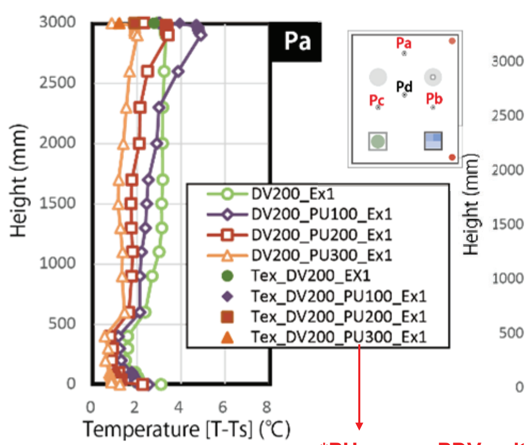
➢**Group 2** : Changing DV supply flow rate (q_s) with the same PDV unit flowrate

➢**Group 3** : Changing the ratio of q_s & q_{sm} under the same total flow rate

Group 1: Effect of Changing PDV unit's supply flowrate

Osaka University

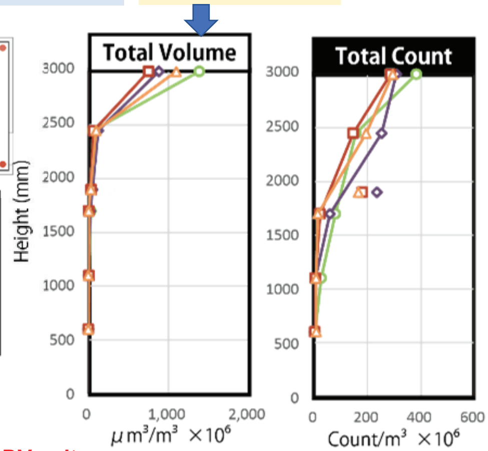
- **Constant DV flowrate (200 m³/h)**
- **Varied PDV unit flow rate (0~300 m³/h)**



Temperature

*PU means PDV unit

Total volume of particles with different diameters



Particle concentration

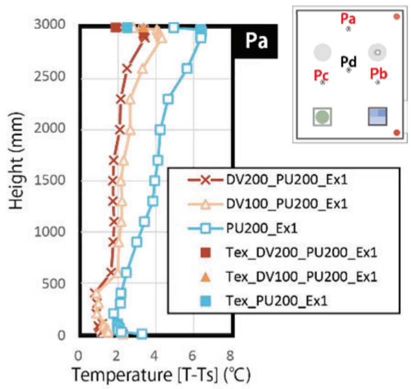
Temperature:
- It is observed that cases with PDV unit of 100 or 200 m3/h have a stronger temperature stratification.
- When PDV unit flowrate is the larger, the overall temperature becomes the lower.

Particle concentration:
- The effect of the PDV unit's flowrate on the particle concentration is not so large.

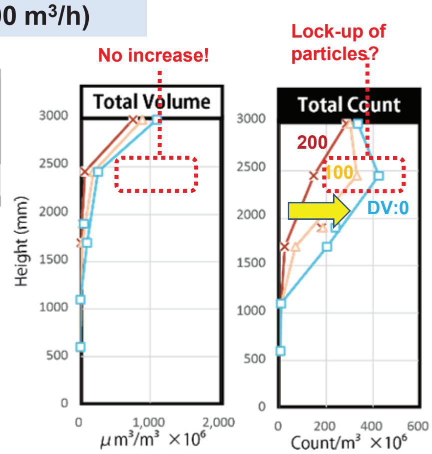
Group 2: Effect of Changing DV supply flowrate

Osaka University

- Constant PDV unit flowrate (200 m^3/h)
- Varied DV unit flow rate (0~200 m^3/h)



Temperature



PM concentration

Temperature:

- Decreasing the DV supply flowrate from 200 to 0 m^3/h cause a shift in the temperature distribution.
- Especially, the case without DV (that is PDV only) shows the increase of temperature ranging from 1 to 2 ℃ with a stronger temperature stratification.

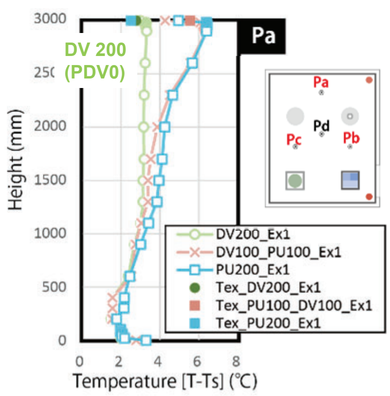
Particle concentration:

- Decreasing the DV airflow rate brings the increase of the particle count and slight increase of volume concentration.
- There is no particles in the lower zone even if no ventilation.
- PDV unit has the distinct effect of cleaning air in occupant zone and increase of stability due to strong temperature stratification.

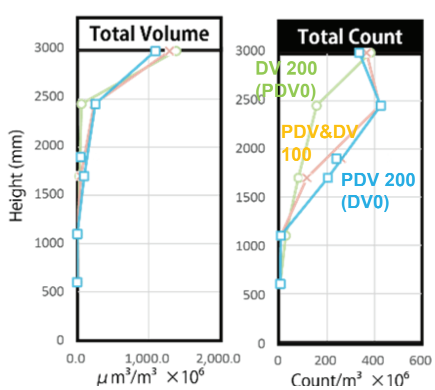
Group 3: Effect of Changing flowrate ratio

Osaka University

- DV flowrate + PDV unit flow rate is constant at 200 m^3/h



Temperature



PM concentration

Temperature:

- The case of DV200 shows the lowest temperature in upper zone.

Particle concentration:

- Increasing PDV unit airflow rate causes an increase in the top zone particle count.
- It can be said that DV is more effective than the PDV unit if the airflow rate is the same, but PDV unit has the capacity of air purification in the occupancy zone.
- Purification capacity of PDV unit depends on suction location!

INPUT and Imaginary COP in Experiment

Osaka University

b. PDV unit capacity, COP, and required input power

Cases		Experiment			
		Q_{sm} (W)	Q_{hm} (W)	COP(−)	I(W)
Far Exhaust	DV200_ PU100_Ex1	217	411	1.1	195
	DV200_PU200_Ex1	379	329	−7.6	−50
	DV200_PU300_Ex1	428	407	−20.7	−21
	DV100_PU200_Ex1	316	454	2.3	138
	DV100_PU100_Ex1	228	417	1.2	189
	DV300_PU300_Ex1	348	445	3.6	97
PU only	PU200_Ex1	507	385	−4.2	−122

Input power and COP:

- Supposed Input power(100W) and COP(3.5) of the cooling unit are turned out to be not the same as the calculated ones based on the measurement data in the experiment. This might be caused by energy loss through ducts.

Zonal model			
Q_{sm} (W)	Q_{hm} (W)	COP(−)	I(W)
350	450	3.5	100

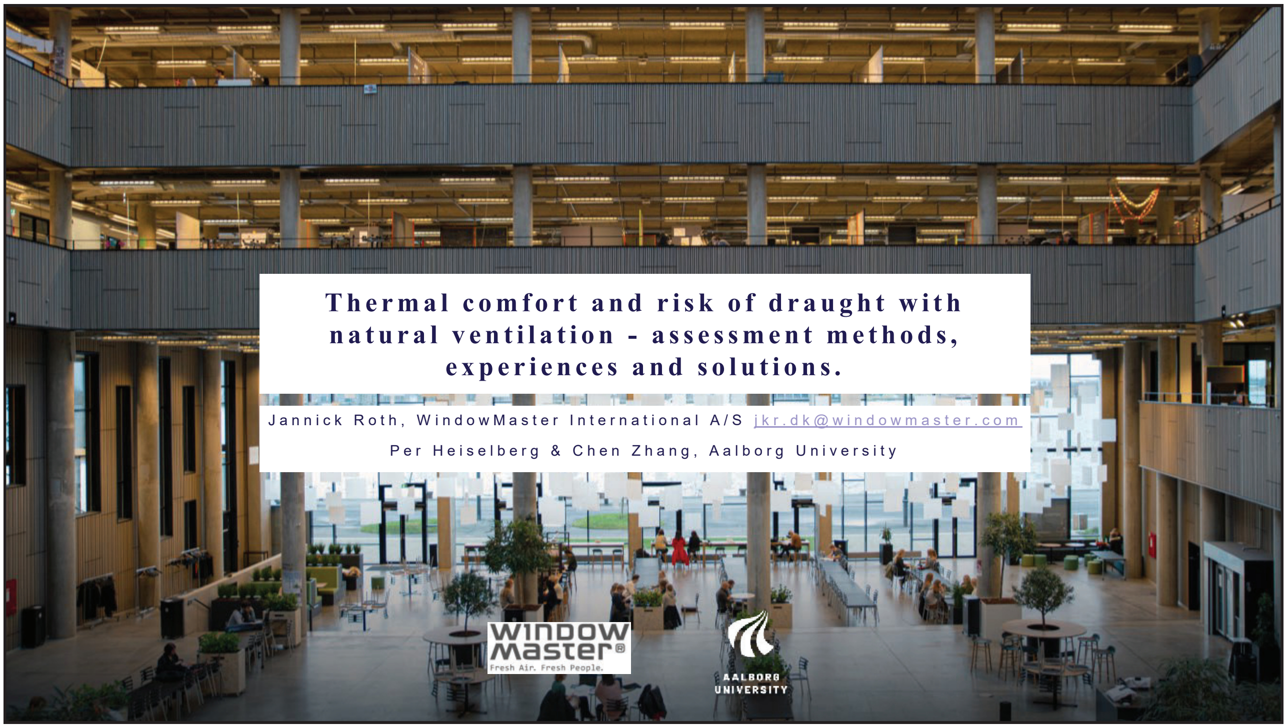
Concluding remarks

Osaka University

- **The novel PDV unit** can enhance the temperature stratification and reduce the particle concentration in the occupied zone with Displacement Ventilation.
- Additionally, **this PDV unit** could work as a replacement system for Displacement Ventilation system.
- **As for the effect of parameters:**
  - **Increasing PDV unit flowrate** reduces temperature at all heights
  - **Decreasing DV flowrate** supplemented by the PDV unit have no effect on occupied zone (lower zone)
  - **PDV unit alone is** potentially effective in cooling and filtering the occupied zone, and the height and location of suction opening is important.
- **Improvement:**
  - **Filtration** will be recommended to be applied for hot air exhaust as well.

Thank you for listening!

OSAKA UNIVERSITY



Thermal comfort and risk of draught with natural ventilation - assessment methods, experiences and solutions.

Jannick Roth, WindowMaster International A/S jkr.dk@windowmaster.com
Per Heiselberg & Chen Zhang, Aalborg University

1

Objectives

Estimating the risk of draught for natural ventilation systems

The key objectives

- Is the current (Fangers) Draught Rate method suitable for the evaluation of natural ventilation and are there currently other more appropriate methods for assessing the risk of draught?
- What are the main findings and experiences until now and to what extent can we use these?
- Examples of solutions for ensuring thermal comfort in cold periods.

Why

- The majority of research and hence the assessment methods and tools for thermal comfort assessment of ventilation systems are not based on findings for natural ventilation solutions and do not take into account the specific characteristics of natural ventilation.
- This has created a lack of suitable methods for the assessment and performance evaluation of natural ventilation.

2

Assessment methods - Fanger

Fanger – risk of draught

Predicted percentage dissatisfied (%) expressed by:

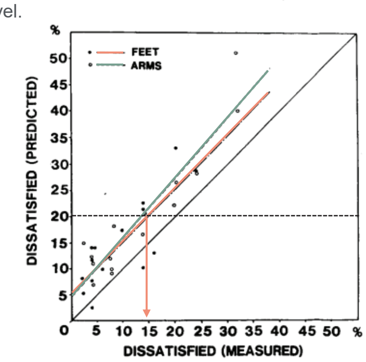
$DR = (34 - t_{a,l})(\bar{v}_{a,l} - 0.05)^{0.62}(0.37 \cdot \bar{v}_{a,l} \cdot Tu + 3.14)$

Where:

- *DR is the predicted percentage dissatisfied, %*
- *$t_{a,l}$ is the **local air temperature**, in degrees Celsius, 20 °C to 26 °C;*
- *$\bar{v}_{a,l}$ is the **local mean air velocity**, in metres per second, < 0,5 m/s;*
- *Tu is the **local turbulence intensity**, in percent, 10 % to 60 %*

Observations

- Model applies to people with sedentary activity and with a neutral thermal sensation for the whole body.
- Model is designed to predict the draught rate at the neck level.
- Overestimation is expected when predicting the draught at the arm or feet level.



WindowMaster®
Fresh Air. Fresh People.

Assessment methods - Berkeley

Berkeley (Schiavon et al 2016; Liu et al 2017)

- The maximum air speed at ankle level can be derived using:
- $V_{ankle} < 0.35 \cdot TS + 0.39$

Where:

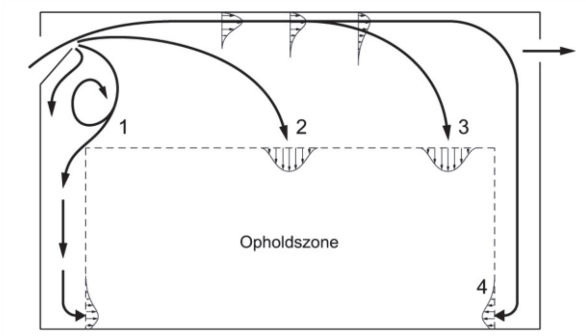
- *V_{ankle} air speed at 0.1m above floor, m/s*
- *TS whole body thermal sensation; Equal to PMV calculated using the input air temperature and speed averaged over two heights: 0.6m and 1.1m for seated occupants and 1.1m and 1.7m for standing occupants.*

Observations

- A new draught risk assessment method has been added in the recent ASHRAE 55-2020
- The method assesses the risk of draught at the ankle region, 0.1m above floor level, valid for clo < 0.7 and met < 1.3.

Airflow pattern with high-positioned openings

Typical air distribution conditions



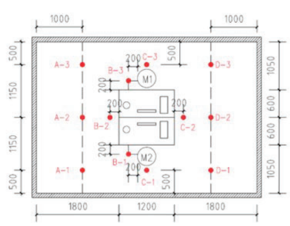
Explanation of air distribution conditions

Flow regime	Typically occurring	Flow pattern
1	Small driving forces (0.2 – 0.4 Pa) or low outdoor temperature supply air (high indoor/outdoor temperature difference).	Air distribution in the room will follow the displacement principle and the draught risk will be highest along the floor.
2 & 3	Driving forces ($\Delta p > 4$-6 Pa) or higher outdoor temperatures ($\Delta t < 5$ K)	Air distribution in the room will act as a thermal jet and traditional jet theory can be used to predict airflow path and draught risk will typically be highest at neck level.
4	For bottom-hung windows close to the ceiling during warmer outdoor temperatures	Air distribution in the room will act as an isothermal jet.

Laboratory measurements

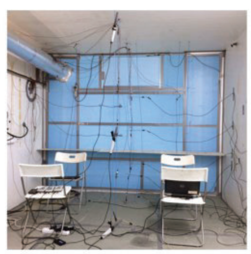
From research projects

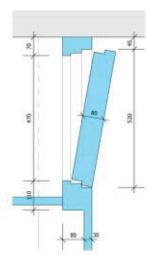
"Natural cooling and ventilation through diffuse ceiling supply and thermally activated building constructions" – AAU uni.



- Scenario 1: Heat load 30 W/m², a constant **ACH of 2** (85,5 m³/h)
- Scenario 2: Heat load 60 W/m² and a constant **ACH of 4** (171 m³/h).
- Temperature difference (indoor/outdoor air) varied from **0-32K**.
- Tu = 20%
- Named hereafter: **Zhang et al.**

"Naturligvis" (Naturally) - SINTEF



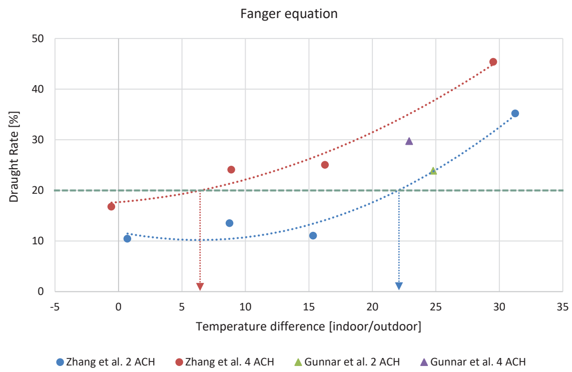


- Scenario 1: a constant **ACH of 2** (50,4 m³/h)
- Scenario 2: a constant **ACH of 4** (104 m³/h)
- Temperature difference (indoor/outdoor air) varied from **23-25K**.
- Tu = 20%
- Named hereafter: **Gunnar et al.**

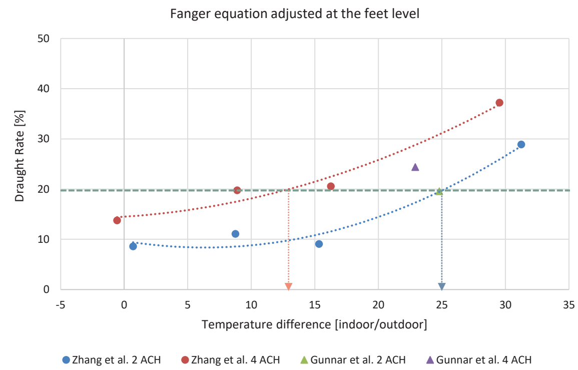
Fangers equation

Based on the highest DR in the room

A draught rate < 20% can be achieved at a temperature difference below 6 K and 22K for 4 and 2 air changes, respectively.

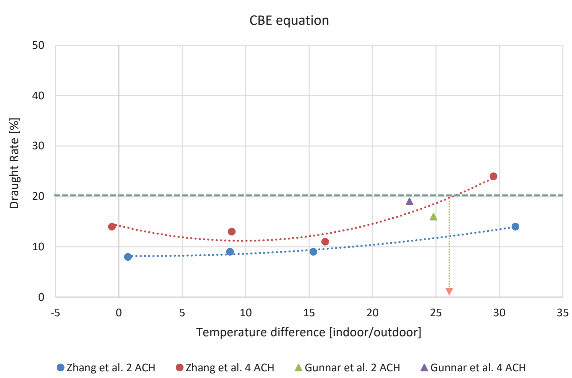


A draught rate < 20% can be achieved at a temperature difference below 13 K and 25K for 4 and 2 air changes, respectively.



Berkeley (Schiavon et al 2016; Liu et al 2017)

A draught rate < 20% can be achieved at a temperature difference below 26K for 4 air changes.

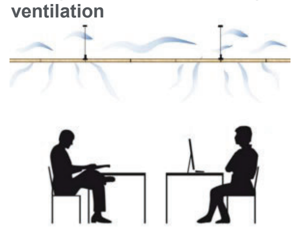


Solutions coping with draught

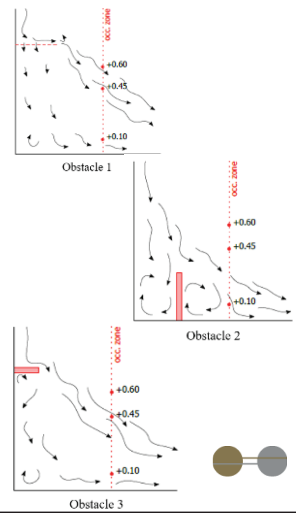
Examples

Goal	Solution
Higher air inlet temperature	▪ Double skin façade solutions
Lowered air velocities	▪ Diffuse ceiling supply ▪ Obstacles e.g. a perforated plate like a window sill. ▪ Radiator below incoming air.
Higher air inlet temperature and lowered air velocities	▪ Diffuse ceiling supply

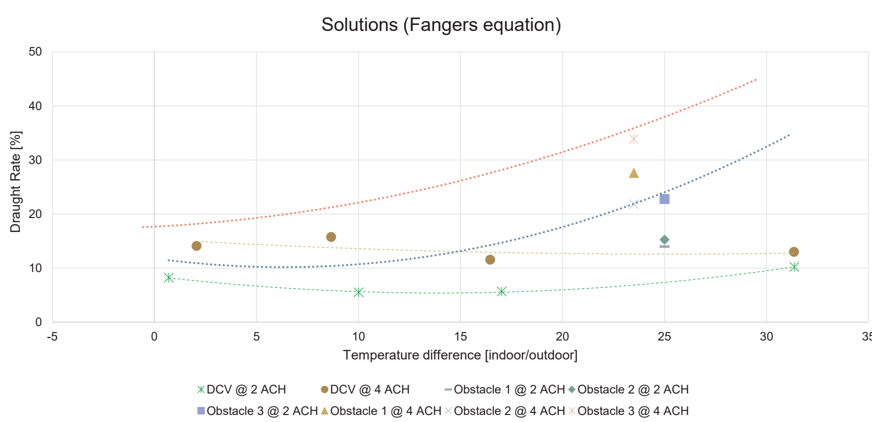
Zhang et al. – Diffuse ceiling ventilation



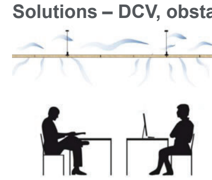
Gunnar – obstacles

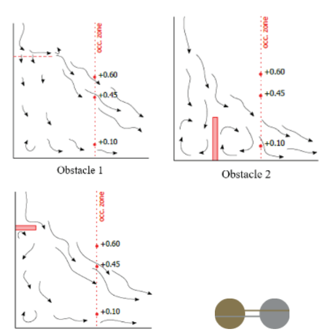


Solutions coping with draught



Solutions – DCV, obstacle 2, 1, 3





Conclusion & acknowledgement

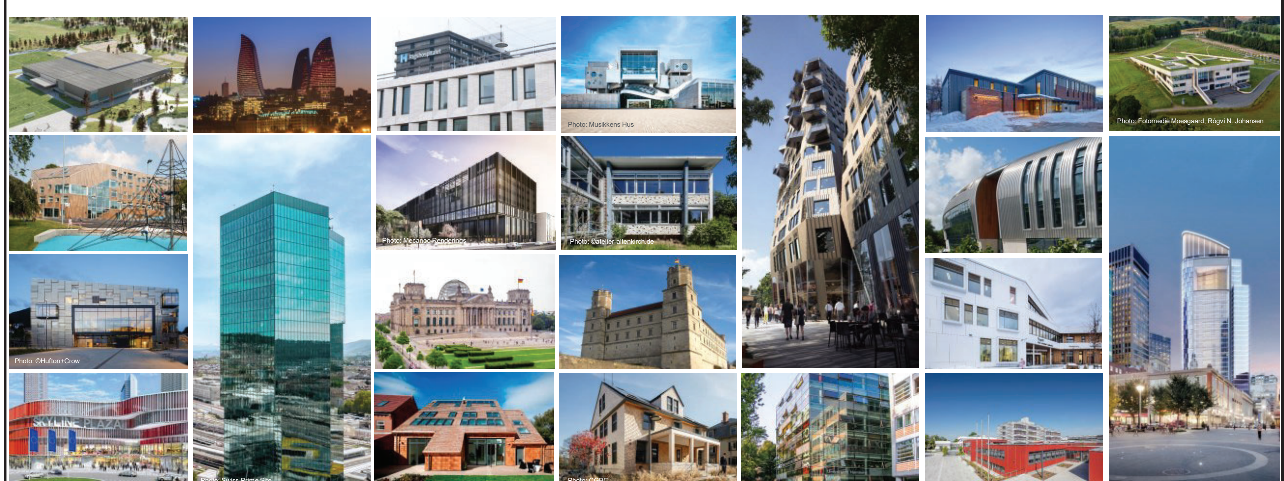
Main findings

- The commonly used **Fanger's method tends to overestimate** the draught risk associated with natural ventilation, especially in systems using displacement air distribution patterns.
- The results indicate **significant deviations in predicted draught rate** when different methods are utilized.
- **Further investigation** is needed to identify the most suitable method for evaluating draught risk in natural ventilation systems.

Acknowledgement

- This work was supported by the project: Hybridene – Optimal hybrid ventilasjon I fremtidens bygg, financed by The Research Council of Norway (project nr. 327591).

Questions?



Evaluation of sensor-based air cleaners to remove $PM_{2.5}$ and TVOC from indoors with pollutant sources of smoking and burning candles

- Kathrine Andersen, Aarhus University,
- Stig Koust, Danish Technological Institute
- Freja Rasmussen, Danish Technological Institute
- Li Rong, Aarhus University

AARHUS UNIVERSITY

DANISH TECHNOLOGICAL INSTITUTE

1

Motivation

- 90 % of time indoor and air pollution is a large cause of mortality.
- Light candles and smoke cigarettes
  - Increases the emissions of particles.
  - Smoke: PM2.5
  - Candles: Ultrafine
  - Both: TVOCs
- To combat these emissions: employ portable air cleaners
- To simplify the control: embedded IAQ sensor with auto mode

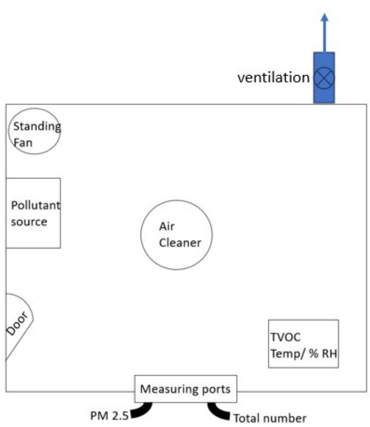
2

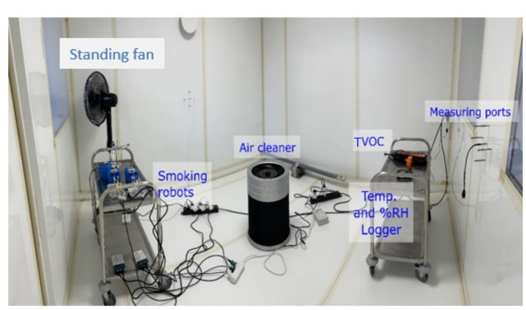
Objectives of this study

- 1) Accuracy of embedded sensors in air cleaners
  - Cigarettes smoke
  - Burning candles
- 2) Regulation of fan speed by auto mode
  - PM2.5
  - TVOCs

Methodology

- An airtight test chamber of 20 m^3 with Teflon surfaces.
- The set-up



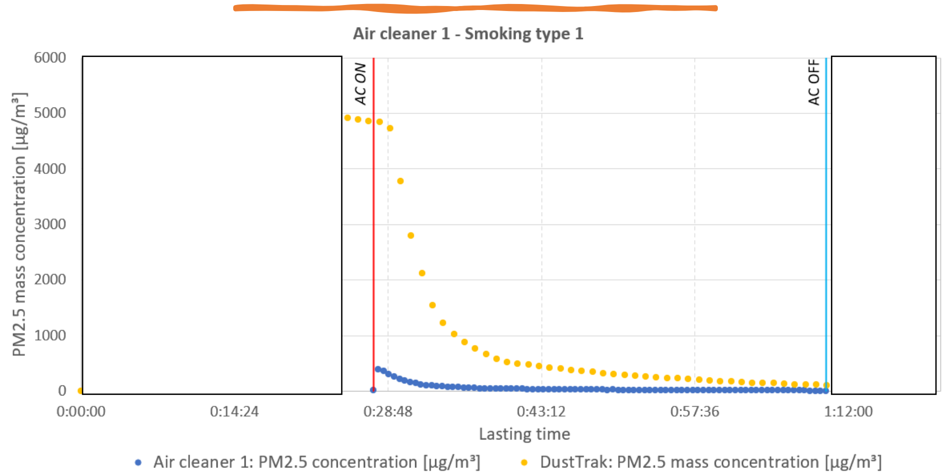


Air cleaners and types of experiments

- Register and control from outside of the test chamber
- Two TVOC sensors
- Types of experiments:
  - 2 types of smoke experiments
  - 1 type of candles experiments.
- For more details about each air cleaner and the procedure see the paper.

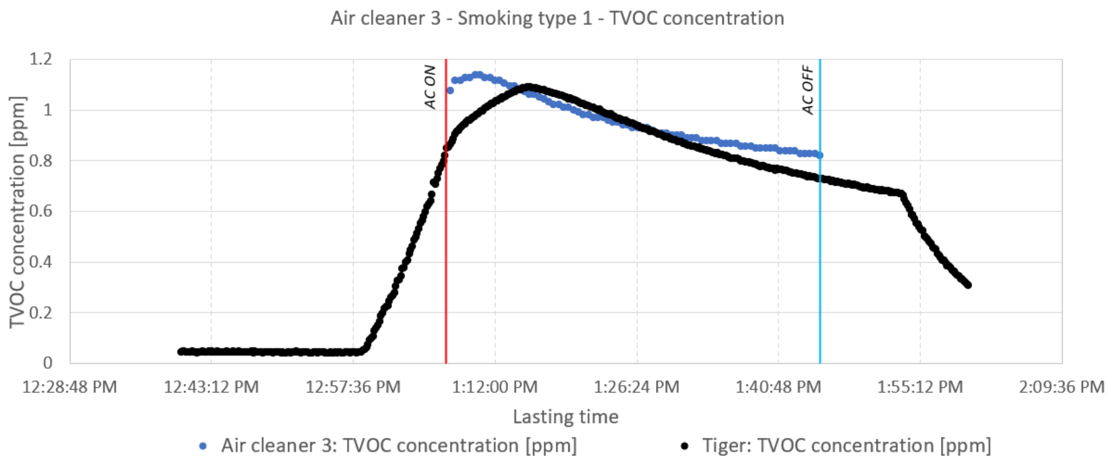
5

Smoke experiment – Air cleaner 1

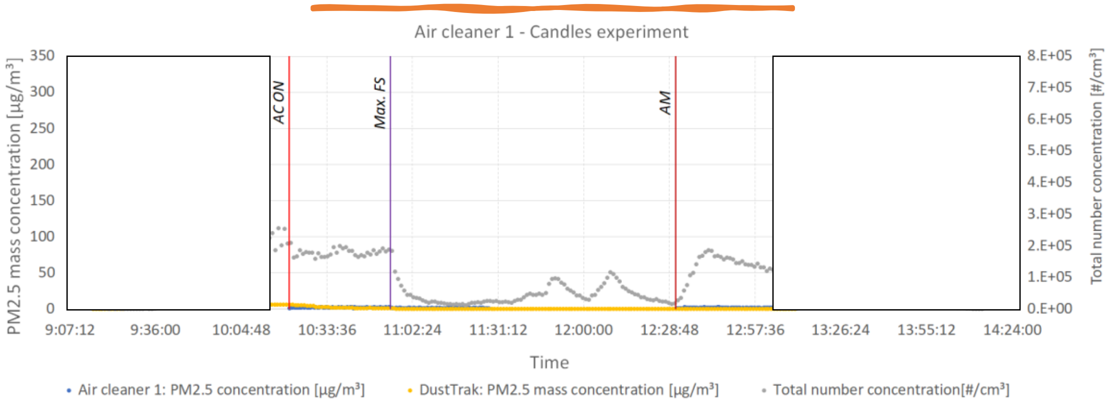


6

Smoke experiment – Air cleaner 3



Candles experiment – Air cleaner 1



Conclusions

- All embedded sensors detected the PM2.5 mass concentration emitted by smoke.
  - Underestimated, to different degrees, compared to the advanced instruments.
  - Affected the adjustment of fan speed
  - Extended exposure time.
- None of the sensors detected the rise of the ultrafine particles from candles
  - No automatically adjustment of fan speed
  - All the air cleaners: able to reduce
  - Reduction rate increased with the fan speed
  - Not done by auto mode
  - Auto mode is not preferred for high concentrations of ultrafine particles
- The TVOC sensor with exacted data
  - Register the TVOC concentration for smoke
  - No influence on the fan speed adjustments

ACKNOWLEDGEMENTS

This study was part of a larger project conducted by Danish Technological Institute founded by RealDania and Grundejernes Investeringsfond:

https://www.teknologisk.dk/projekter/mobile-luftrensere-hvor-godt-virker-de/44379

Thank you for your attention!

- Kathrine Andersen, Aarhus University, kand@teknologisk.dk
- Stig Koust, Danish Technological Institute, stko@teknologisk.dk
- Freja Rasmussen, Danish Technological Institute, frer@teknologisk.dk
- Li Rong, Aarhus University, li.rong@cae.au.dk

AARHUS UNIVERSITY

DANISH TECHNOLOGICAL INSTITUTE

Developing methodology for testing of gas-phase air cleaners based on perceived air quality

Pawel Wargocki (pawar@dtu.dk)
Technical University of Denmark, DTU Sustain

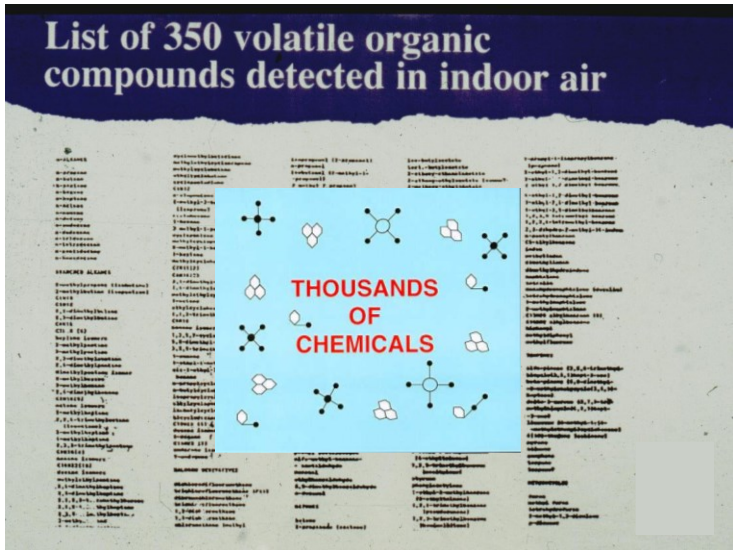
43rd AIVC -11th TightVent & 9th venticool Conference
October 4-5, 2023
Aalborg University, Copenhagen, Denmark

1

Background

2

Organic chemicals in indoor air



3

Methods and standards for testing gas-phase air cleaners

Standard/Protocol	Methods	Challenge Gaseous	Measured Gaseous	Performance index
Air cleaner, Standardization Administration of China (GB/T-18801)	Pulldown	Single species gas e.g.,	Formaldehyde toluene	CADR
Air cleaner, Standardization Administration of China (GB/T-18801)	Singlepass	Single species gas e.g.,	Formaldehyde toluene	Single-pass efficiency
Reduced Energy Use Through Reduced Indoor Contamination in Residential Buildings, NCEMBT (NCEMBT 061101), US report	Pulldown	Eight VOCs mixture	$TVOC_{toluene}$ formaldehyde	CADR
Air cleaner, Japanese Standard Association (JIS C 9615-2007)	Singlepass	NO_2, SO_2	NO_2, SO_2	Single-pass efficiency
Air cleaners of household and similar use, Japan Electrical Manufacturers Association (JEM 1467-1995)	Pulldown	Tobacco smoke	Ammonia, acetaldehyde, and acetic acid	Removal rate
Independent air purification devices for tertiary sector and residential applications - Test methods - Intrinsic performances, Association Française De Normalisation (XP B44-200)	Singlepass	Four VOCs mixture	Acetone, acetaldehyde, heptane, and toluen	Single-pass efficiency , CADR
Test method for assessing the performance of gas-phase air cleaning media and devices for general ventilation (ISO 29464:2017)	Singlepass	VOCs, acids, bases, and others	VOCs, acids, and bases, and others	Single-pass efficiency

Source: Afshari et al. (2022)

Afshari et al. (2022)

4

Byproduct generation Incomplete oxidation

Aldehydes → **formaldehyde**, formic acid, CO

Alcohols → aldehydes → acids → shorter carbon chain alcohols and acids →**formaldehyde**, methanol → CO_2 and H_2O

Benzene → phenol

1-Butanol → butanal (butyraldehyde), butanoic acid, ethanol, acetaldehyde, (propanal (propionaldehyde) and propanol, propanoic acid) → (ethanol, **formaldehyde**) → methanol, **formaldehyde** and formic acid

Ethanol → methanol, acetaldehyde, **formaldehyde**, acetic acid, formic acid

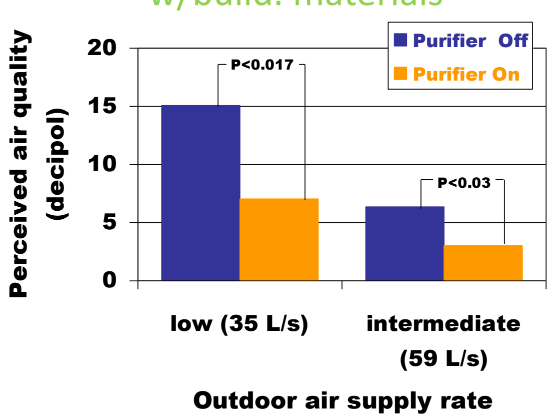
Methanol → methyl formate (measured in liquid form only), **formaldehyde**, methylal (formaldehyde dimethyl acetal

Toluene → benzaldehyde, benzoic acid, cresol, benzyl alcohol, phenol, benzene, formic acid

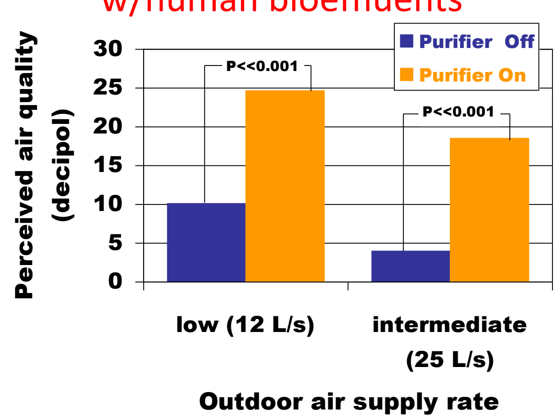
Source: Mo et al. (2009)

Detection of by-products using sensory assessments

improved PAQ (lower decipol) w/build. materials



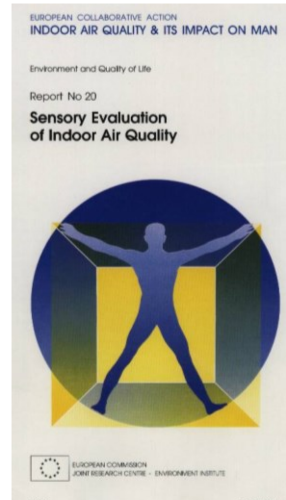
reduced PAQ (higher decipol) w/human bioeffluents



Source: Kolarik and Wargocki (2006)

Sensory evaluations of air quality

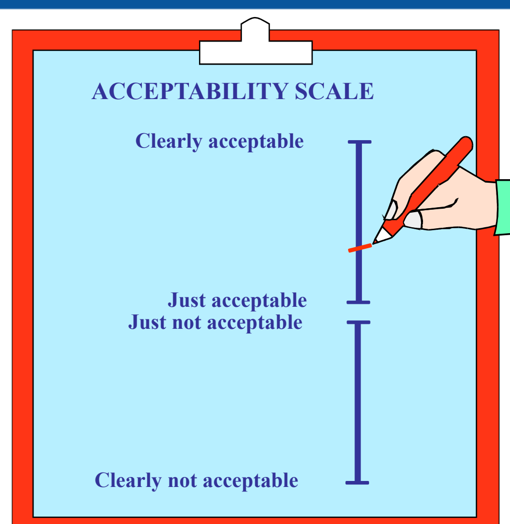
- Sensory evaluations of air quality have been used routinely in indoor air research for the past 25 years.
- Perceived air quality has been used to define ventilation rates prescribed in the majority of present standards (eg. 16798, ASHRAE 62.1)
- Perceived air quality has been used to examine emissions from building materials, it is included as a part of testing in few labelling schemes for building and furniture materials (Finnish M1 Label; Danish Indoor Climate Label, and German AgBB Scheme) and the standard describing sensory testing in connection with emission testing (ISO 16000-30)
- Perceived air quality has been used extensively in the past in field studies as a measure of air quality in rooms and buildings (eg. Wargocki et al., 2004)



Continuous acceptability scale

How do you assess the air quality?

Pay attention to the dichotomy between acceptable and not acceptable.

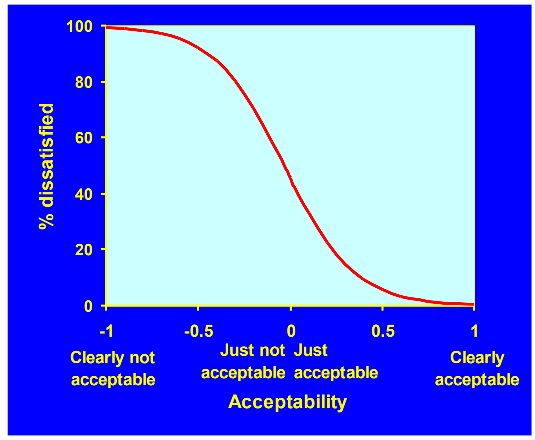


Measuring metric

Acceptability

↓

% dissatisfied



Development of a standard method for assessing the performance of gas-phase air cleaning

Overall objective

- Develop the protocol for rating gas-phase air cleaners
- Examine the protocol by performing the actual measurements
- Use the protocol in the Round-Robin tests
- Implement the protocol in the standard for testing the performance of air cleaners.

General approach

- Two-stage-testing:
  - Stage 1: Pass/no pass with respect to the effect on indoor air quality
  - Stage 2: Determine clean air delivery rate (CADR) and compare with equivalent ventilation requirements

Specific objective

Examine the protocol by testing different types of air purifiers

Perform sensory evaluation and chemical measurements

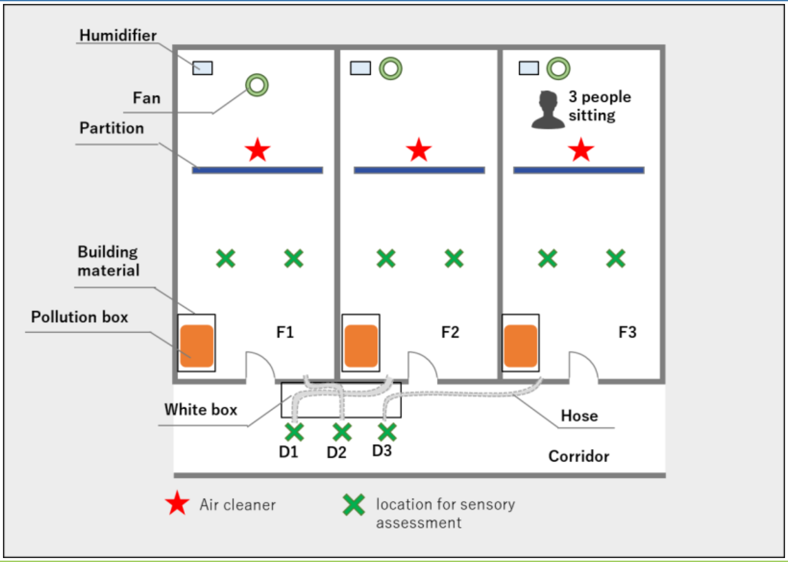
Test two types of pollution sources: building materials (building) and human bioeffluents (humans) and their combination

Determine the effect of air cleaners on air quality in terms of clean air delivery rate

Overall protocol

- Portable air cleaners were tested; all operated at close to the maximum capacity
- Air cleaners were challenged with different types of pollutants representing people and building materials
- Conditions under test: ca. 23^{o}C (73^{o}F) and 50%RH
- Up to four levels of ventilation with outdoor air were tested
- Different number of air cleaners were placed in the rooms during testing
- Measurements of air quality were performed with air cleaners idled and in operation

Set-up



15

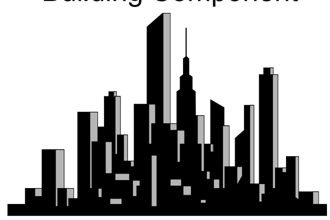
Sensory assessments

16

ASHRAE 62.1, ventilation rate procedure

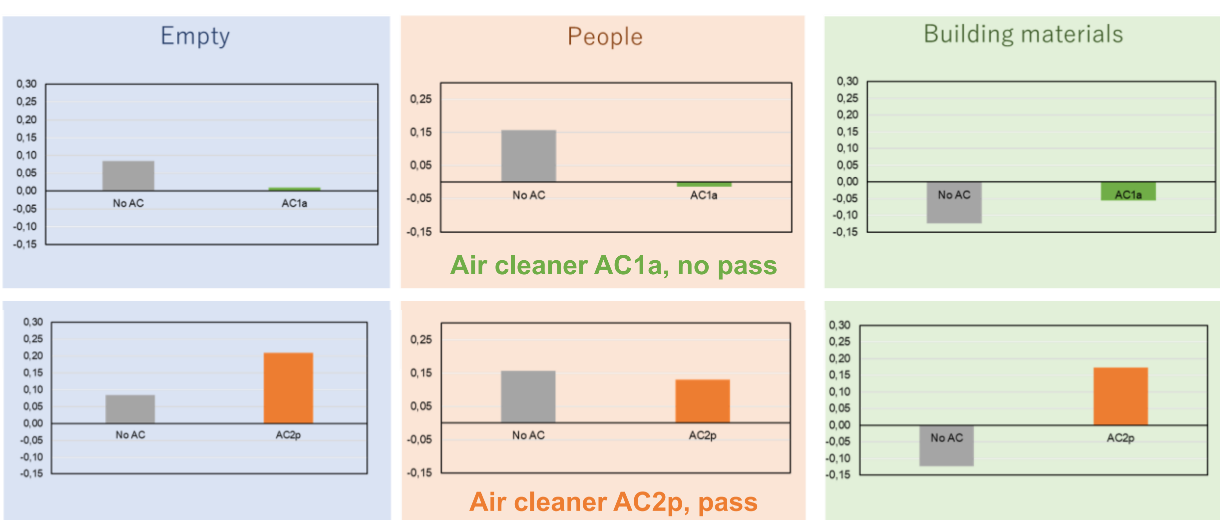
People Component

Building Component

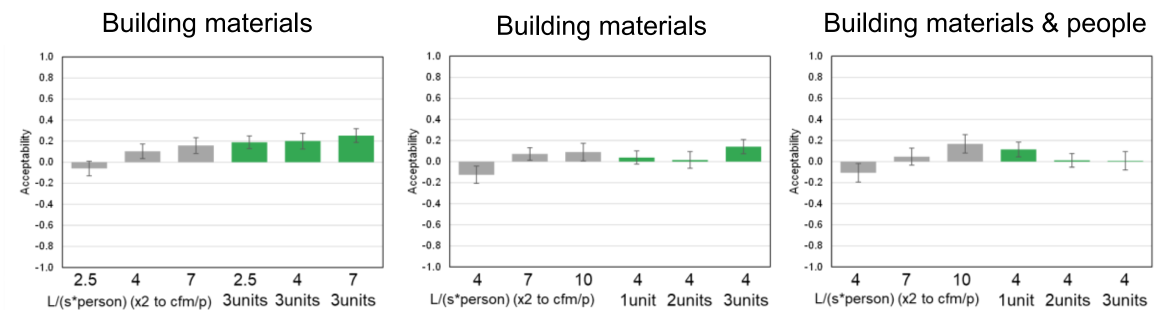


People + Building

Stage 1 – pass/no pass, example

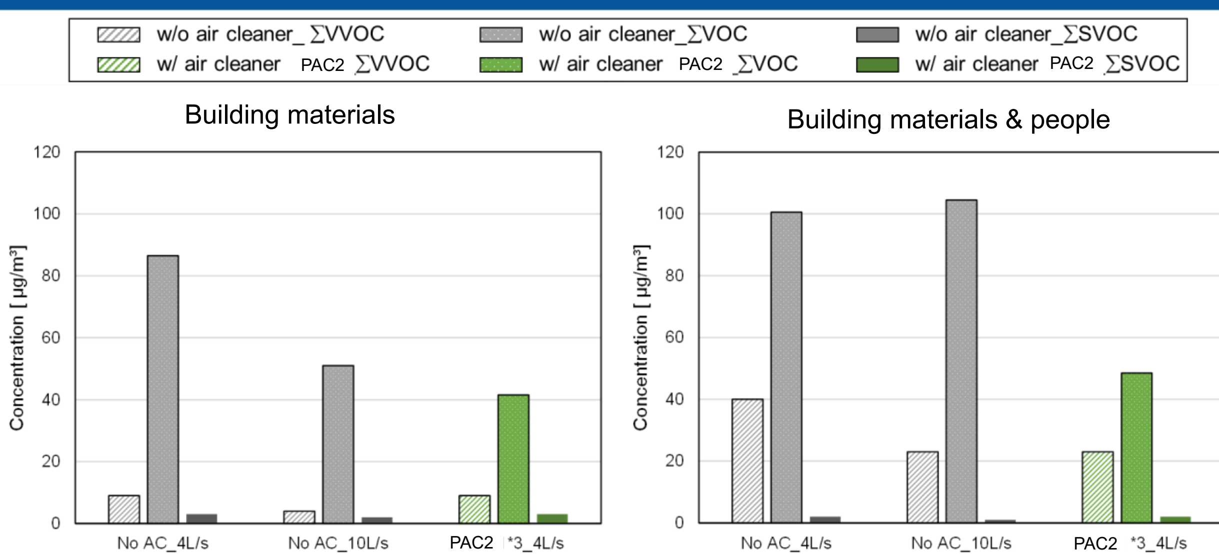


Stage 2 – testing, sensory assessments, example



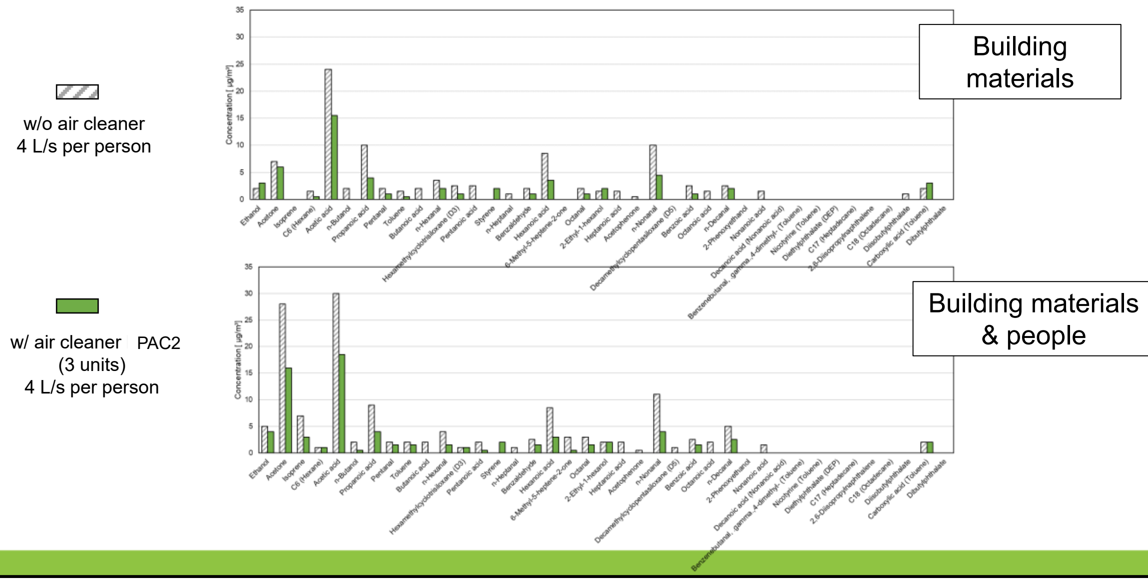
19

Stage 2 – testing, chemical measurements



20

Stage 2 – testing, chemical measurements

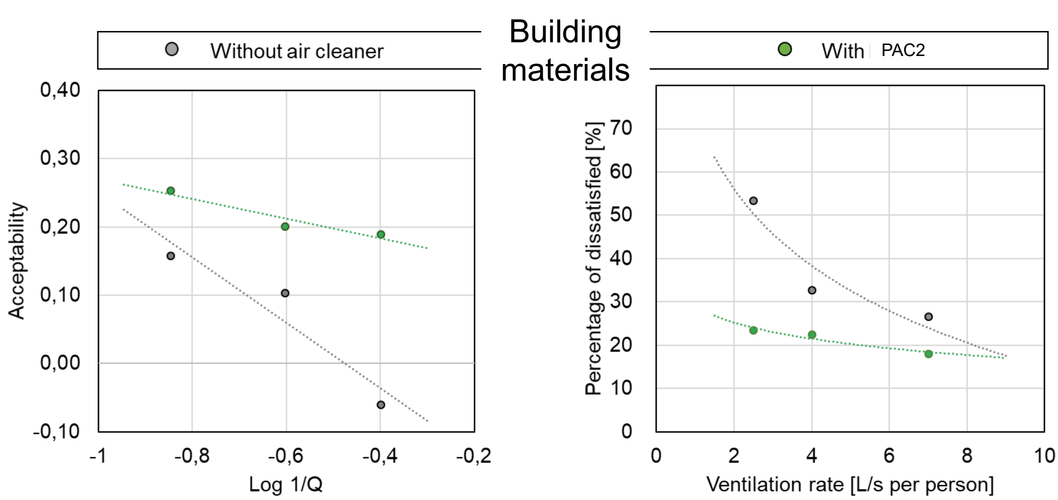


Concluding remarks

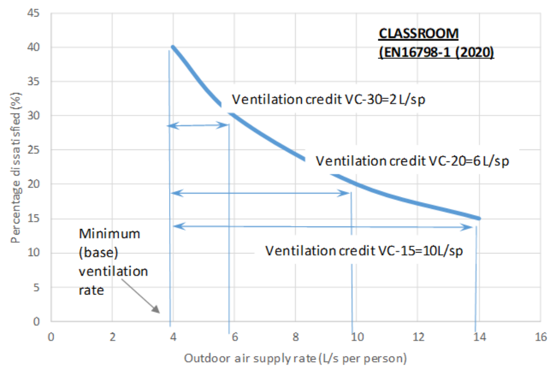
Preliminary conclusions

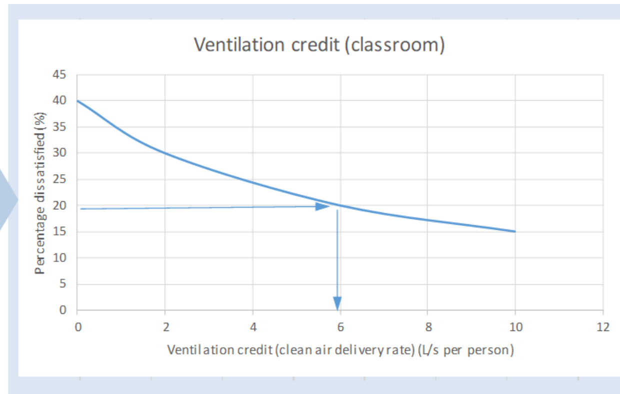
- We succesfully examined methodology for testing gas-phase air cleaners
- Passive air cleaners performed better than active air cleaners
- There were some inconsistences between chemical analyses and sensory assessments
- More analyses are in progress

Determination of clean air delivery rate

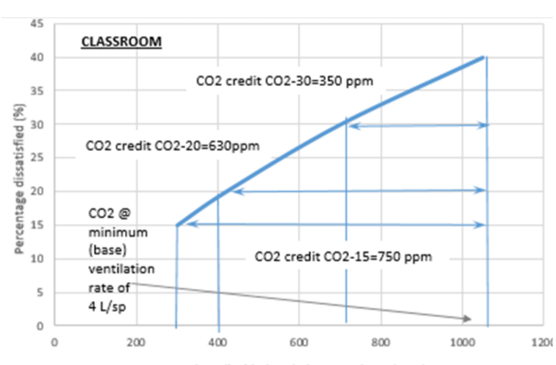


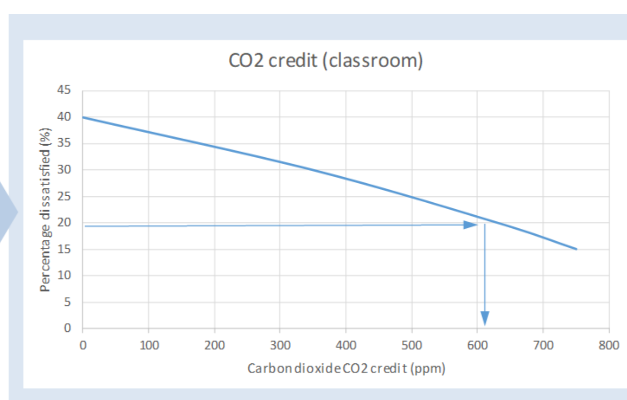
New concept, ventilation credit



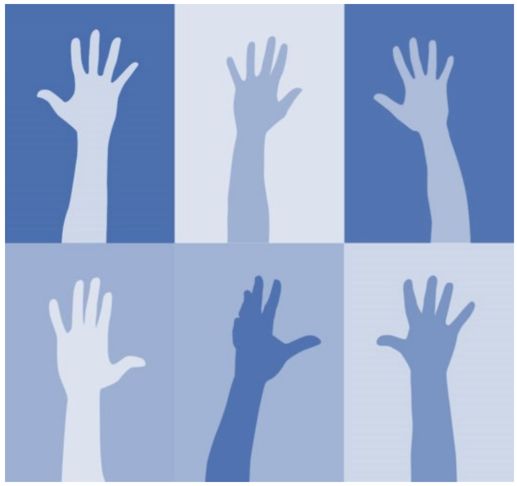


New concept, CO_2 credit





Questions



pawar@dtu.dk

vito

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

EVALUATING THE IMPACT OF AIR CLEANING ON BIOAEROSOLS AND OTHER IAQ INDICATORS IN BELGIAN DAYCARE FACILITIES

Sarah L. Paralovo (presenter)
Klaas de Jonge
Arnold Janssens
Jelle Laverge
Reinoud Cartuyvels
Koen Van den Driessche
Borislav Lazarov
Maarten Spruyt
Marianne Stranger

vito

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

INTRODUCTION

COVID-19 pandemic increased awareness about the spread of viral particles through the air[1,2] ➔ Ventilation and air cleaning emerged as main strategies to reduce infection risk.

But health and comfort of occupants are influenced by many different parameters:

- IAQ: Physiochemical, Biological
- Thermal
- Acoustic
- Lighting

(all together: IEQ)

A study was conducted in Flanders (Belgium) to investigate the impact of ventilation and air cleaning strategies on IEQ in public spaces, to enable an objective evaluation of the effectiveness and impact of such risk reduction methods

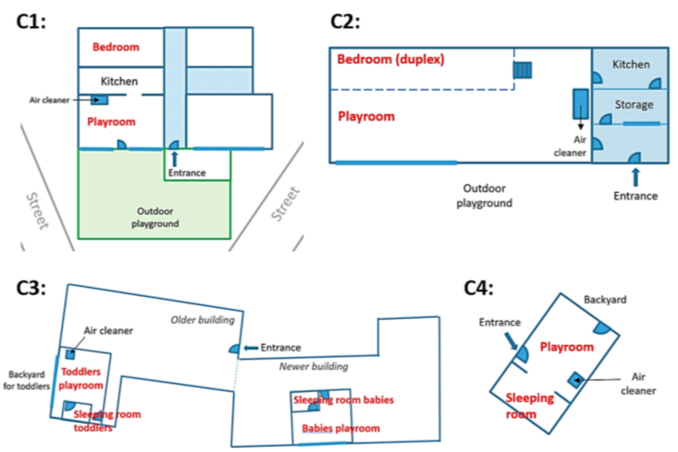
vito

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

MATERIAL AND METHODS

Focus: One category of public space (daycare facilities) and selected IAQ parameters

Facilities assessed in spring (C1/C2) and summer (C3/C4)



Continuous monitoring of:

- T/RH
- CO_2 (by stationary sensors)
- PM_x

Scheduled* measurements of:

- ACHs (via artificially injected CO_2 decay test[3])
- Air tightness (via blower door test)
- Pathogenic bioaerosols (via collection by cyclonic impinger[4])

*under different and pre-determined ventilation and air cleaning scenarios.

vito

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

RESULTS AND DISCUSSION

Ventilation characterization:

- C1 and C4 had no mech. vent. system;
- C3 had two separate mechanical balanced vent. systems (newer and higher flow rates in K2/K4);
- C2 had a mech. vent. system, but measurements showed it was not operational;
- None of the rooms reached the Belgian guideline for COVID-19 protection of **40 m³ h⁻¹ per person** (considering each room's occupancy) under the most common scenarios;
- In C2, C4 and the newer part of C3, the guideline is reached when **cross-ventilation** is provided.

C1	Air tightness	'Normal' scenario (window tilted in room next to the assessed room)				'Summer' scenario ('Normal' + door to outdoor playground open)			
	n50 (h^{-1} 50Pa)	ACH (h^{-1})		Vol. flow ($m^3 h^{-1}$)		ACH (h^{-1})		Vol. flow ($m^3 h^{-1}$)	
K1	8.7	1.10		75.6		5.40		372	
C2	**Air tightness**	**All doors and windows closed**		**'Winter'** (Front door open, door to playground slightly open, storage room door closed)		**'Enhanced winter'** ('Winter' + storage room door open with window tilted)		**'Summer'** (Sliding windows to playground open)	
	n50 (h^{-1} 50Pa)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)
K1/K2	3.1	0.18	38.0	0.82	174	3.61	768	13.2	2807
C3	**Air tightness**	**All doors and windows closed**		**Door to corridor open**		**Sliding window open** (to width of mosquito screen)		**Door + sliding window open** (to width of mosquito screen)	
	n50 (h^{-1} 50Pa)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)
K1	-	0.67	167	1.20	299	2.01	501	1.80	449
K2		1.82	363	2.93	585	2.30	458	4.44	886
K3	-	1.23	50.0	2.57	104	-	-	-	-
K4	-	5.34	138	12.0	310	-	-	-	-
C4	**Air tightness**	**All doors and windows closed**		**Door to backyard open**		**Window to the street side open**		**Door to backyard + window to street side open**	
	n50 (h^{-1} 50Pa)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)	ACH (h^{-1})	Vol. flow ($m^3 h^{-1}$)
K1	-	<1	<140	3.33	465	1.11	155	12.0	1669

vito

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

RESULTS AND DISCUSSION

Temperature and RH:

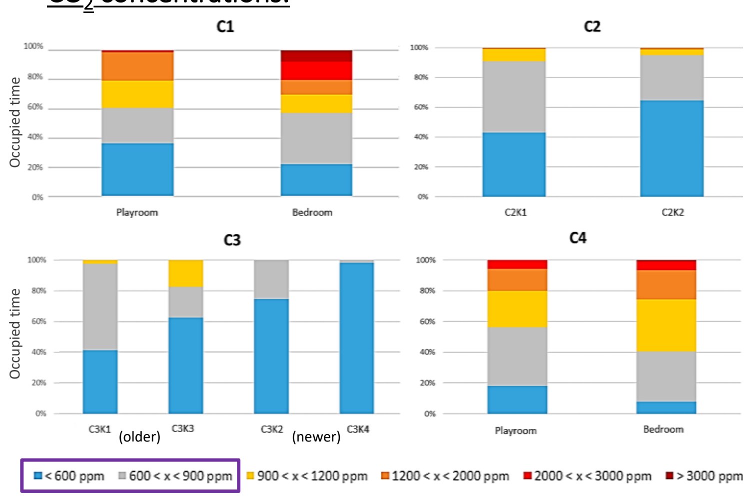
- T and RH are important comfort parameters, but RH also impacts airborne pathogen transmission (influences evaporation kinematics and particle growth, lower RH increases sensitivity of airways[5,6]);
- Temperatures in C2, C3 and C4 were most of the occupied time in accordance with the Flemish Indoor Environment Decree (20-24°C in cold season; 22-26°C in warm season);
- In C1 the temperatures were < 20°C for over a quarter of the occupied time in both rooms;
- RH in C3 and C4 was most of the occupied time in accordance with the Flemish Indoor Environment Decree (30-70% in warm season);
- In C1's playroom the median RH was below the recommended level (40-60% in cold season), and in C2 the median RH was < 25% in all assessed rooms.

vito

43rd AIVC
11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

RESULTS AND DISCUSSION

CO_2 concentrations:



- Belgian guideline for COVID-19 protection sets a maximum of 900ppm;
- C1 had the lowest occupancy, but the highest CO_2 concentrations (peaks in the bedroom consistently >3500 ppm);
- In C4 the CO_2 concentrations were the most frequently > 900ppm, with greater exceedances in the second (colder) week;
- Although C4 allowed high ACHs by cross ventilation, this is not often applied;
- C2 consistently had peaks >900 ppm, but overall situation was good despite faulty mech. vent.;
- C3 had the lowest CO_2 concentrations, but a clear difference was noticed between the two parts of the facility.

vito

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

RESULTS AND DISCUSSION

PM_X concentrations:

Important air cleaning evaluation parameter.

	C1		C2		C3		C4	
	Air cleaner status		Air cleaner status		Air cleaner status		Air cleaner status	
	OFF	ON	OFF	ON	OFF	ON	OFF	ON
	I/O ratios: Median (P-75)							
I/O TSP	0,6 (1,2)	1,0 (2,0)	0,3 (0,6)	0,4 (1,0)	2,8 (5,5)	2,7 (5,8)	2,9 (5,1)	2,6 (4,8)
I/O PM_{10}	0,8 (1,1)	1,2 (1,9)	0,9 (1,6)	1,3 (1,8)	1,5 (2,3)	1,4 (1,9)	1,5 (2,0)	1,1 (1,5)
I/O $PM_{2.5}$	0,8 (1,0)	0,9 (1,1)	0,8 (1,1)	0,9 (1,0)	0,6 (0,8)	0,6 (0,8)	1,5 (1,8)	0,9 (1,1)
I/O PM_1	0,7 (0,9)	0,6 (0,8)	0,7 (0,8)	0,8 (0,9)	0,5 (0,6)	0,5 (0,6)	1,9 (2,4)	1,1 (1,5)

- I/O ratios >1 indicate either indoor sources of PM or an accumulation of outdoor PM indoors;
- Only in C4 a consistent decrease of I/O ratios was observed when the air cleaner was switched on (up to 40% reduction for $PM_{2.5}$ and PM_1);
- I/O ratios were either the same or slightly higher with the air cleaner switched on in C1 (except for PM_1), C2 and C3 (except for PM_{10});
- Potential reasons:
  - Inadequate configuration of air cleaner
  - Different activities in the morning and in the afternoon that generate different levels of resuspension
  - Different ventilation/airing during morning and afternoon.

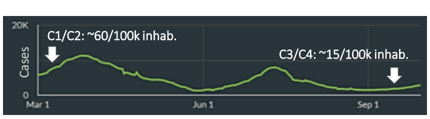
vito

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

RESULTS AND DISCUSSION

Pathogens in air:

- CT-value > 35.0 considered as limit value for SARS-CoV-2 (very low viral load, higher uncertainty);
- Official COVID-19 incidence in Belgium:



(Sciensano, 2023)

			Week 1		Week 2	
			Day 1	Day 2	Day 3	Day 4
C1	K1	AC ON	LV* (CT 36,6) [1]	Negative	LV* (CT 37,0)	Positive (vl *<1000, CT 33,9) [1,3,4,5]
		AC OFF	-	Negative	LV* (CT 34,7)	Negative
	K2	-	Negative [1,2]	-	LV* (CT 35,3) [1]	-
C2	K1	AC ON	Negative	Negative	LV* (CT 36,2)	LV* (CT 39,8)
		AC OFF	-	Negative	Negative [5]	Negative
	K2	-	Negative	Negative	Negative	LV* (CT 36,8)
		-	-	Negative	-	Negative
C3	K1	AC ON	Negative [6,7]	LV* (CT 39,9) [1,7]	Negative [1]	LV* (CT 40,9) [1,3]
		AC OFF	Negative	Negative [1,7]	LV* (CT 38,4) [1]	Negative [3]
	K2	-	Negative [1]	Negative	Negative	Negative
	K3	-	Negative [6]	-	-	Negative [1,3]
	K4	-	-	-	LV* (CT 37,5) [1,6]	-
C4	K1	AC ON	Positive (vl * <1000, CT 30,7) [6]	Positive (vl * < 1000, CT 32,2) [1,3]	Positive (vl * < 1000, CT 29,8) [1,3]	Positive (vl * < 1000, CT 29,6) [1,3,8,9]
		AC OFF	Positive (vl * >1000, CT 27,0) [3]	Positive (vl * > 1000, CT 29,0) [1,3,7]	Positive (vl * < 1000, CT 30,3) [1,3]	Positive (vl * > 1000, CT 28,1) [1,3,10,11]
	K2	-	-	Positive (vl * > 1000, CT 27,6) [1,3,9]	-	-

*LV = limit value
vl = viral load

1. Streptococcus pneumoniae DNA positive
2. Corona virus OC43 RNA at LV
3. Rhinovirus positive
4. Enterovirus RNA at LV
5. Influenza A virus RNA at LV
6. Rhinovirus LV
7. Bordetella parapertussis DNA positive
8. Bordetella parapertussis DNA LV
9. Bocavirus DNA LV
10. Bocavirus DNA positive
11. Adenovirus DNA LV

- At least one pathogen detected in **67%** of C1, **31%** of C2, **73%** of C3 and **100%** of C4 samples.
- Ventilation seems to be more effective than air cleaning in C1, C2 and C3;
- Air cleaning seems to slightly decrease the viral load of SARS-CoV-2 and the presence of other pathogens in C4.

vito

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

CONCLUSIONS

- Comprehensive IAQ assessment in four daycare facilities, with physiochemical (T, RH, ACH, CO_2 and PM_x) and biological measurements (collection of air samples for detection of over 20 respiratory pathogens);
- Most of the time the airflow rates per person were below the recommended in Belgium regarding COVID-19, but could be improved by airing;
- Higher CO_2 concentrations in the facilities without mechanical ventilation, and the lowest in the facility with effective mechanical ventilation system;
- Pathogenic bioaerosols were detected more frequently and in larger quantities in the less ventilated facility;
- Where indoor PM_x concentrations correlated well with air cleaning, the same effect was also noticeable in the pathogens presence;
- Expected positive impact of ventilation over IAQ is corroborated, but impact of air cleaning was not as consistent in all facilities.

vito

43rd AIVC 11th TightVent & 9th venticool Conference
Ventilation, IEQ and health in sustainable buildings

REFERENCES

[1]Morawska, L.; Cao, J. (2020). Airborne transmission of SARS-CoV-2: The world should face the reality. Environment International, 139: 105730. DOI: https://doi.org/10.1016/j.envint.2020.105730.

[2]Randall, K. ; Ewing, E.T. ; Marr, L.C. ; Jimenez, J.L. ; Bourouiba, L. (2021). How did we get here: what are droplets and aerosols and how far do they go? A historical perspective on the transmission of respiratory infectious diseases. Interface Focus, 11: 20210049. DOI: 10.1098/rsfs.2021.0049

[3]Paralovo, S. L ; De Jonge, K. ; Laverge, J.; Janssens, A. (2021). Ventilation assessment in three teaching spaces at a Belgian university. *Proceedings of Healthy Buildings 2021 America*. Presented at the Healthy Buildings 2021 America, Hawaii, USA (Virtual).

[4]Bertin. 2012. Coriolis® µ user manual. Manual code: 05027-006-DU002-F ENG. Revised: November 2021. Bertin Technologies

[5]Ahlawat, A., Wiedensohler, A. and Mishra, S.K. (2020). An Overview on the Role of Relative Humidity in Airborne Transmission of SARS-CoV-2 in Indoor Environments. Aerosol Air Qual. Res. 20: 1856–1861. https://doi.org/10.4209/aaqr.2020.06.0302

[6]Keetels, G. H., Godderis, L. and van de Wiel, B. J. H. (2022). Associative evidence for the potential of humidification as a non-pharmaceutical intervention for influenza and SARS-CoV-2 transmission. Journal of Exposure Science & Environmental Epidemiology. 32: 720 – 726. https://doi.org/10.1038/s41370-022-00472-3

Thank you!

Contact: sarah.limaparalovo@vito.be

REMOVAL OF ODORANTS IN NURSING HOMES USING AIR CLEANERS

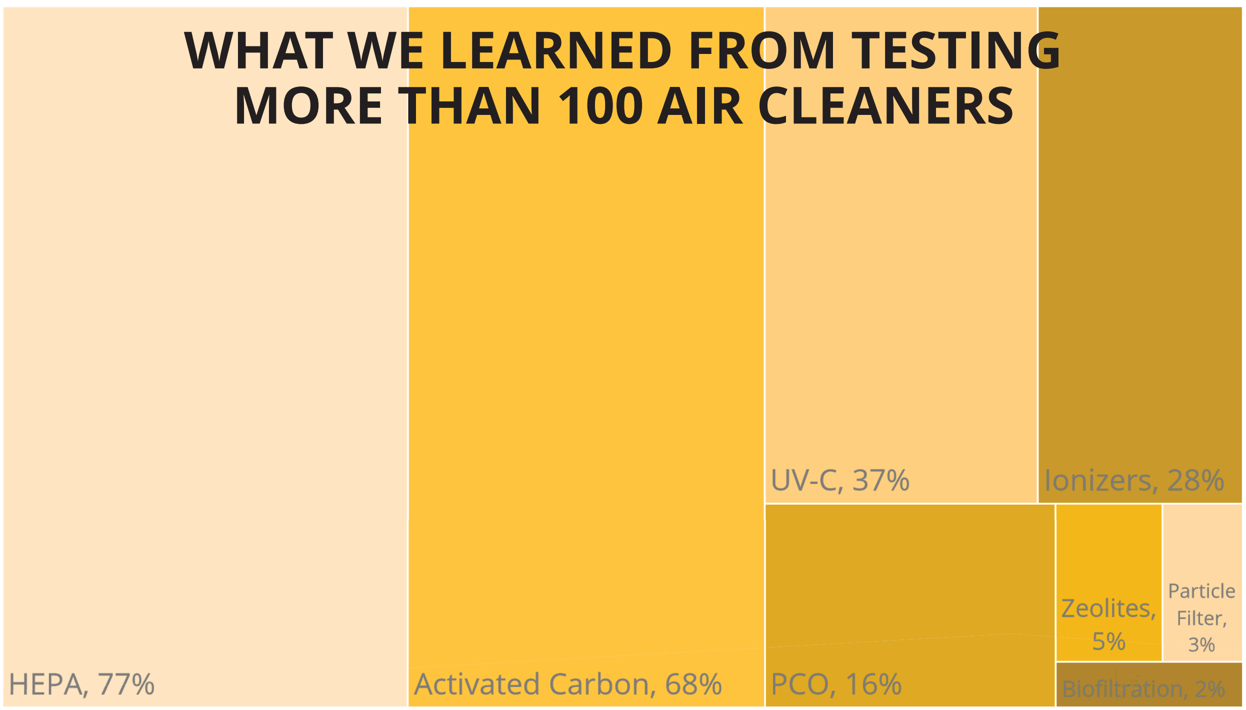
By Freja Rydahl Rasmussen (frer@dti.dk) &
Stig Koust, Ph.D. Nanoscience
(stko@dti.dk)
Danish Technological Institute
Clean Air Technology

AIVC October 5, 2023

AARHUS KOMMUNE

TEKNOLOGISK INSTITUT

WHAT WE LEARNED FROM TESTING MORE THAN 100 AIR CLEANERS



TEKNOLOGISK INSTITUT

HOW MUCH CLEAN AIR WILL 1 DKK BUY YOU?

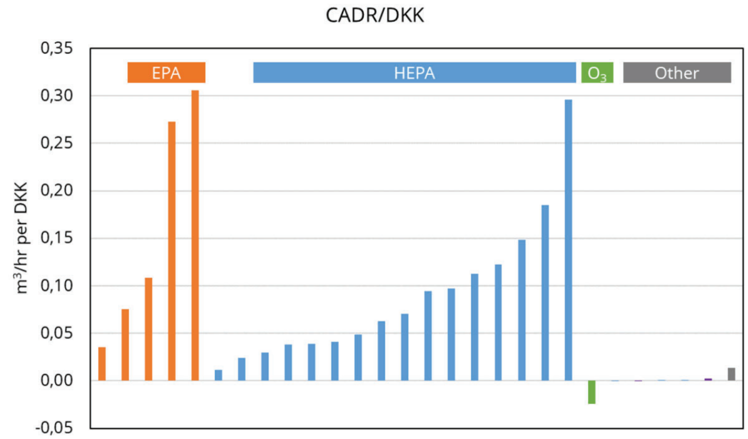
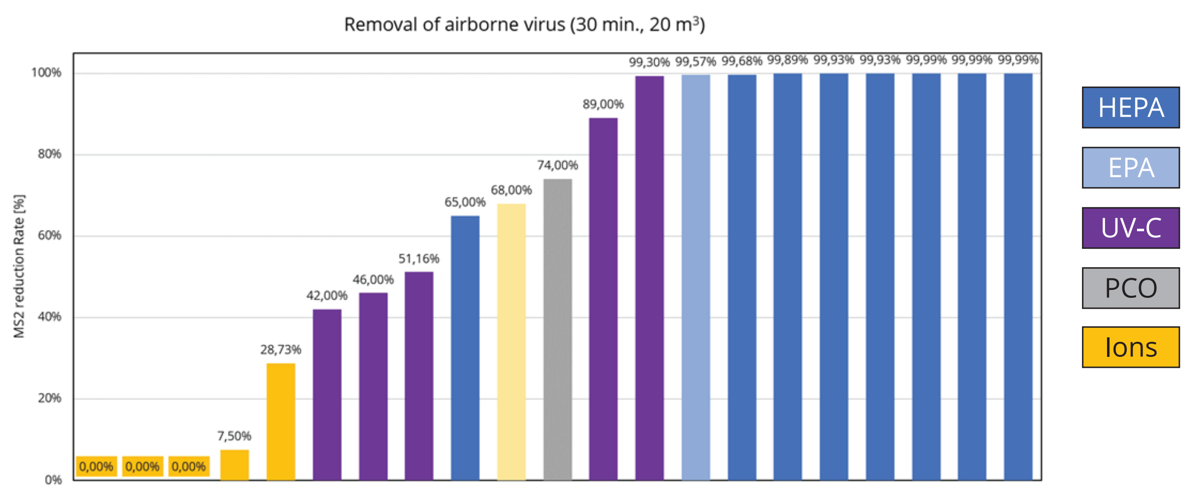


Figure 6: Overview over the cost-effectiveness of all products, calculated as amount of clean air per 1 DKK (CADR [PM2.5] / purchase cost)

TEKNOLOGISK INSTITUT

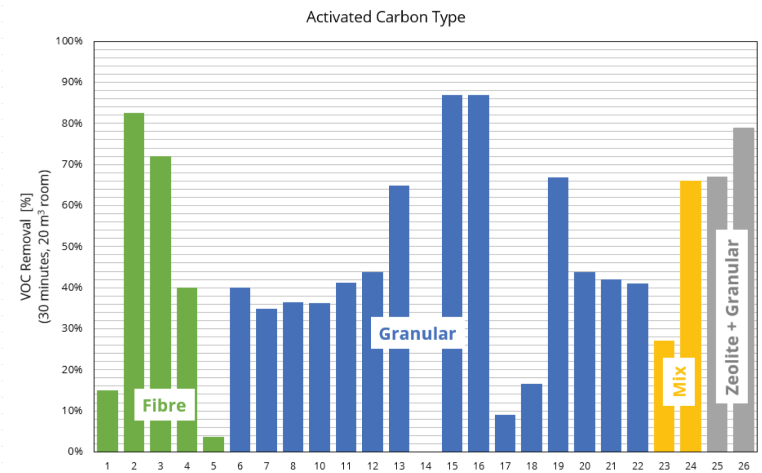
AIR CLEANERS FOR PANDEMIC PREPAREDNESS?



According to ISO 16000-36:2018 - Indoor air — Part 36

TEKNOLOGISK INSTITUT

WILL ACTIVATED CARBON GUARANTEE GAS REMOVAL?



THE ISSUE WITH ODORANTS

- Nursing homes have problems with foul scents from laundry and linen rooms and this smell can often spread to the surrounding common areas
- This leads to a poor working environment and is a great inconvenience for caregivers and residents

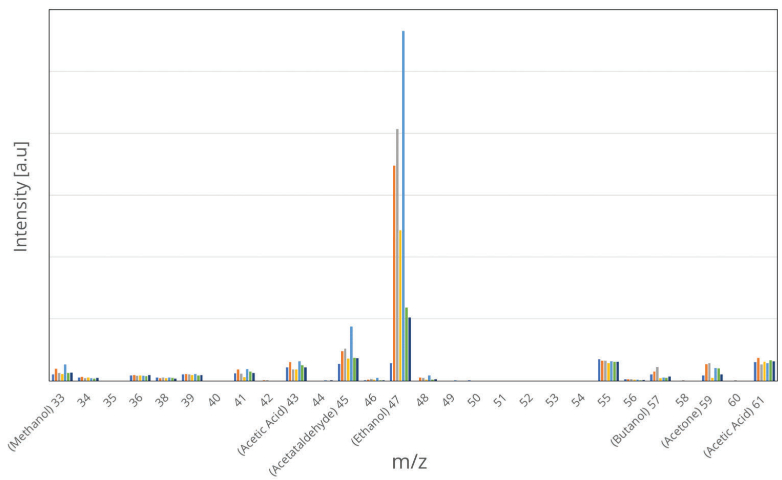
- How do we quantify smell and can air cleaners alleviate the problem?

RESULTS FROM OUR APPROACH

1. **Testing selected air cleaners in the laboratory**
2. Effect on work environment after implementation at 4 selected nursing homes
3. Lifetime of selected air cleaners

TEKNOLOGISK
INSTITUT

WHAT TO TEST FOR IN THE LAB?



- ✓ VOC screening in nursing homes
- ✓ Air samples analyzed using **P**roton-**T**ransfer-**R**eaction **M**ass **S**pectrometry (**PTR-MS**)
- ✓ Acetaldehyde as proxy for odorants

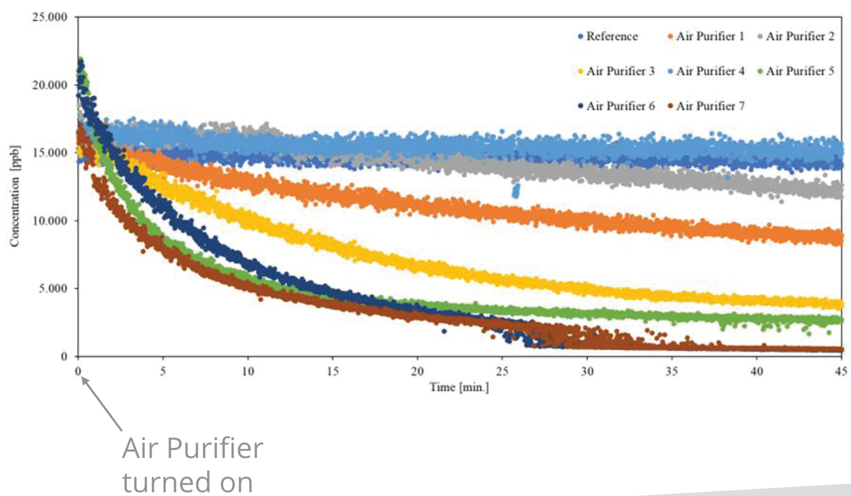
TEKNOLOGISK
INSTITUT

PURIFICATION ABILITY IN THE LABORATORY

- ✓ Acetaldehyde as proxy for odorants
- ✓ 20 m³ specially designed test chamber
- ✓ **P**roton-**T**ransfer-**R**eaction **M**ass **S**pectrometry (**PTR-MS**)
- ✓ Pulldown method – Performance Index %-reduction
- ✓ Byproduct formation
- ✓ Degassing from filter

TEKNOLOGISK INSTITUT

ACETALDEHYDE REMOVAL



	Technology				Removal [%]
	Activated Carbon	PCO	Ionizer	HEPA	
1	X		X	X	44%
2	X		X	X	31%
3	X			X	73%
4		X			8,0%
5	X			X	86%
6	X	X	X	X	97%
7	X (+ zeolites)			X	96%

Link to project report (Danish): https://www.teknologisk.dk/ydelser/udvikling-og-test-af-luftrensere-og-filterteknologier/39676

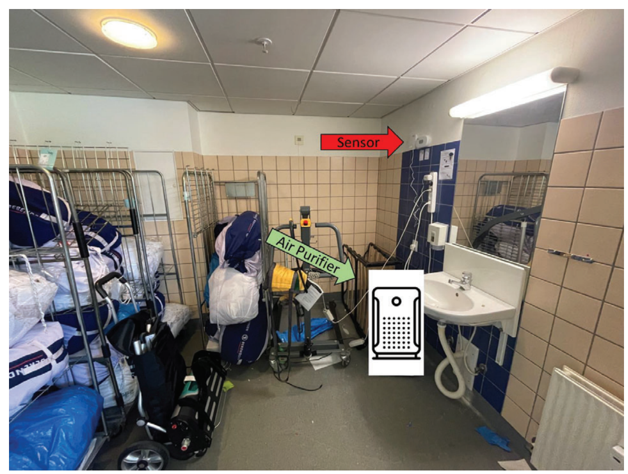
TEKNOLOGISK INSTITUT

RESULTS FROM OUR APPROACH

1. Testing selected air cleaners in the laboratory
2. **Effect on work environment after implementation at 4 selected nursing homes**
3. Lifetime of selected air cleaners

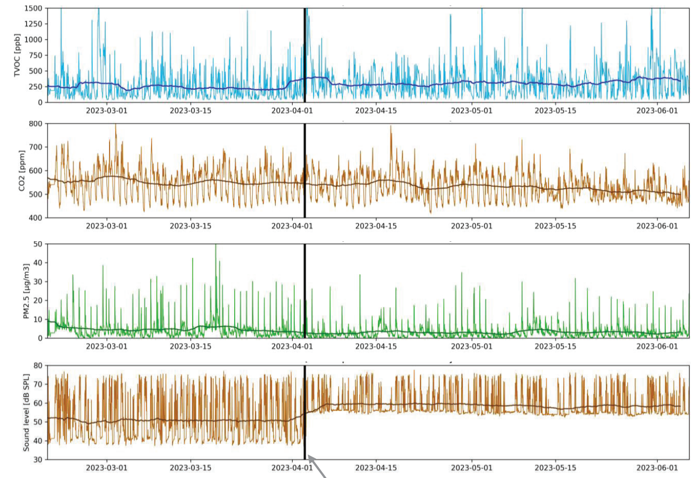
REMOVAL OF ODORANTS IN NURSING HOMES

- Four different locations
  - Low-cost sensors (TVOC as proxy for smell)
  - Air Samples analyzed using PTR-MS



REMOVAL OF ODORANTS IN NURSING HOMES

- Four different locations
  - **Low-cost sensors (TVOC as proxy for smell)**
  - Air Samples analyzed using PTR-MS



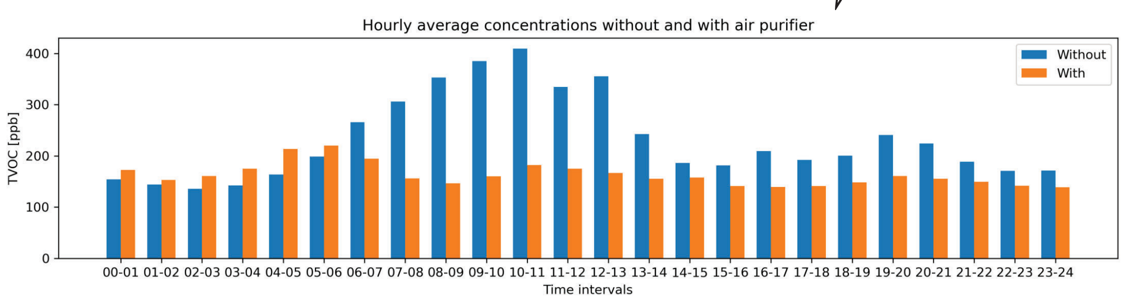
Air Cleaner installed

TEKNOLOGISK
INSTITUT

REMOVAL OF ODORANTS IN NURSING HOMES

- Four different locations
  - **Low-cost sensors (TVOC as proxy for smell)**
  - Air Samples analyzed using PTR-MS

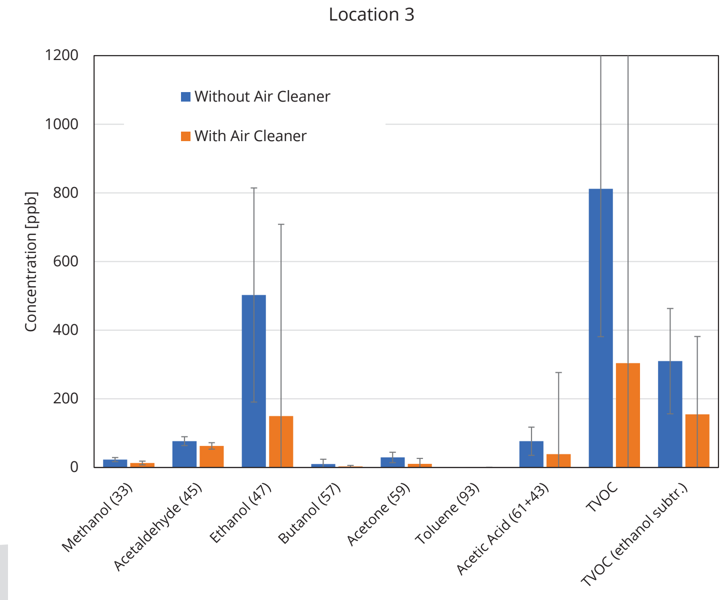
Peak levels reduced
Background unchanged



TEKNOLOGISK
INSTITUT

REMOVAL OF ODORANTS IN NURSING HOMES

- Four different locations
  - Low-cost sensors (TVOC as proxy for smell)
  - **Air Samples analyzed using PTR-MS**

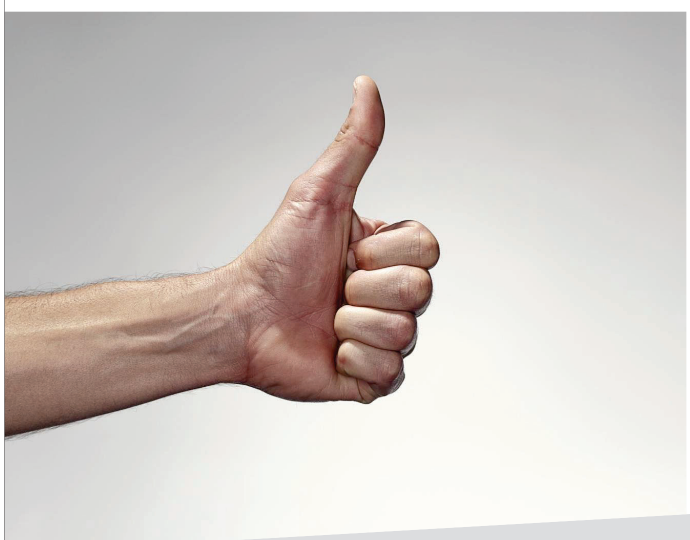


! Air Quality snapshot on 5 different days
! Large variations
! Ethanol from hand sanitizers

✓ TVOC reduction 17 – 57 %

INSTITUT

CONCLUSIONS



- ✓ VOC removal using activated carbon is a multi-complex issue
- ✓ Continuous and real-time work environment measurements
- ✓ Evaluation of possible technical solutions to remove odorants
- ✓ Demonstrated improvement of air quality in laundry rooms

TEKNOLOGISK
INSTITUT

TECHNOLOGY FOR A BETTER FUTURE

THANK YOU

stko@dti.dk

DANISH TECHNOLOGICAL INSTITUTE

RESULTS FOR THREE DIFFERENT STEPS

1. Testing selected air purifiers in the laboratory
2. Effect on work environment after implementation at 4 selected nursing homes
3. **Lifetime of selected air purifiers**

TEKNOLOGISK INSTITUT

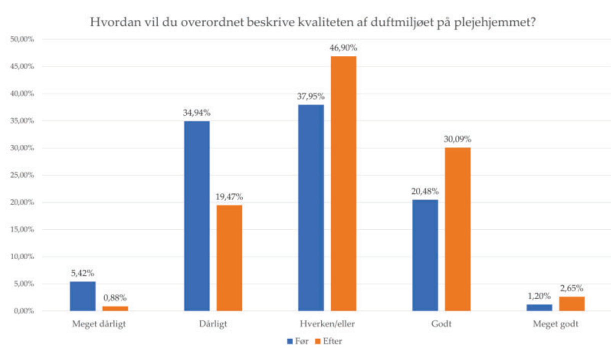
LIFETIME OF SELECTED AIR PURIFIERS

- After operation in nursing homes for 2 months
- Similar test as before implementation

Air Purifier	Reduction in cleaning performance, acetaldehyde (%)	Reduction in CADR (particles) (%)
3	12	57
5	23	44
6	13	3
7	24	8

TEKNOLOGISK INSTITUT

”PERCEIVED” AIR QUALITY



Hjemlige duft- og lydmiljøer - Et interventionsstudie på aarhusianske plejehjem
Sofie Kønig Wilms, Sissel Raahede Lundgård, Mads Duevang Dahl, Anne-Sofie Udsen, Amalie Rævsbæk Birch, Susanne Højlund, Johanne Korsdal Sørensen* og Marie Koldkjær Højlund*, MANTRA, Aarhus University*

TEKNOLOGISK INSTITUT

What can CO_2 measurements tell us about ventilation and infection risk in classrooms?

Carolanne Vouriot

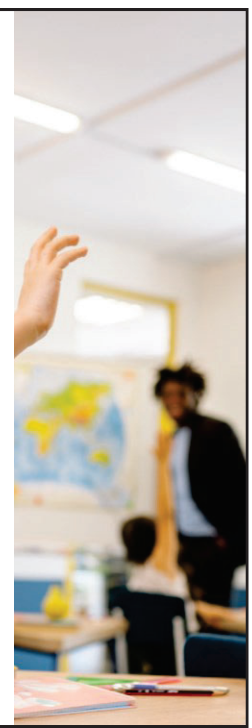
43rd AIVC - 11th TightVent & 9th Venticool Conference

University of Sheffield

05/10/2023

Air quality in classrooms matters

- 11 million pupils and staff in the UK (15% of the population)
- Spending 20% of their time inside classrooms
- Direct impact on health and academic performance
- Previous campaigns have shown insufficient ventilation provision



CO_2 monitoring in classrooms

Part of the pandemic response and becoming widespread in classrooms.

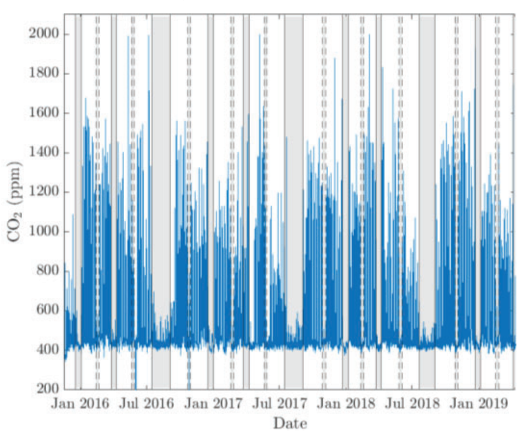
Potential for long-term and large-scale monitoring.

What can we learn from those CO_2 measurements?

3

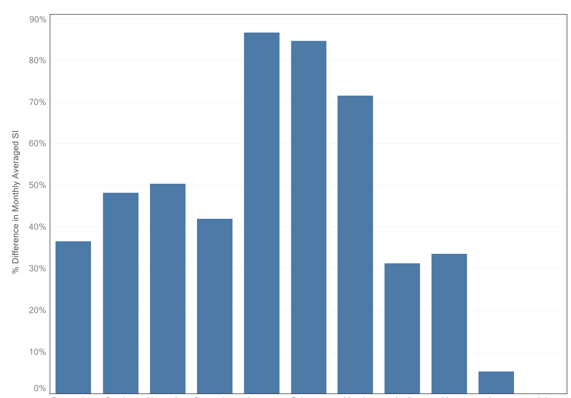
Predicting airborne infection risk

Measurements in 45 classrooms from 11 schools in England (November 2015 – March 2020) [1]



[1] Data provided by Monodraught, with the assistance of Nick Hopper and Nyssa Hayes, and by the K2n platform, with the assistance of Professor Ian Knight.

Rebreathed fraction calculated from CO_2
Number of secondary infections (SI) from one infector



Vouriot, C.V.M., Burridge, H.C., Noakes, C.J. and Linden, P.F., 2021. Seasonal variation in airborne infection risk in schools due to changes in ventilation inferred from monitored carbon dioxide. *Indoor Air*. https://doi.org/10.1111/ina.12818

4

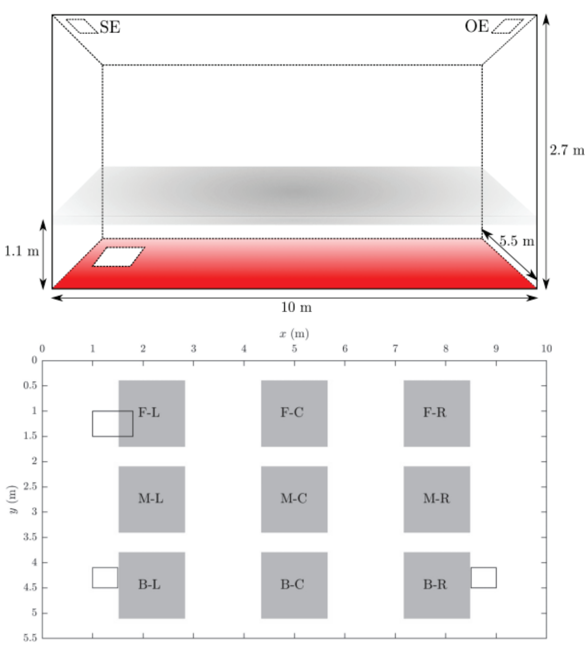
CO_2 as a proxy for airborne infection risk

Assumptions:
1. Known number of occupants
2. Quanta generation rate
3. Single point measurement

90% of classrooms in the UK are naturally ventilated.

CFD simulations : what is the impact of the well-mixed assumption?

5

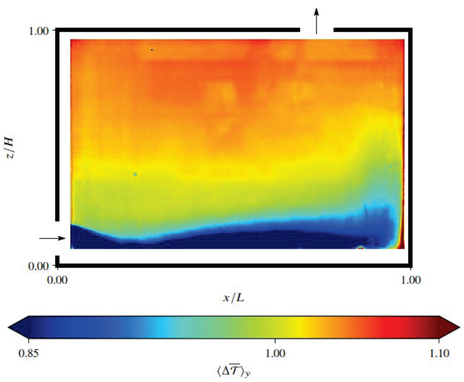


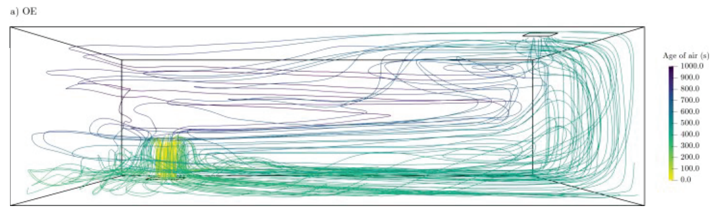
Numerical set-up

- Idealised primary classroom in wintertime.
- Buoyancy driven ventilation with a distributed heat source.
- High and low-level vents in two configurations.
- Passive scalars introduced at breathing height.
- OpenFOAM RANS simulations using buoyantPimpleFoam.

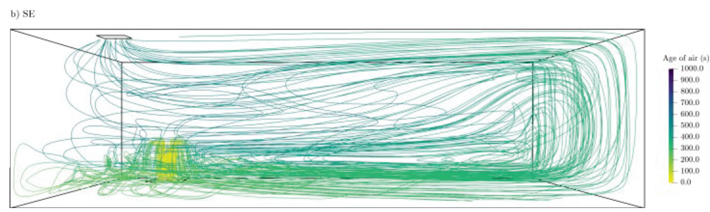
6

Vent position impact on ventilation efficiency





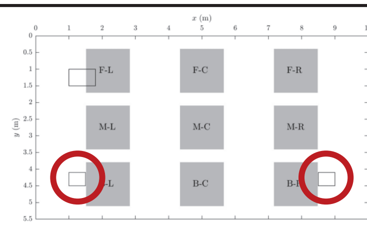
Contaminant removal efficiency: 1.05



Contaminant removal efficiency: 1.24

Vouriot, C.V., Higton, T.D., Linden, P.F., Hughes, G.O., van Reeuwijk, M. and Burridge, H.C., 2023. Uniformly distributed floor sources of buoyancy can give rise to significant spatial inhomogeneities within rooms. *Flow*, 3, p.E18. https://doi.org/10.1017/flo.2023.11

CO_2 as a proxy for infected breath

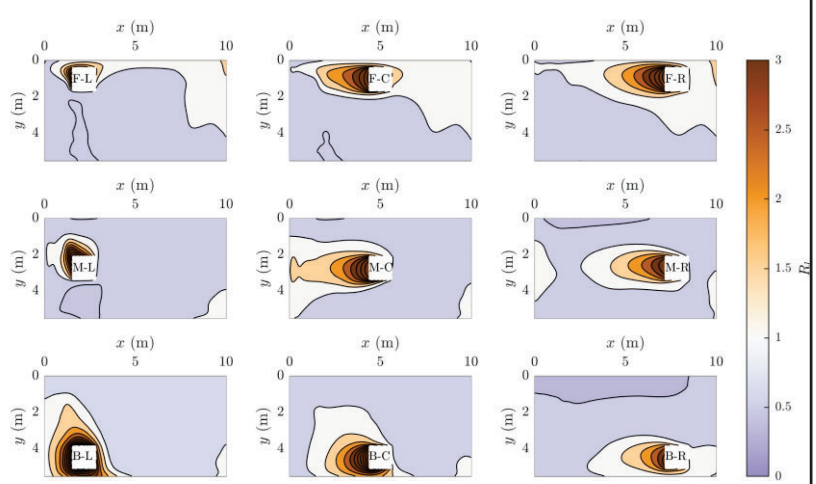


R_l ratio of:

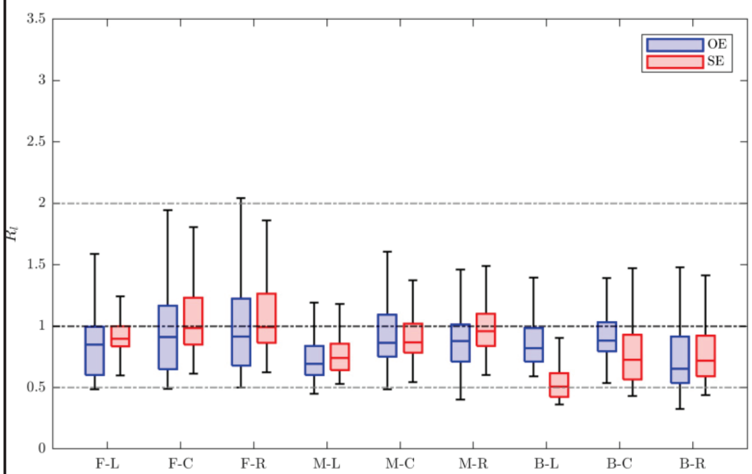
- the infected breath proxy exposure (infected scalar concentration)
- to the CO_2 proxy exposure (local CO_2 concentration)

Accuracy depends on:

- Infector location
- Position of the vents



Conclusions and future work



Non uniform CO_2 distribution.
Uncertainty due to a single point measurement will depend on the:

- Ventilation configuration
- Infector location

Exposure calculated from overall CO_2 within a factor 2 of exposure from infected breath.

Quanta generation rate varies by 4 orders of magnitude

Conclusions and future work

Ventilation can be estimated from steady-state concentration with $Q_c = \frac{NG}{C_c - C_a}$.
Accuracy of the CO_2 measurement matters along with accurate estimates of the **occupancy levels and CO_2 generation rates.**

SAMHE project aims to gather more contextual information:

SAMHE
SCHOOLS' AIR QUALITY MONITORING FOR HEALTH AND EDUCATION
www.samhe.org.uk

Carolanne Vouriot
c.v.vouriot@sheffield.ac.uk

University of Sheffield

Indoor air modelling and infection risk assessment in a naturally ventilated patient room

Natalia Lastovets, Mohamed Elsayed, Ville Silvonen, Anni Luoto,
Topi Rönkkö and Piia Sormunen

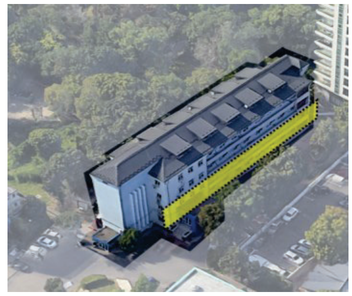
Motivation

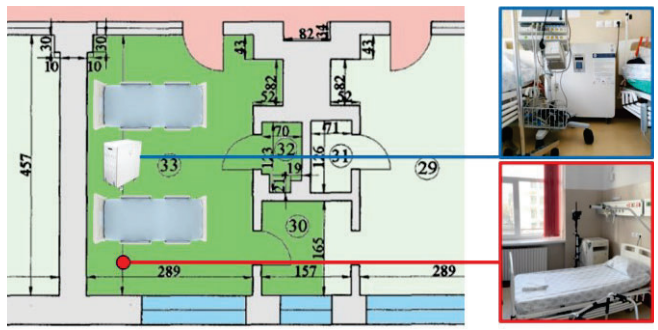
- **Sufficient ventilation in hospitals** is crucial to reduce **airborne virus exposure** for occupants.
- Current **infection risk models** favor **mechanically ventilated** facilities.
- Finnish hospitals use mechanical ventilation, while **southern and eastern European countries** like Romania rely more on **natural ventilation.**
- The research aims to create an **infection risk assessment method** for naturally-ventilated healthcare buildings.

Tampere University

Case study

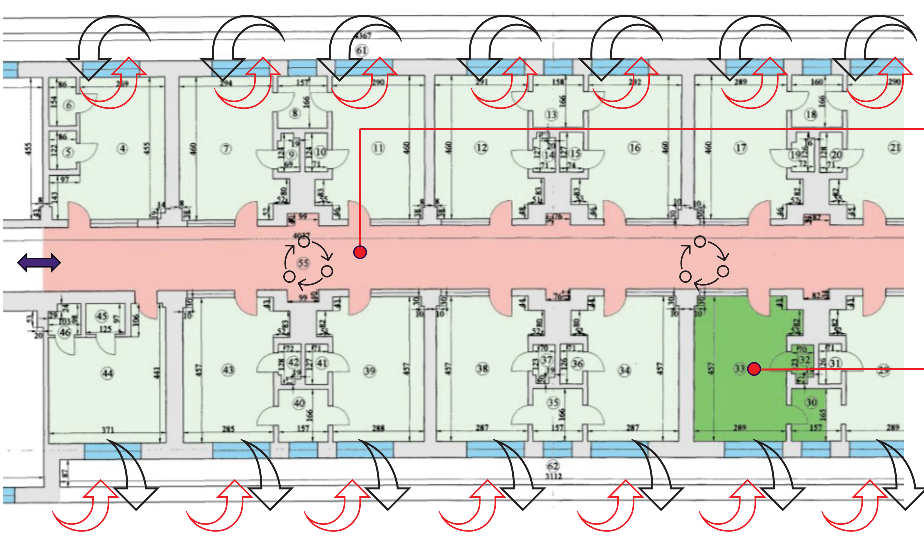
- Matei Bals hospital, Romania, Bucharest built at the beginning of the 20th century
- Studied patient room is located on the second floor of a four-story hospital building
- A closed hallway separates the patient rooms on opposite sides of the building.
- The building is ventilated only by natural ventilation

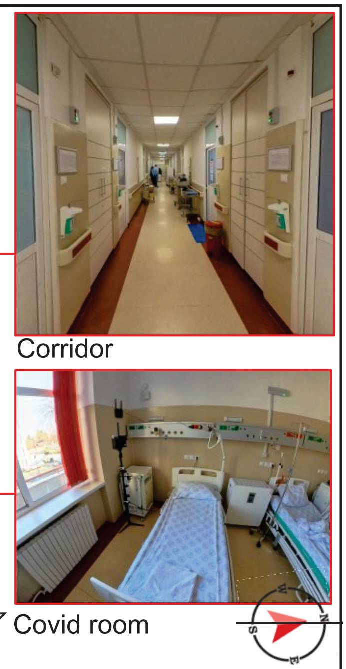




Tampere University

Covid ward space





Tampere University

Methods

Pre-study
- Architectural drawings
- HVAC systems
- Building use: occupancy profile window opening
- IAQ monitoring: Cloud-Based Logger
- Virus risk observation (surveys)
- Possible technological solutions

Initial data for simulations
- Zone geometry, orientation
- Zone boundary conditions
- Building envelope and window properties
- Building energy systems: heating/cooling power and control
- Internal loads: occupants, equipment, lighting
- Occupancy and window opening scenarios

Parameter predetermination
- Exposure time interval ***D*** (h),
- Quanta generation rate ***q*** (quanta/ (h pers.))
- Breathing rate Q_b (m³/h)
- First-order loss rate coefficients: Surfaces deposition λ_{dep} (h^{-1}), Virus decay ***k*** (h^{-1}), Filtration removal rate k_f (h^{-1})
- facial mask eff. for susceptible persons η_s (-)
- facial mask eff. for infected persons η_s (-)
- Number of infected people ***I*** (pers.)

Measurements
- Indoor air temperature
- Indoor air CO_2

Validation

- Outdoor climate parameters:
  - temperature
  - relative humidity
  - solar radiation
  - wind direction and speed

Dynamic building simulation, IDA ICE
- Indoor air temperature
- Indoor air CO_2

- Outdoor air supply Q_v (m^3/s), ACH the air change rate ***N*** = Q_v/V (h^{-1})

Infection Risk Calculation

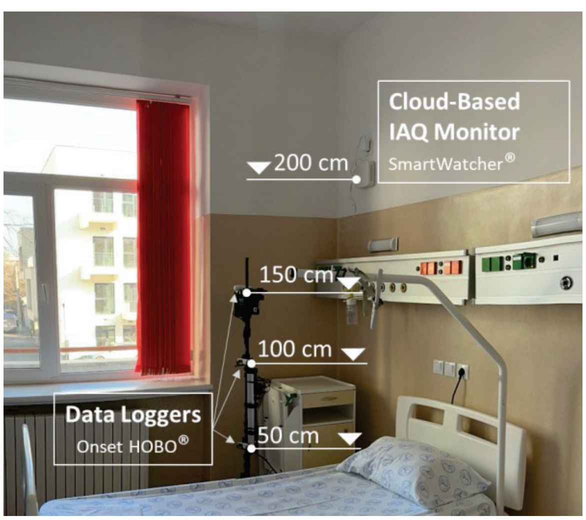
$$p = 1 - e^{\frac{(1-\eta_i)\cdot I\cdot q\cdot Q_b\cdot(1-\eta_s)\cdot D}{(N+\lambda_{dep}+k+k_f)\cdot V}}$$

calculated for the **cases**

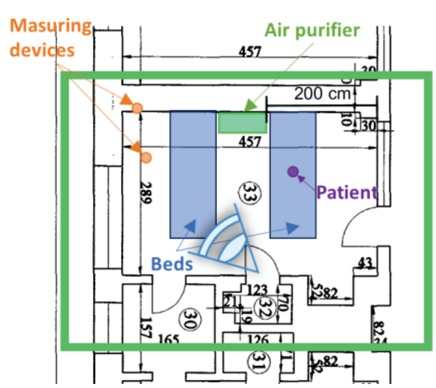
Ventilation and air purification strategies
- Natural ventilation + portable air purifier
- Mechanical ventilation with different design airflow rates

Tampere University

Measurements



- ➢ CO_2
- ➢ Indoor air temperature
- ➢ Outdoor air temperature data were taken from the local meteorological institute



Tampere University

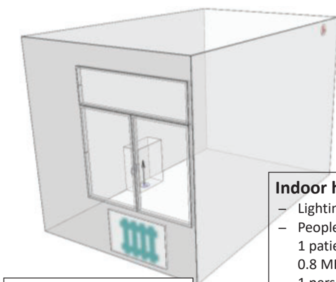
Dynamic simulation of air exchange

Building constructions:
- outdoor walls, brick U-value = 0.95 W/(m^2K)
- windows: 2-plane glazing, no shading, U-value = 2.9 W/(m^2K) g-value = 0.7, area = 3.6 m^2

Infiltration:
- Building leakage rate n_{50} = 4 ACH
- Equivalent Leakage Area at ΔP_4 = 4 Pa, C_d =1: ELA = 0.004 m^2
- Height from the ground z_{out} = 4 m
- Height from the floor z_{in} = 1m

Wind pressure:
For city centre location:
- Wind profile coefficient: a_0 = 0.47
- Wind profile exponent: a_{exp} = 0.35
- Wind surface pressure coef. $C_{d,wind}$

Outdoor climate:
- Measured outdoor climate data Bucharest, Romania: Outdoor temperature T_{out}, relative humidity H_{out}, solar radiation, wind speed v_{ref} at reference level (H_{ref} = 10m) and wind direction



Zone outlet:
$\zeta_{term,in}$ = 1
Z_{exh} = 2.9 m

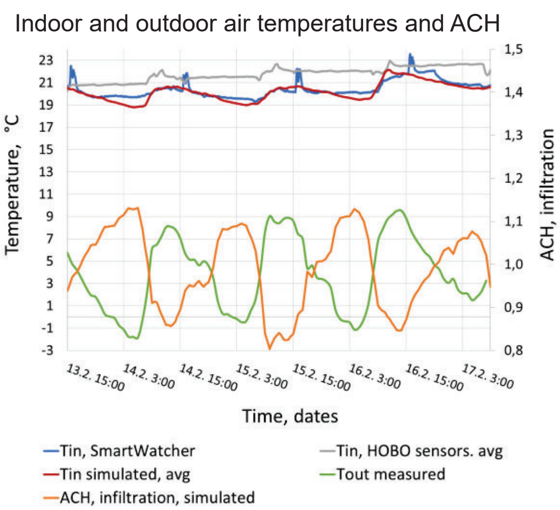
Air exhaust through ventilation shaft
- shaft length dz_{shaft} = 7m
- shaft area A_{sh} = 0.023 m^2
- roughness ε = 0.003 m
- Pressure loss coef. $\zeta_{term,out}$ = 0.6
- shaft top height dz_{out} = 12.9 m

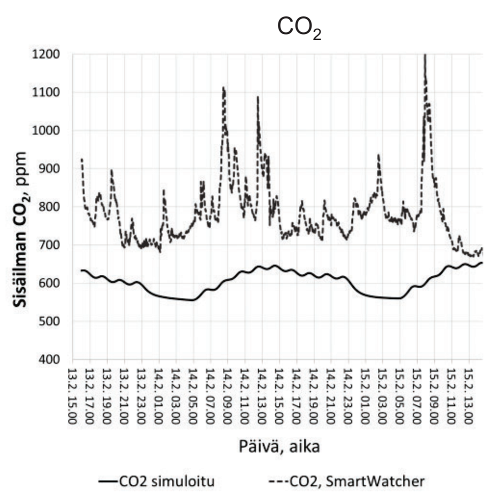
Indoor heat gains:
- Lighting: 164 W
- People:
  1 patient (constant): 0.8 MET and 0.61 clo
  1 personnel (periodic): 1.2 MET and 0.8 clo
- Air purifier: 51 W

Heating, water radiator
Q_{heat} = 60 W/m^2

Tampere University

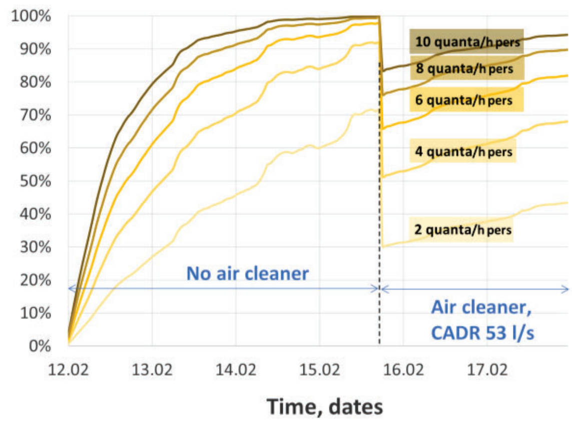
Results

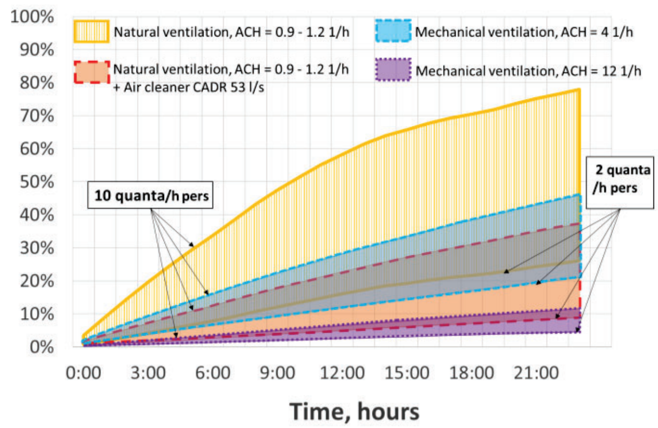




Tampere University

Infection risk probability





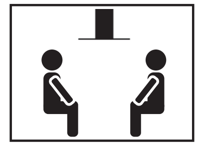
Tampere University

Conclusions

- The simulation model calculated dynamic air flows using natural ventilation to assess infection risk.
- Based on the case study results, natural ventilation alone does not effectively dilute airborne pollutants.
- Combination of ventilation strategy and air purification are needed in the patient room to prevent infections.
- The simulation tool can be used for infection risk analysis to optimize the operation of the hospital ventilation system.

43rd AIVC October 4-5, 2023

Performance of Local Ventilation System Combined with Underfloor Air Distribution as Preventative Measures for Infectious Diseases in Consulting Room



2023/10/5

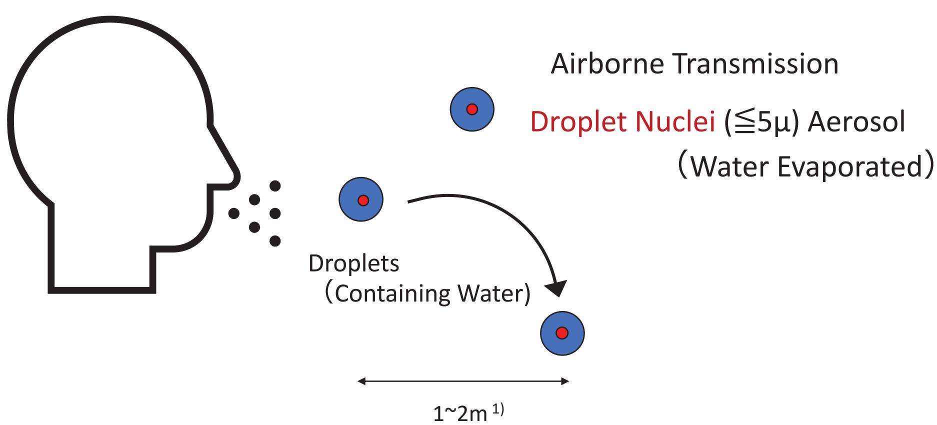
OSAKA UNIVERSITY

Jun Yoshihara
yoshihara_jun@arch.eng.osaka-u.ac.jp
Ph.D. Student, Division of Global Architecture,
Graduate School of Engineering, **Osaka University**, JAPAN

Introduction

Pandemic of COVID19（2019.10~）

- Infection Route（Droplets and Droplet Nuclei ） [1)]



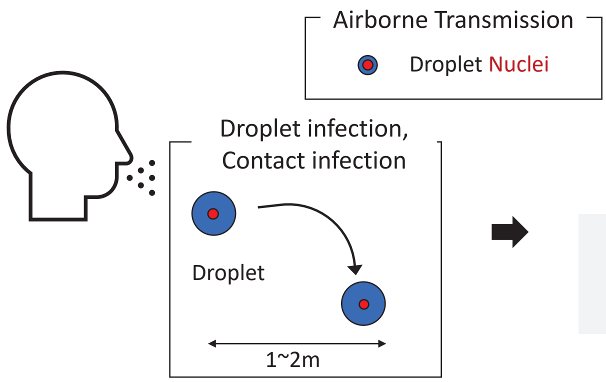
1) X. Xie1, Y. Li1, "How far droplets can move in indoor environments – revisiting the Wells evaporation–falling curve" Indoor Air 2007; 17: 211–225

Introduction

3

Pandemic of COVID19（2019.10~）

・Infection Route（Droplets and Droplet Nuclei）[1)]



➡ Proper Ventilation

Healthy Indoor Environment

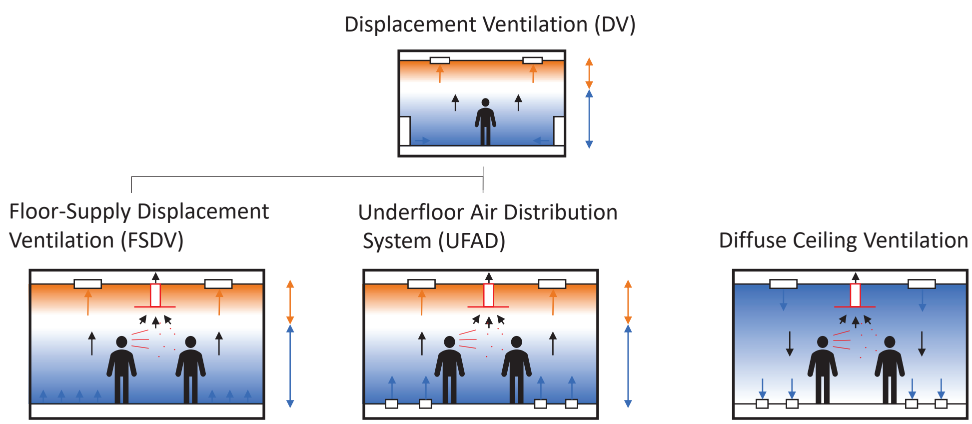
➡ Mask, Washing Hands,

Gargling

Introduction

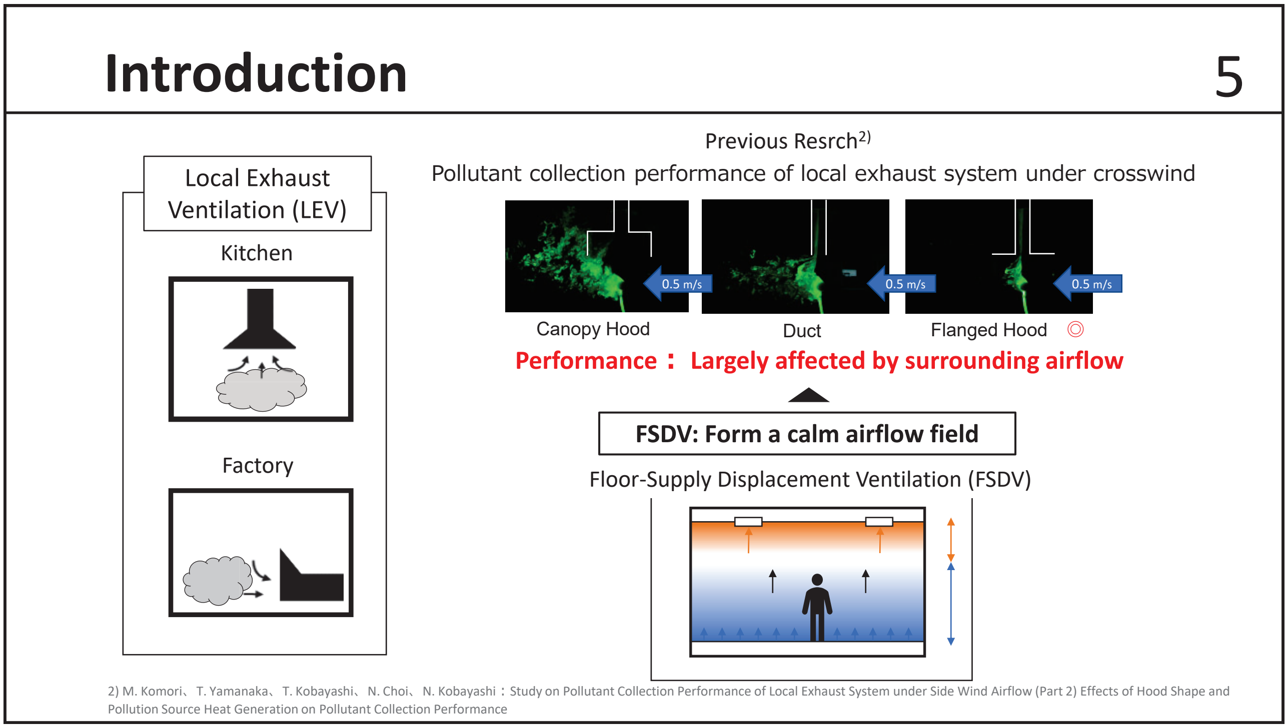
4

Various Ventilations to Prevent Airborne Transmission



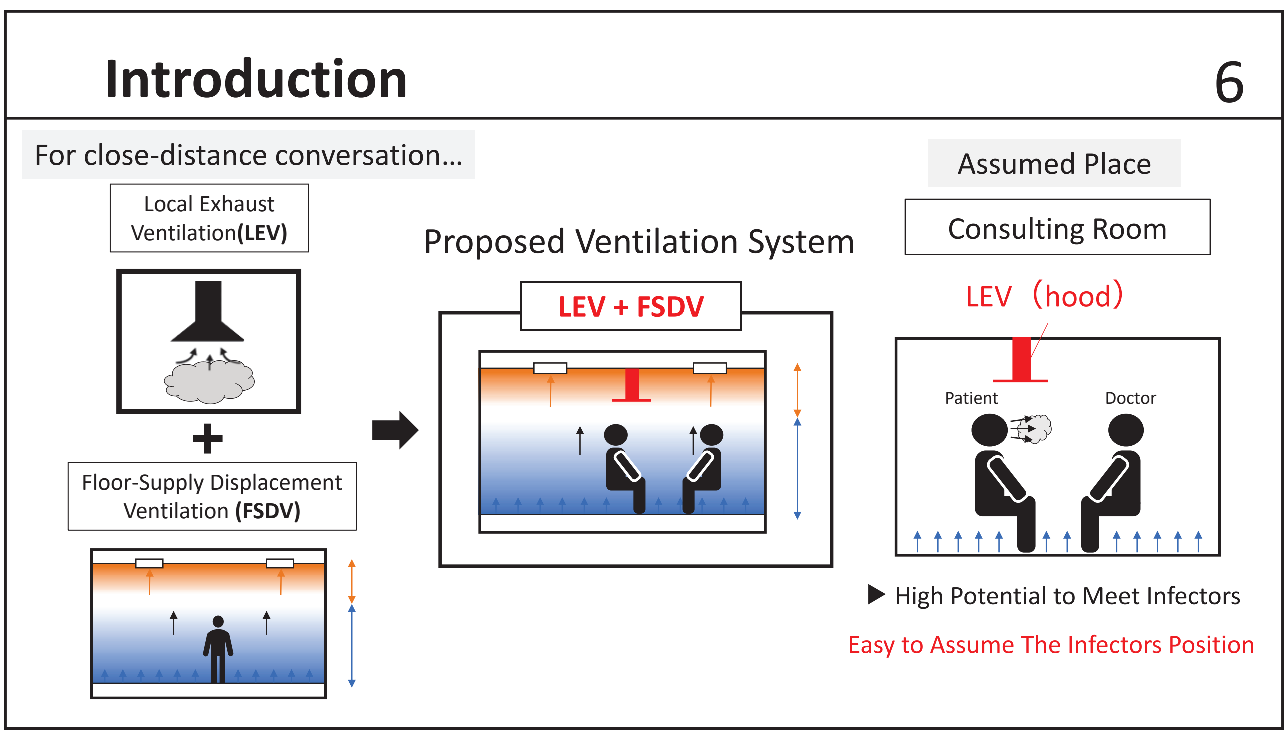
Effect of Entire Scale Ventilation: **Limit to Close-Distance Conversation**
(Especially without Mask)

⇦ **Local Exhaust Ventilation(LEV)**



Introduction
5
Local Exhaust Ventilation (LEV)
Kitchen
Factory
Previous Resrch2)
Pollutant collection performance of local exhaust system under crosswind
0.5 m/s
0.5 m/s
0.5 m/s
Canopy Hood
Duct
Flanged Hood ◎
Performance： Largely affected by surrounding airflow
FSDV: Form a calm airflow field
Floor-Supply Displacement Ventilation (FSDV)
2) M. Komori、 T. Yamanaka、 T. Kobayashi、 N. Choi、 N. Kobayashi：Study on Pollutant Collection Performance of Local Exhaust System under Side Wind Airflow (Part 2) Effects of Hood Shape and Pollution Source Heat Generation on Pollutant Collection Performance

5



Introduction
6
For close-distance conversation…
Local Exhaust Ventilation(LEV)
+
Floor-Supply Displacement Ventilation (FSDV)
Proposed Ventilation System
LEV + FSDV
Assumed Place
Consulting Room
LEV（hood）
Patient
Doctor
▶ High Potential to Meet Infectors
Easy to Assume The Infectors Position

6

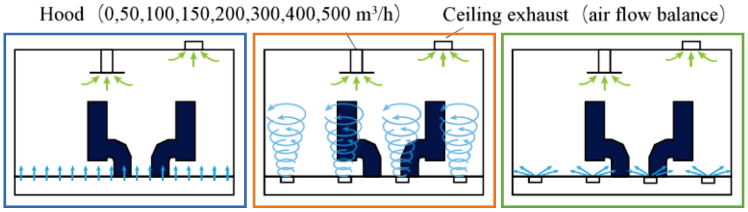
Experiment Method

Method (Parameter)

Parameter：Under-floor Flow Supply Manner → Verified the significance of air conditioning with full floor ventilation

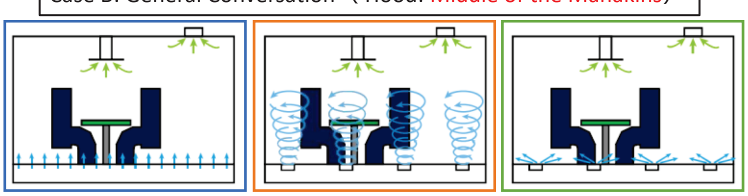
Case A: Consulting Room（Hood: Above the patient）

Hood（0,50,100,150,200,300,400,500 m³/h） Ceiling exhaust（air flow balance）



Floor-Supply Ventilation Swirling Flow Type Diffuser Displacement Flow Type Diffuser

Case B: General Conversation（Hood: Middle of the Manakins）



＊Flow Rate
1,000 m3/h (=50ACH)

Swirling Flow Type Diffuser*)

Displacement Flow Type Diffuser *)

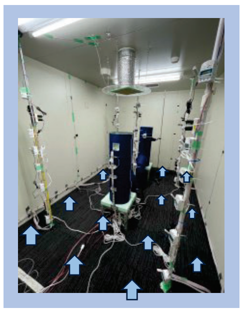
Total 48

＊） 空研工業HP電子カタログ P10, https://www.kuken.com/wp-content/uploads/2020/08/FukidashiSuikomi_20200728P.pdf

Method (Parameter) 9

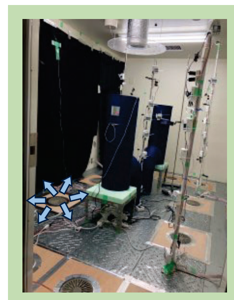
Picture of Experiments

Case A: Consulting Room （Hood: Above the patient）



Floor-Supply Ventilation

Swirling Flow Type Diffuser

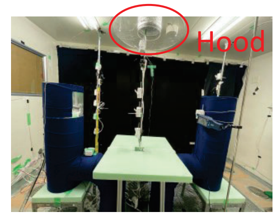


Displacement Flow Type Diffuser

Side View

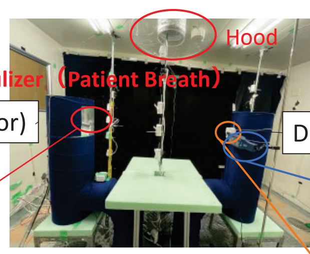
Case A: Consulting Room

Case B: General Conversation



Method (Reproduction of Exhalation) 10

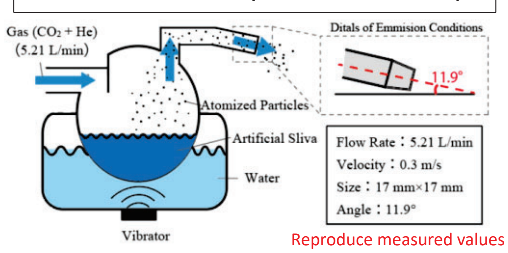
Reproduction of Exhalation



Patient (Infector)

Doctor (Non-Infectors)

Ultrasonic Nebulizer（Mixed Gas＋Particle）



Reproduce measured values

CO_2 Recorder

↓

・ Mixed Gas
As a Droplet Nuclei

↓

Calculate Doctor's quanta

Particle Counter
（3889-01 KANOMAX）

↓

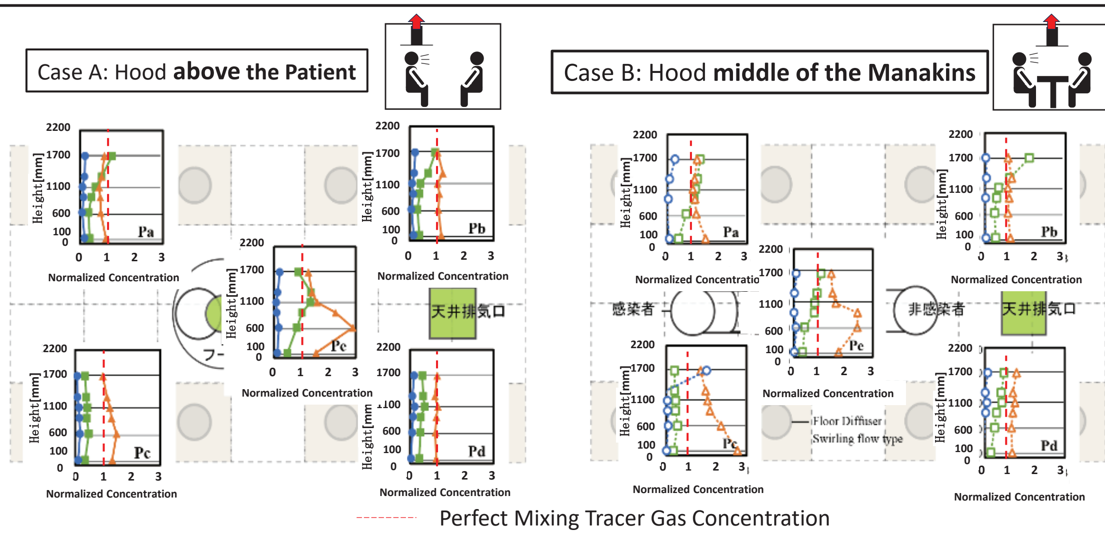
・ Particle
Adhesion and Deposition
Close to Real Droplet

↓

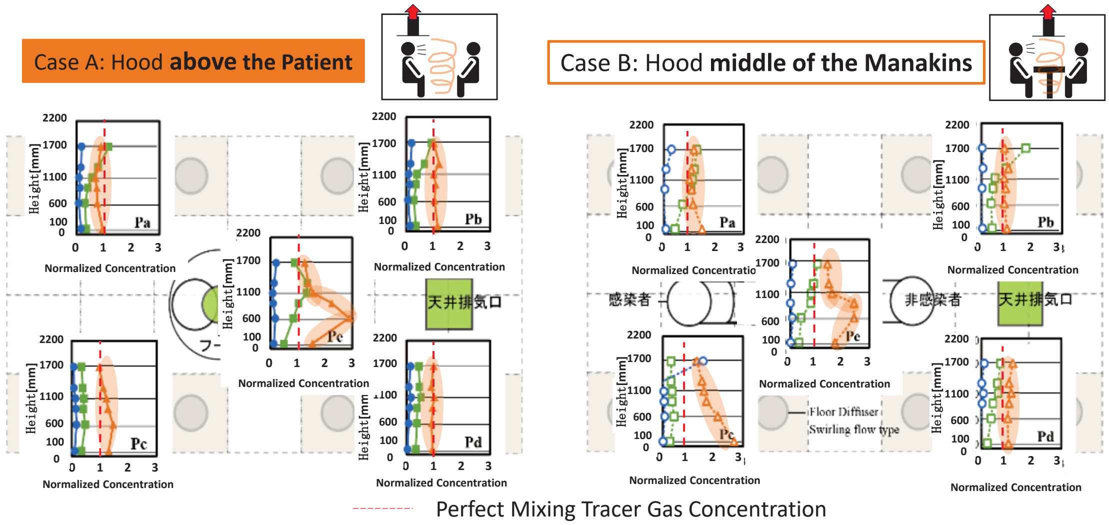
Calculate Doctor's quanta

Results

Results (Vertical Distribution of Tracer Gas)



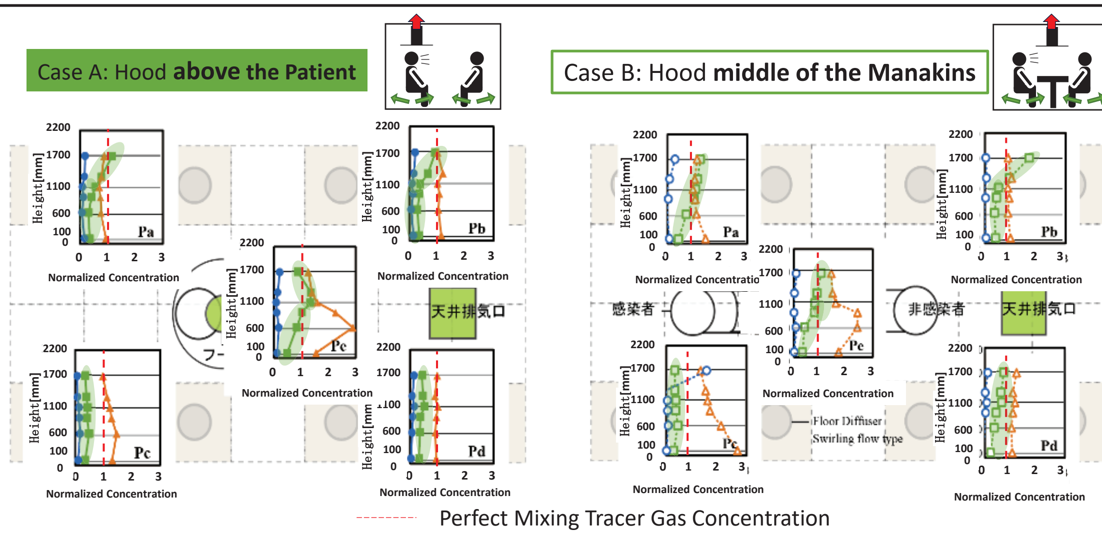
Results (Vertical Distribution of Tracer Gas) 13



Swirling Flow Type Diffuser : Normalized Concentration = 1 → **The Room : Perfect Mixing**

13

Results (Vertical Distribution of Tracer Gas) 14

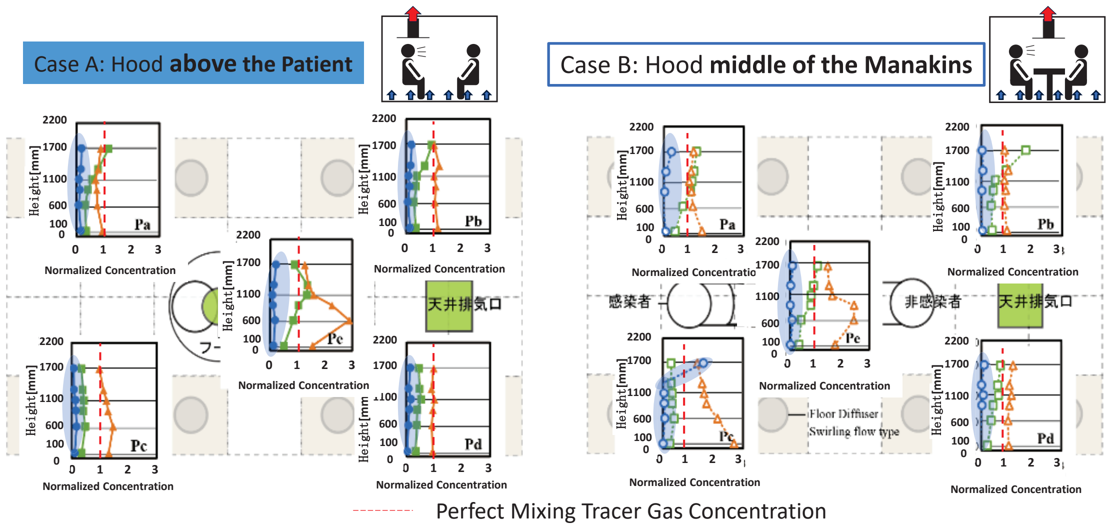


Displacement Flow Type Diffuser : Normalized Concentration = 0.5～1 → **The Room : Relatively Calm**

14

Results (Vertical Distribution of Tracer Gas)

15



Floor-Supply Ventilation : Normalized Concentration = 0 → **The Room : Extremally Calm**

Method (Calculation)

16

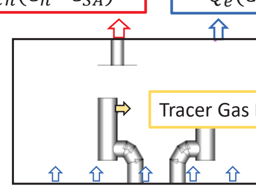
Capture Efficiency

$$\eta = \frac{Q_h(C_h - C_{SA})}{Q_h(C_h - C_{SA}) + Q_e(C_e - C_{SA})}$$

η [-]: Hood capture efficiency
Q_h [m³/h]:Hood flow rate
Q_e [m³/h]:Ceiling exhaust flow rate

Hood
$Q_h(C_h - C_{SA})$

Ceiling Exhaust
$Q_e(C_e - C_{SA})$



C_{qd} : Quanta concentration in front of the doctor's mouth [quanta/m3]

$$C_{qd} = q \cdot \frac{C_d}{M}$$

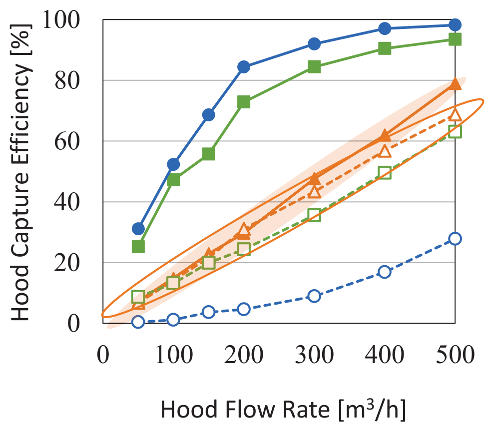
= (quanta Emission Rate) [quanta/h] × (Tracer Gus Concentration in front of Doctor's mouth) [m3/m3] / (Tracer Gas Emission Rate) [m3/h]

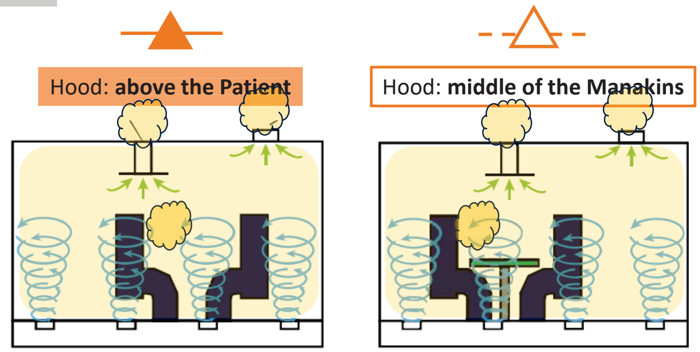
Assume Conversation→ q = 42 [quanta/h] 4)

4) REHVA:COVID-19 guidance document version4.2021

Results (Hood Capture Efficiency of Tracer Gas) 17

Hood Capture Efficiency of The Tracer Gas

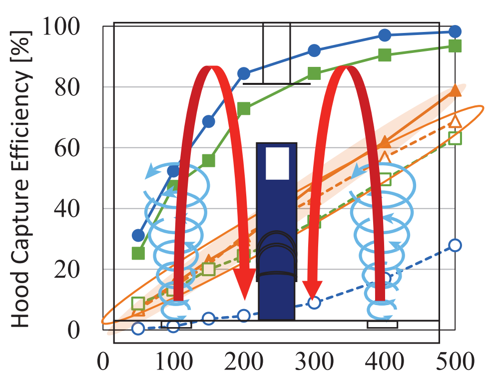


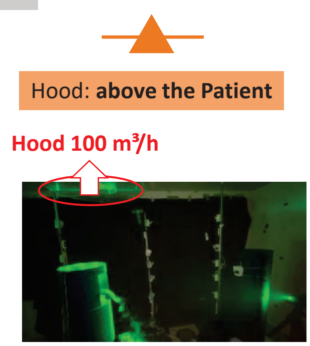


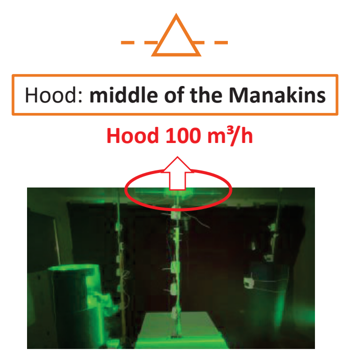
Tracer Gas : **Mixed Well**
→ **The Difference** of Hood Capture Efficiency : **Small**

Results (Hood Capture Efficiency of Tracer Gas) 18

Hood Capture Efficiency of The Tracer Gas





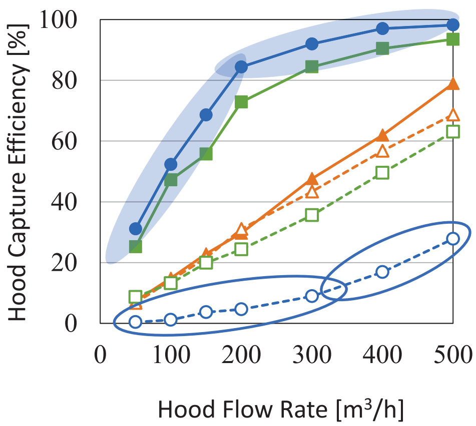


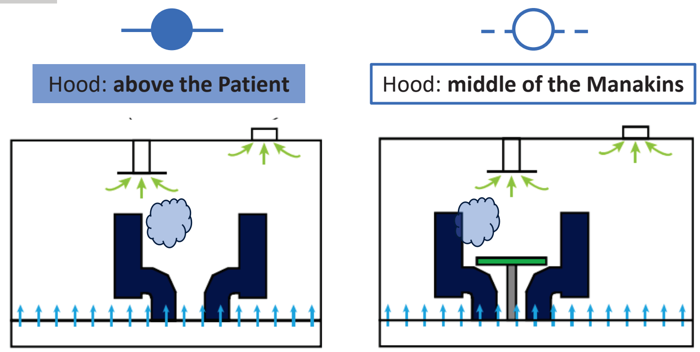
＊In order to Visualize : Breath Flow Rate was a little Big

Swirling Flow Type Diffuser : 1,000 m3/h = **50 ACH** → Supplying up Flow > Exhaust → **Circulation Flow ?**

Results (Hood Capture Efficiency of Tracer Gas) 19

Hood Capture Efficiency of The Tracer Gas

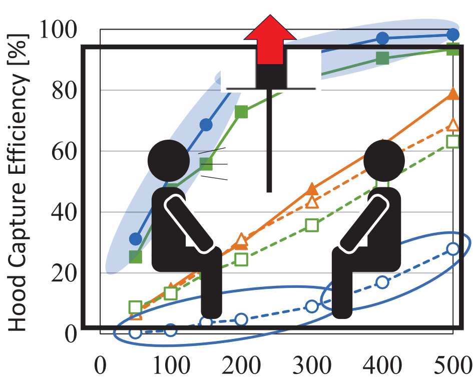


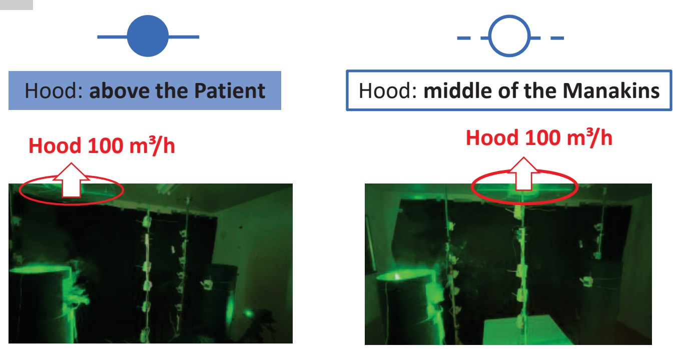


Tracer Gas : **Go Up** After Emitted
→ **The Difference** of Hood Capture Efficiency : **Large**

Results (Hood Capture Efficiency of Tracer Gas) 20

Hood Capture Efficiency of The Tracer Gas

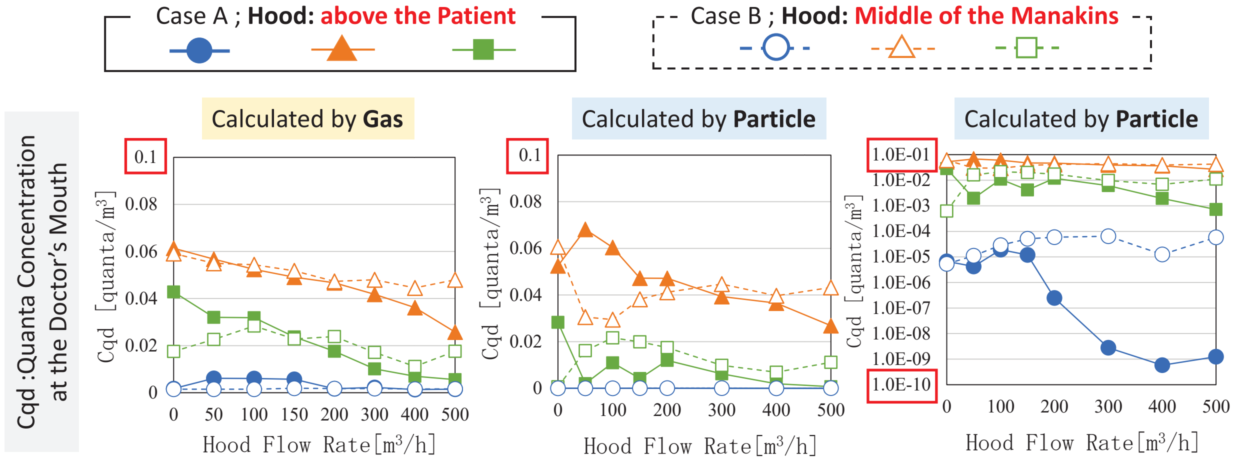




＊In order to Visualize : Breath Flow Rate was a little Big

Hood couldn't affect the doctors Breathing Zone → **Other ways should be considered to** Install in a Meeting Room

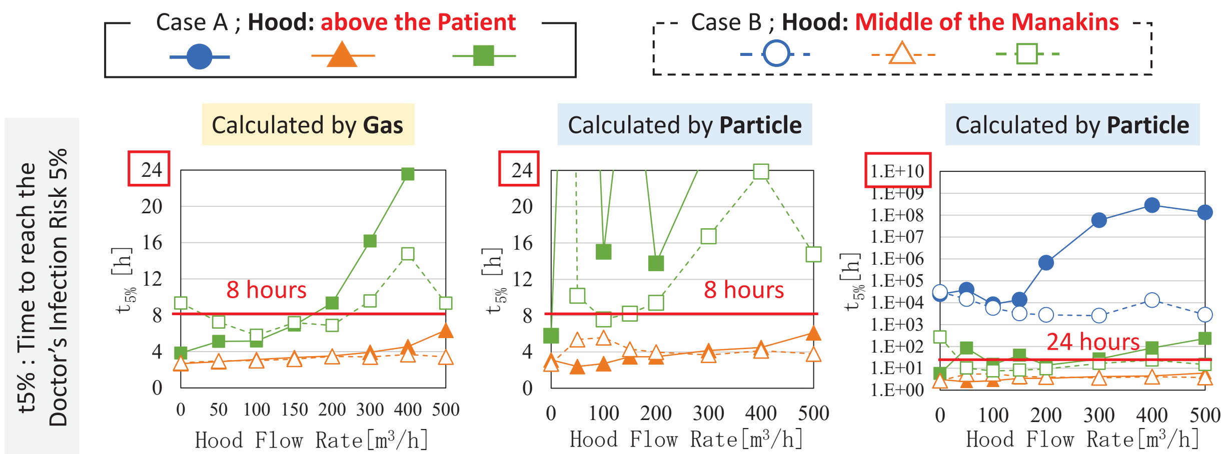
Results (Infection Risk: Gas and Particle) 21



Infection Risk : Swirling Flow Type ＞ Displacement Flow Type ＞ Floor-Supply Ventilation

△ ○ ◎

Results (Infection Risk: Gas and Particle) 22



Floor-Supply Ventilation	: **Sufficient without Hood** (Cased by **50 ACH**)
Displacement Flow Type	: **With Hood** → Infection Risk **Low** (t5%>8h)
Swirling Flow Type	: **With Hood** → Infection Risk **High** (t5%≒4h)

Summarization

Air Flow Condition

Floor-Supply Ventilation : Normalized Concentration = 0 → **The Room : Extremally Calm**

Displacement Flow Type : Normalized Concentration = 0.5〜1 → **The Room : Relatively Calm**

Swirling Flow Type : Normalized Concentration = 1 → **The Room : Perfect Mixing**

Infection Risk

Floor-Supply Ventilation : **Sufficient without Hood** (Cased by **50 ACH**) (t5%>24h)

Displacement Flow Type : **With Hood** → Infection Risk **Low** (t5%>8h)

Swirling Flow Type : **With Hood** (500 m^3/h) → Infection Risk **High** (t5%≒4h)

Case B (Hood: Middle of the Manakins): **Hood couldn't work properly**
→ **Other ways should be considered** in a Meeting Room, Restaurant

＊**Limitation: 50 ACH (1,000 m^3/h)** (Decided by the Experimental Settings)
Future View: Experiments at 6〜12 ACH, Large Hood, Air Purifier, Partitions

Thank you for your attentions!

Ph.D.student Jun Yoshihara

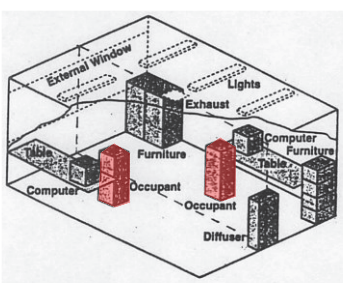
OSAKA UNIVERSITY

The numerical investigation of human micro-climate with different human simulators

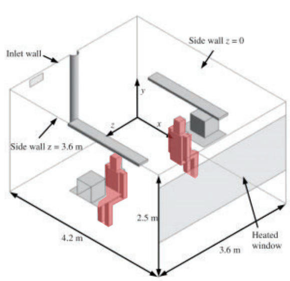
Haruna Yamasawa (Osaka University)
Sung-Jun Yoo (Kyushu University)
Kazuki Kuga (Kyushu University)
Kazuhide Ito (Kyushu University)

Introduction: General background

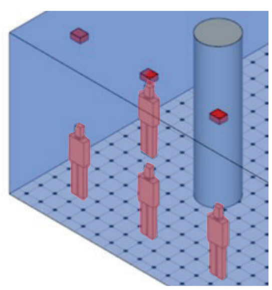
- ✓ The computational fluid dynamics (CFD) is commonly used in various studies
- ✓ Indoor environment: Human simulator (HS) is needed to be installed



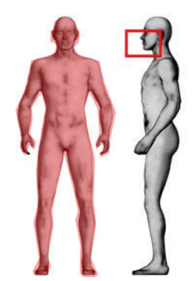
Yuan et al. (1999)



Chen et al. (2013)



Yin et al. (2021)



Yoo et al. (2022)

- ✓ The researchers develop HS by themselves addressing previous works
- ✓ The **geometries** varies by the year of publications and the aim of the studies
- ✓ The thermal plume is important especially in high-efficiency vent. systems

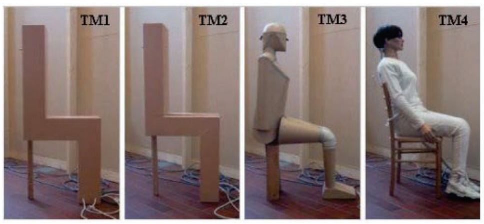
***C**omputer **S**imulated **P**erson*

Introduction: Research questions and aim of the study

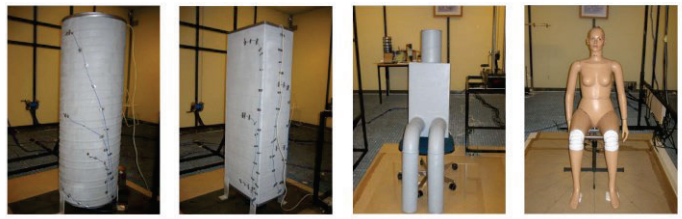
3

Research question:

What influence does the HS geometries have on the micro-climate?



Nielsen et al. (2003)



Zukowska et al. (2007)

Present work:

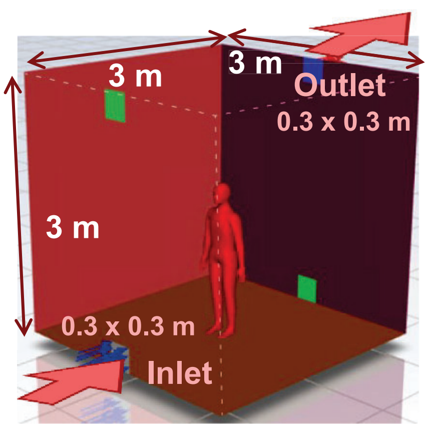
CFD analysis is conducted under steady state

→the heat generation and thermal plume from human simulators

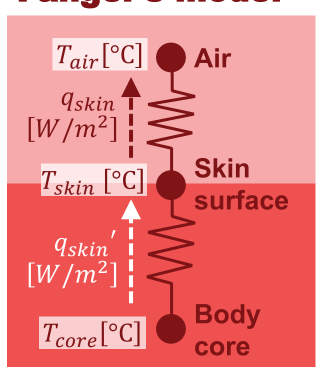
3

4

Analytical domain & conditions



Fanger's model



Heat flux through the skin surface [W/m²]

$$q_{skin} = q'_{skin} = K(T_{core} - T_{skin})$$

$*K = 18.5$ [W/m²°C] $*T_{core} = 36.4$ [°C]

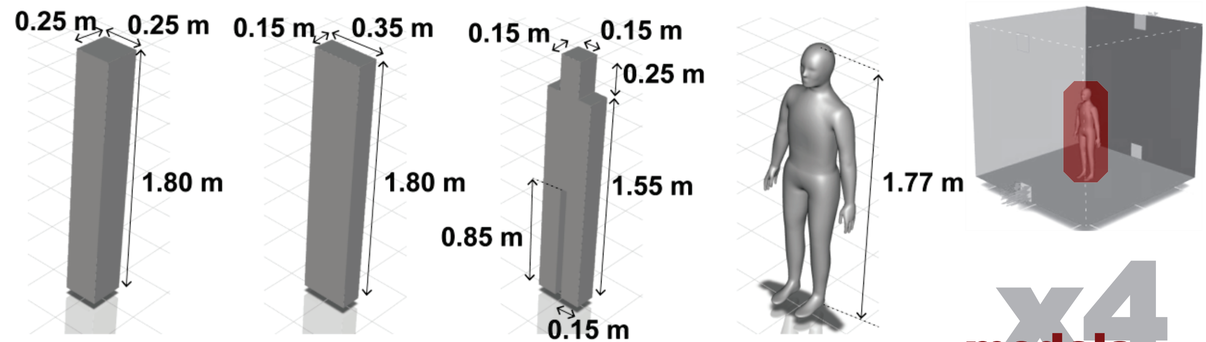
Analytical conditions

Turbulence model	SST k-ω model
Radiation	S2S model
Inlet	0.1 m/s, 20°C
Outlet	Gradient zero
Skin surface	Fanger's model (Fanger, 1972)
Other walls	Gradient zero (Adiabatic)

4

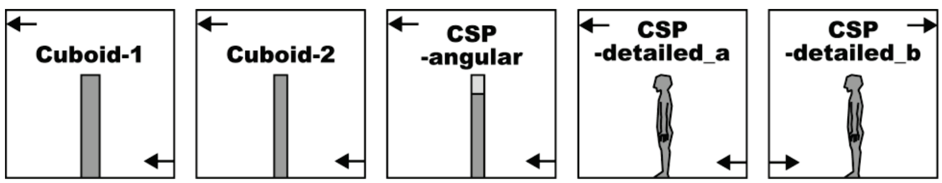
Studied cases

5



Cuboid-1	Cuboid-2	CSP-angular	CSP-detailed
1.84 m² (-1.1%)	1.83 m² (-1.6%)	1.91 m² (+2.7%)	1.86 m² (Ref.)

x4 models



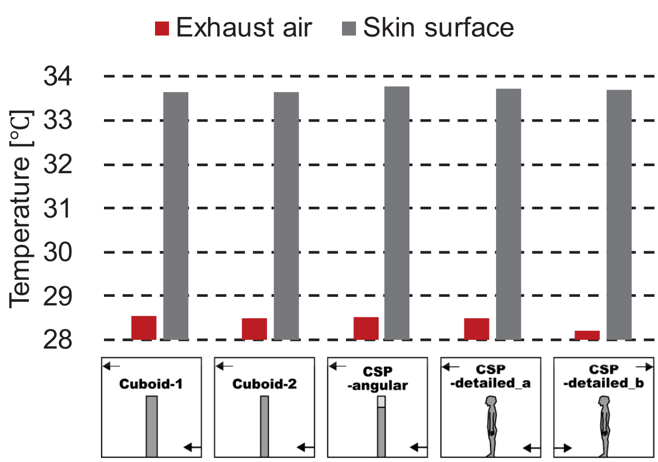
x5 cases

*Number of cells: 1.2 – 5.7 million

5

Results: Temperature

6



Even the simple model worked well regarding the temperature!

However, the points are:

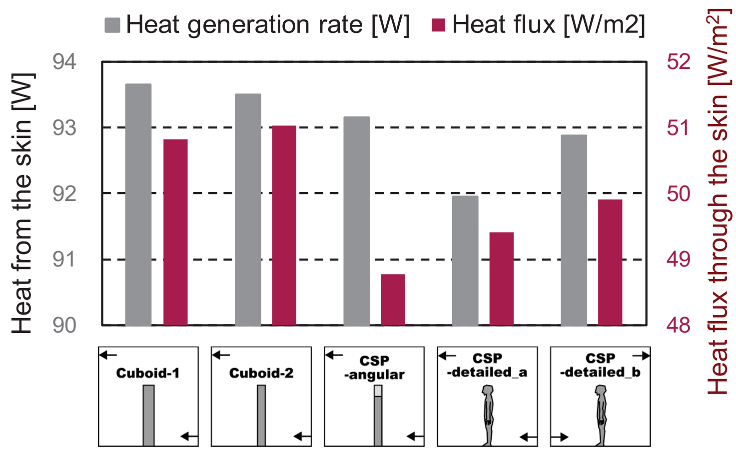
- ✓ **Heat generation rate**
- ✓ **Thermal plume**

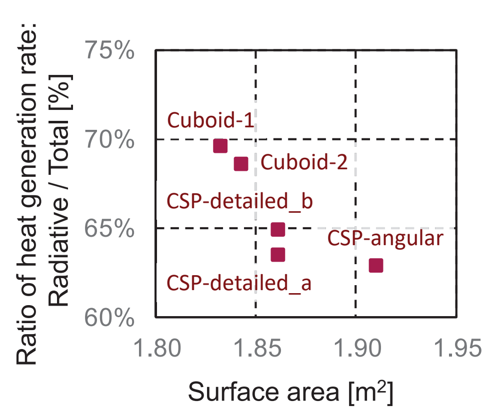
✓ The exhaust and skin surface temperature are almost the same among all the cases

6

Results: Heat generation from the skin

7



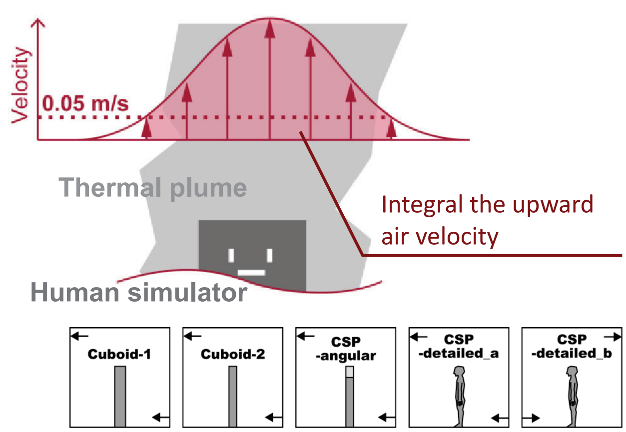


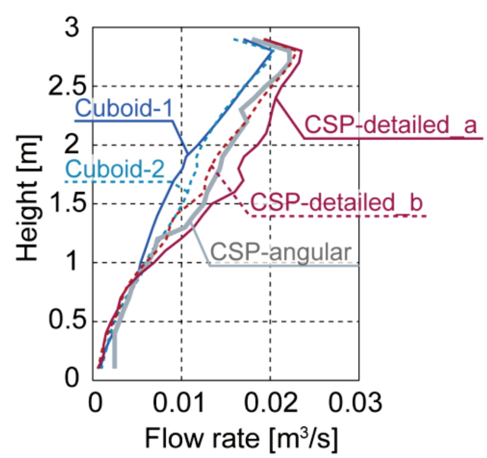
- ✓ The heat generation is all most the same
- ✓ The ratio between rad.-convec. is different
- ✓ The surface area seems to have some influence on the rad.-convec. ratio?

Results: Flow rate of thermal plume

8

How was the flow rate calculated:





- ✓ The flow rate profile of Cuboid-1 and Cuboid-2 are similar to each other
- ✓ The flow rate profile of CSP-angular is similar to that of CSP-detailed_b
- ✓ There are some discrepancies between cuboids and CSPs (Due to rad.-convec. ratio? Geometry?)

The numerical investigation of human micro-climate with different human simulators

9

Conclusions & perspectives

§ **The studied models**

- ✓ two kinds of cuboids, one simple CSP, and one detailed CSP

§ **Results and discussions**

- ✓ It is shown that although the total sensible heat generation is almost the same among all the cases, however, the ratio between radiative and convective heat transfer differed.
- ✓ This also led to the difference in thermal plume flow rate.

§ **Perspective**

- ✓ HSs with absolutely the same surface area
- ✓ Contaminant concentration
- ✓ Clothing

etc...

IEA Energy in Buildings and Communities TCP

EBC

IEA EBC Annex 87

Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems (PECS)

Bjarne W. Olesen and Ongun Berk Kazanci
Intl. Centre for Indoor Environment and Energy, Technical University of Denmark

AIVC2023, October 2023, Copenhagen

Technology Collaboration Programme
by iea

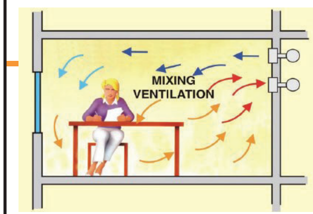
IEA Energy in Buildings and Communities TCP

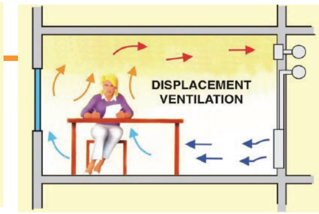
EBC

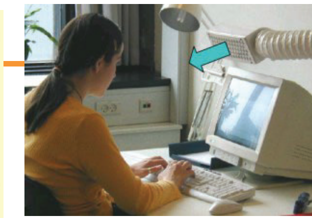
WHAT IS PECS?

- Personal Environmental Control System (PECS) with the functions of heating, cooling, ventilation, lighting and acoustic has advantages of controlling the localized environment at occupant's workstation by their preference instead of conditioning an entire room.
- This improves personal comfort, health and energy efficiency of the entire heating, ventilation and air-conditioning (HVAC) system substantially.
- Personalized ventilation will also protect against cross contaminations, which are critical in open plan offices and work places with close distance.

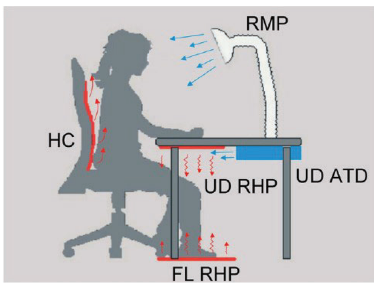
Technology Collaboration Programme
by iea







Source: Melikov 2010



Source: Watanabe et al. 2010

Source: Zhang et al. 2010

Why PECS?

- Has several benefits compared to ambient (total volume) conditioning systems
  - Improved comfort, health and productivity
  - Higher satisfaction with the indoor environment, due to
    - Improvements in the immediate indoor environment experienced by the occupants
    - Possibility of personalized control
  - Potential energy savings
  - Increasing focus on individual differences between people → PECS can address these individual differences
  - Even more relevant due to COVID-19 (pandemic-proofing)

EBC

Why PECS?

- Not entirely new – significant amount of research exists
- Despite the proven benefits
  - No design guide or manual for such systems and their integration in building HVAC systems
  - Far from ”solved”, still several issues to be addressed
  - Not at the level of a common solution in buildings
  - Very limited ”real world” and commercial examples

EBC

Meetings

- 2022 Preparation phase
  - May 20th, 2022 Rotterdam
  - October 17-18th, Copenhagen
- 2023-2025 Working Phase
  - 1. meeting of the working phase of IEA EBC Annex 87, 19th and 20th of May 2023, Tokyo
  - 2. meeting in September 11-12, 2023 (Lausanne, Switzerland, before CISBAT2023 Conference)
- 2026 Reporting Phase

IEA Energy in Buildings and Communities TCP

EBC

OBJECTIVES

- Establish design criteria and operation guidelines for PECS
- Quantify the benefits regarding health, comfort and energy performance.
- Control concepts and guidelines for operating PECS in spaces with general ambient systems for heating, cooling, ventilation and lighting.

Technology Collaboration Programme by iea

IEA Energy in Buildings and Communities TCP

EBC

SCOPE

- Includes all types of PECS for local heating, cooling, ventilation, air cleaning, lighting and acoustic.
- Includes desktop systems, which are mounted on desks or integrated in a furniture
- Chairs with heating/cooling and ventilation.
- Wearables, where heating/cooling and ventilation are included in garments or devices attached to occupants' body.
- Not including cars

Technology Collaboration Programme by iea

EBC

TARGET AUDIENCE

- Manufacturers (who need design guidelines)
- Building owners and consultants (who need information on performance, advantages, problems, operation, how PECS is operated together with other building systems)
- Users (need same info as building owners and for home workplaces)
- Standardisation Bodies (revision of standards for indoor environmental quality).

IEA Energy in Buildings and Communities TCP

EBC

Activities

- Seminar in CLIMA2022 (ca. 30 people attended)
  - https://clima2022.org/extra_content/seminar-new-iea-ebc-annex-on-personalized-environmental-control-systems-pecs/
- Topical session in AIVC2022 (ca. 45 people attended)
  - https://aivc2022conference.org/topical-session-08/
- AIVC Webinar on Monday, 12th of Dec 2022
  - Registration link:
  - https://inive.webex.com/inive/j.php?RGID=rd4ce219c23589874419137a1bff98911

Technology Collaboration Programme
by iea

EBC

Subtask A: Fundamentals

- **Leader**
  - **Mariya P. Bivolarova, Technical University of Denmark, Denmark**
- **Co-leader:**
  - **Dolaana Khovalyg, EPFL, Switzerland**
- **Activity A1:** Definition and identification of the requirements of PECS in terms of localized and background Indoor Environmental Quality (IEQ) i.e., thermal, air quality, lighting, and acoustics.
- **Activity A2:** Outline the benefits of PECS regarding comfort, health and productivity based on literature and new research.
- **Activity A3:** Outline the minimum energy cost requirements for PECS.

IEA Energy in Buildings and Communities TCP

EBC

Subtask B: Applications and Technologies

- **Leader:**
  - **Kai Rewitz, RWTH Aachen University, Germany, pending**
- **Co-leader**
  - **Joyce Kim, University of Waterloo, Canada**
- **Activity B1:** Summarize the working principles, capabilities and limitations of existing PECS, based on literature.
- **Activity B2:** Identify future development and improvement suggestions for PECS for optimal energy, IEQ and cost performance.

IEA Energy in Buildings and Communities TCP

EBC

Subtask C: Control, operation and system integration

- **Leader:**
  - **Joon-Ho Choi, University of Southern California, USA**
- **Co-leader**
  - **Wooyoung Jun, University of Arizona, USA**
- **Activity C1:** Identify and summarize existing methods for controlling PECS (including sensors used for control).
- **Activity C2:** Develop guidelines on integrating PECS with ambient conditioning systems in buildings.

Technology Collaboration Programme
by iea

IEA Energy in Buildings and Communities TCP

EBC

Subtask D: IEQ and Energy Performance evaluation

- **Leader:**
  - **Douaa Al-Assad, KU-Leuven, Belgium**
- **Co-leader**
  - **Marco Perino, Politecnico di Torino, Italy**
- **Activity D1:** Collection of existing methods of studying and testing PECS.
- **Activity D2:** Identification of generic power requirements for PECS to achieve energy savings compared to ambient conditioning systems.
- **Activity D3:** Development of universal and standardized ways of evaluating and reporting performance of PECS.

Technology Collaboration Programme
by iea

IEA Energy in Buildings and Communities TCP

Subtask E: Policy and advisory actions

- **Leader:**
  - **Rajan Rawal, CRABSE, CEPT University, India**
- **Co-leader:**
  - **TBD**
- **Activity E1:** Summary of national and international building codes and standards regarding PECS.
- **Activity E2:** Develop ways of overcoming current barriers for a wide implementation of PECS in buildings.
- **Activity E3:** Provide input to existing national and international standards about requirements, characteristics, and performance of PECS.

Technology Collaboration Programme by iea

IEA Energy in Buildings and Communities TCP

DELIVERABLES

1. Guidebook on requirements for PECS
2. State-of-the-art report on PECS
3. Guidebook on PECS design, operation and implementation in buildings (including integration of PECS with ambient conditioning systems)
4. Report on test methods for performance evaluation of PECS
5. Universal criteria about requirements, characteristics, and performance of PECS to be used in national and international standards

Technology Collaboration Programme by iea

Participating countries

- Australia, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Italy, Netherlands, Republic of Korea, Singapore, Switzerland, Turkey, USA

Further information

- www.iea-ebc.org/projects/project?AnnexID=87

KU LEUVEN

Subtask D: IEQ and Energy performance evaluation of PECS

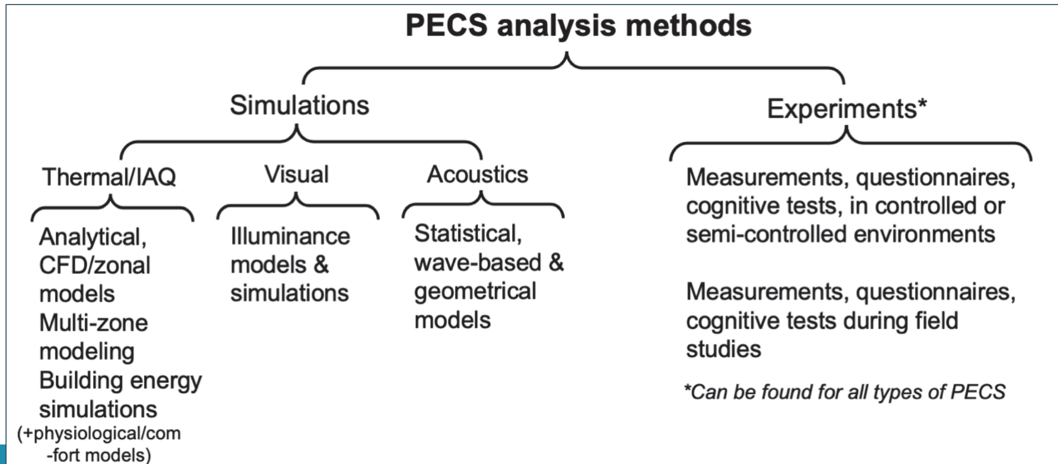
Douaa Al-Assaad[1], **Hilde Breesch**[1], Marco Perino [2]
[1] KU Leuven, [2] Politecnico di Torino

Aim & activities

- Aim
  - Review methods evaluating performance of PECS: IEQ (thermal, air quality, acoustics, lighting) and energy performance
  - Identify missing performance evaluation methods.
  - Performance evaluation: qualitative and quantitative KPIs from literature and new metrics (Subtask B)
- Activities
  - D1: Collect existing methods studying and testing PECS
  - D2: Identify energy requirements PECS
  - D3: Develop universal and standardized ways evaluating and reporting IEQ performance PECS

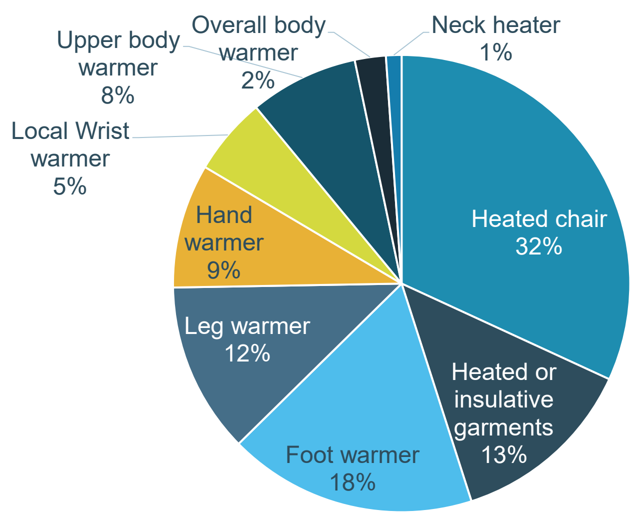
Activity D.1 Literature review performance methods

- Overview methods analyzing PECS' performance



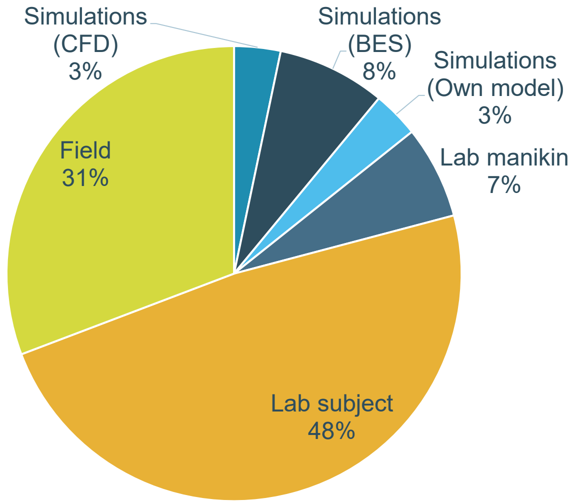
Activity D.1 Literature review performance methods

- Example heating PECS: review 69 studies



Activity D.1 Literature review performance methods

- Example heating PECS:
  review 69 studies

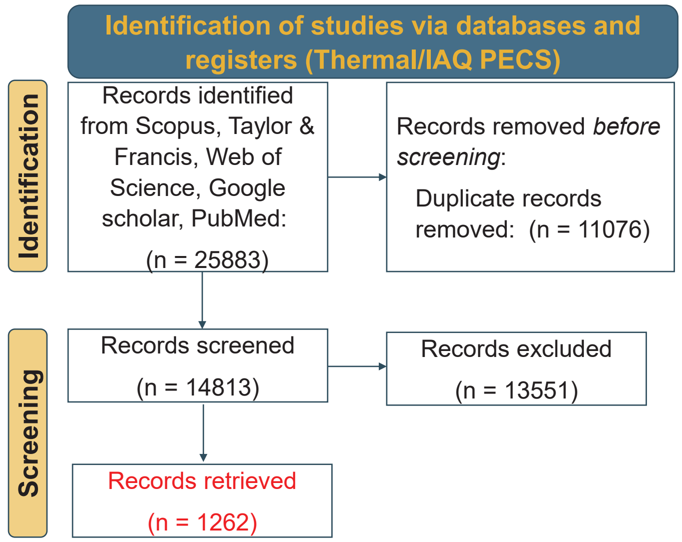


Activity D.1 Literature review performance methods

- Review objectives
  - Overview different methods analyzing PECs' performance
  - How to use these methods effectively to obtain accurate performance output?
  - How to ensure quality of results?
  - Which method most suited for specific analysis? Or specific PECS?
  - Challenges and/or limitations using this method? -> Agenda for future activities

Activity D.1 Literature review performance methods

- Systematic review process
  - cfr. Prisma guidelines
  - Next step:
    - Split into different analysis methods
    - Extract info methodological elements



KU LEUVEN

Activity D.1 Literature review performance methods

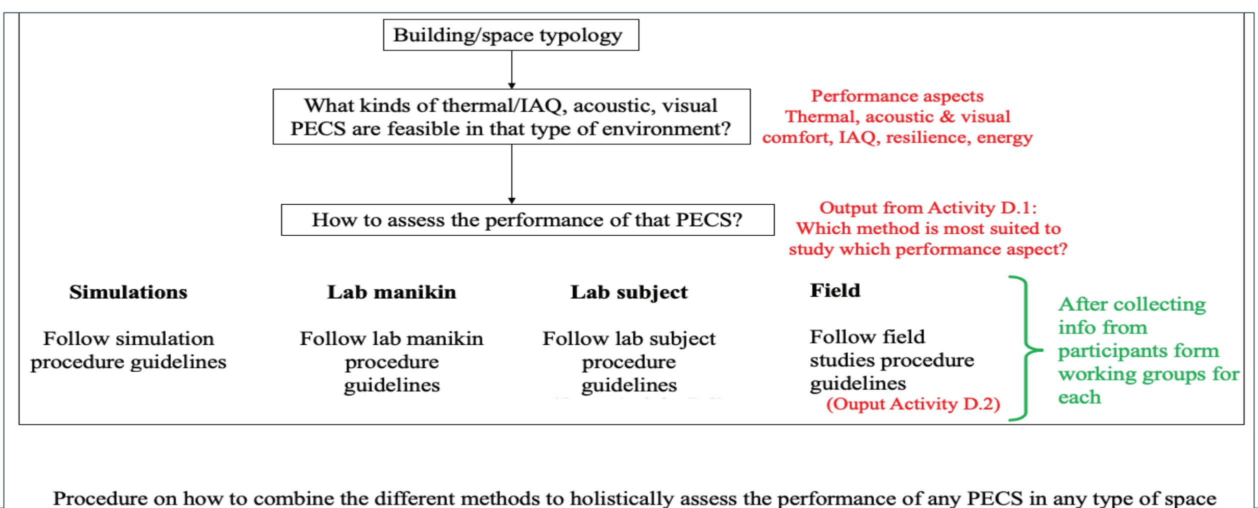
- Examples methodological elements for thermal/IAQ PECS
  - Analytical methods/ CFD
    - Numerical methods
    - discretization schemes
    - convergence criteria
    - occupant modeling
    - modeling HVAC system diffusers and terminals
    - boundary conditions
  - Building Energy Simulations (BES)
    - Building type
    - Location
    - envelope characteristics
    - modeling of energy systems
    - thermal zoning
    - schedules and patterns
    - modeling occupant behavior

KU LEUVEN

Activity D.1 Literature review performance methods

- Examples methodological elements for thermal/IAQ PECS
  - Chamber studies
    - Chamber characteristics and conditioning
    - human subjects or manikin details
    - measurements' locations, Intervals, durations
  - Field studies
    - Building type
    - outdoor climatic conditions
    - number of PECS installed
    - occupancy schedules, patterns, density
    - questionnaires and response rate
    - measurement locations, intervals and durations

Activity D2 & D3: guidelines evaluating and reporting performance PECS



KU LEUVEN

Subtask D: IEQ and Energy performance evaluation of PECS

Douaa Al-Assaad[1], Marco Perino [2], **Hilde Breesch**[1]
[1] KU Leuven, [2] Politecnico di Torino

1

Dragos-Ioan Bogatu
drabo@dtu.dk
International Centre for Indoor Environment and Energy – ICIEE, DTU SUSTAIN, Technical University of Denmark

Physiological sensing for thermal comfort assessment

2

Highlights and agenda

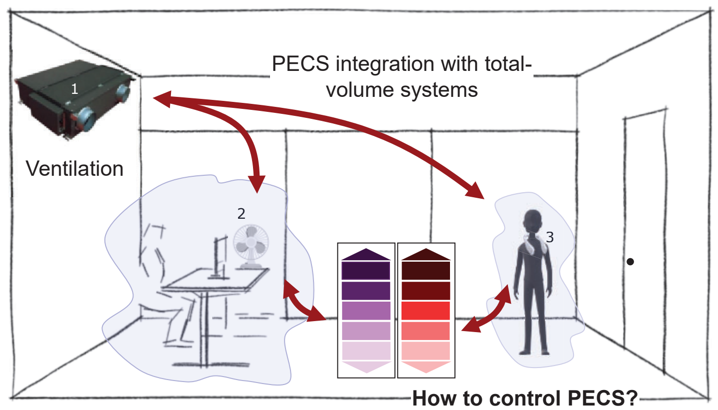
- Systematic review of data-driven thermal comfort prediction for HVAC control.
- Overview of physiological indicators, sensing strategies, and derived indicators.
- Statistical analysis of the influence of features on model prediction performance.
- Discuss principles and examples of automatic control for PECS

Personalised environmental control system

“A **personalised Environmental Control System (PECS)** is a system that can provide individually controlled thermal, air quality, acoustic, or luminous environments in the immediate surroundings of an occupant, without affecting directly the entire space and other occupants’ environment.”

IEA EBC - Annex 87 - Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems, https://annex87.iea-ebc.org/

Personalised environmental control system



Is the occupant feeling hot, cold, or neutral?

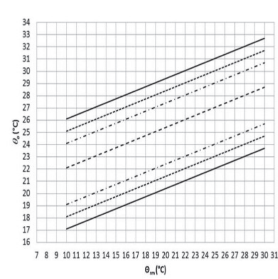
[1] Mitsubishi Electric; [2] Freepik.com; [3] Coolpriser.dk Neck Fan

Existing comfort models

”The **PMV** is an index that predicts the **mean value of the votes of a large group of persons** on the 7-point thermal sensation scale, based on the heat balance of the human body”

$$PMV = [0{,}303 \cdot \exp(-0{,}036 \cdot M) + 0{,}028] \cdot \left\{ \begin{aligned} &(M - W) - 3{,}05 \cdot 10^{-3} \cdot [5\,733 - 6{,}99 \cdot (M - W) - p_a] - 0{,}42 \cdot [(M - W) - 58{,}15] \\ &-1{,}7 \cdot 10^{-5} \cdot M \cdot (5\,867 - p_a) - 0{,}0014 \cdot M \cdot (34 - t_a) \\ &-3{,}96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{aligned} \right\}$$

Adaptive: indoor temperature as a function of running mean outdoor temperature (takes into account adaptation)



CEN, EN ISO 7730, 2006; EN 16798-1:2019

Personal comfort models

- Adequately represent the need of a specific individual
- Input is required from the occupant as comfort is a function of both thermoregulatory and psychological aspects
- Need for subjective thermal response emulators to reduce interaction with the occupant
- Indicators can be derived from **environmental** changes, and **thermoregulatory** reactions, **behavior**, and occupant differences in body type (i. e., **anthropometric** information).

Bogatu et al., Human physiology for personal thermal comfort-based HVAC control – A review, B&E, 2023, https://doi.org/10.1016/j.buildenv.2023.110418

Physiological indicators

Physiological signals

Physiological indicators gathered for thermal comfort models stem from signals representative of human thermoregulation.

- **Neural activity**: brainwave [Hz] Alpha (8–14), Beta (13–35), Delta (0.5–4), and Gamma (35–45)
- **Heartbeat**: HR, HRV, SpO2
- **Blood flow**: blood volume changes, blood pressure
- **Activity**: MET, activity level, standardized values
- **Temperature**: T_{SK}, T_{MSK}, T_{CORE}
- **Sweat**: EDA, RH_{SK}

May be used as indicators. Some signals are representative of stress, excitement, emotion

Bogatu et al., Human physiology for personal thermal comfort-based HVAC control – A review, B&E, 2023, https://doi.org/10.1016/j.buildenv.2023.110418

Derived indicators from physiological signals

Time, spectral, and non-linear domains

- Changes in time or over body & general statistics (mean, min, max)
- Representation of a signal or data in terms of its frequency components
- Short and long term signal perturbations and predictability of the signal

Examples: LF/HF, heat loss, gradient of skin temperature

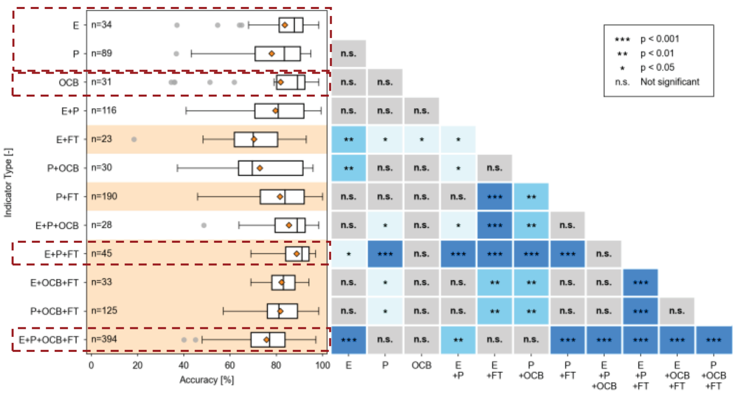
Complemented by Environmental (E), Occupant behaviour (OCB), and Feature Transformation (FT)

Bogatu et al., Human physiology for personal thermal comfort-based HVAC control – A review, B&E, 2023, https://doi.org/10.1016/j.buildenv.2023.110418

DTU

Model performance (ML based)

- E > P
- Clothing and activity important
- FT important
- Including all (E, P, AB, FT) may not necessarily lead to a high accuracy



Environmental (E) // Physiological (P) // Occupant behaviour (OCB) // Feature Transformation (FT)

Bogatu et al., Human physiology for personal thermal comfort-based HVAC control – A review, B&E, 2023, https://doi.org/10.1016/j.buildenv.2023.110418

DTU

Model performance and physiological indicators

- An accuracy of 70–80% should be attainable. KNN potential baseline, however **no definitive list of physiological indicators** is available.
- **Sweat, RH_{SK}, and SpO_2** are **biased** to the hot part of the thermal sensation spectrum.
- **T_{SK} and heart** signals present **higher variability across** thermal sensation **states**.
- So far **only skin temperature and heart rate** were **included in control strategies**.
- The usefulness and availability of each indicator is **challenged** though **by** the **measuring strategy and location**.

Physiological sensing

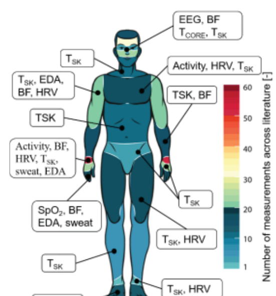
Physiological sensing

- Most measurements made at wrist level
- T_{SK} most investigated for each body part

- **Neural activity (EEG)** – light, easy to set up, intrusive

- **HRV (ECG)** – electrodes, least intrusive chest
- **HR** (PPG/RGB/Doppler), **SpO2** (PPG) – smartband
- **MET** (cardiopulmonary tester), **activity** (3-axial acc.)

- $\boldsymbol{T_{SK}}$ (thermocouples, button devices, smartbands, IR cameras)
- $\boldsymbol{T_{CORE}}$ (radio-pills, IR cameras, T_{SK} and heat flux)
- $\boldsymbol{RH_{SK}}$**, sweat rate, EDA** (humdity, electrodes, durometer)



Frequency of physiological measurements across the human body

Bogatu et al., Physiological sensing for thermal comfort assessment , AIVC, 2023

DTU

Capabilities and limitations of current sensing strategies

- Wearable devices (cheap and mature products); wired/wireless (probes, smartwatch, headset)
- Contactless (RGB, IR cameras, Doppler)
- Not always ‘plug and play’

Device	Capabilities	Limitations
Wearable	• May be integrated in a device attached to an occupant • May measure multiple parameters • Clothing does not interfere with the measurement • Mature products • May be relatively cheap • Can be placed directly on the skin • Can be placed on different and multiple body areas • Can be connected via cloud-based solutions	• Measurement length dependent on the battery life and data storage capacity of the equipment • Could be intrusive and invasive (e.g., chest strap) • Accuracy issues (improper use, movement, fastening option) • Sensor accuracies may be unknown • Covers body area where measurement is made • Narrow operating ranges • Single point measurement • Influenced by physical pressure, insulation from fitting material and thermal inertia of the sensor • Inconvenient if wired
Contactless	• Can gather data on body areas not covered by clothing, e.g. face • Non-invasive and non-intrusive • Can capture a bigger surface area • Can detect changes from the skin naturally and directly impacted by the surrounding environment	• May require a complex system consisting of multiple nodes (e.g. depth and thermal image camera) • Privacy concerns • Little flexibility regarding placement • Correction regarding clothing might be required • May not be suitable for multi-occupancy spaces due to the limited field of view • Error in detecting area of interest for measurements • Can be difficult to implement in building due to size and compatibility issues (e.g. in Building Management Systems). • Higher cost compared to wearable sensors

Bogatu et al., Physiological sensing for thermal comfort assessment , AIVC, 2023

DTU

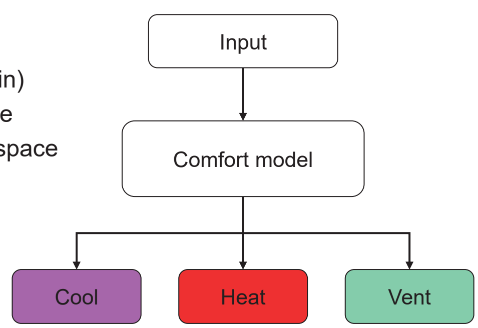
Physiological sensing

- **Further development required** – not all devices are ‘plug-and-play’ and designed for thermal comfort
- **Contactless devices** can **only** be used to acquire **skin temperature and HR** (low resolution, error correction required)
- Measurement **accuracy rarely provided** for consumer products
- **Smartbands acquire multiple physiological indicators** (consumer oriented devices protected by 3rd party protocols)
- Wearable devices are connected to the occupant which makes it **difficult to determine ownership, operation, and maintenance responsibility**

Automatic control

Automatic control

- Trained model predicts state **cold / neutral / warm**
- Air temperature changed in **increments**, usually ±1 K, in direction of comfort
- **Setpoint changes**:
  – made at Δt = x min (usually 30 min)
  – when occupant provided a change
  – when occupants entered/left the space

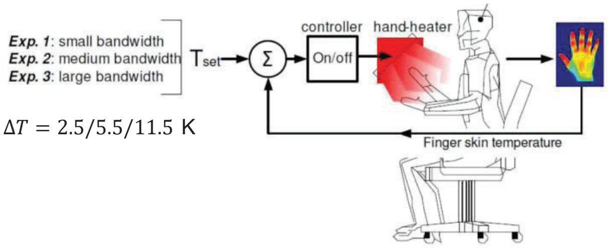


Examples

Automatic control

Personal heater control

- Two incandescent reflector heating lamps (98 W)
- $T_{room} = 20$ ℃
- Input: finger skin temperature



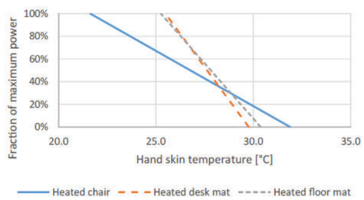
$\Delta T = 2.5/5.5/11.5$ K

- In general it was possible to maintain neutral or higher TSV.

Zeiler et al., Thermal response of different body parts: the fingertip as control sensor for personalzied heating, EnergyProcedia 78, 2015, 10.1016/j.egypro.2015.11.622

Personalised heater control

- 18 ℃, heated chair, desk mat, floor mat
- Personalized heating controlled proportionally to T_{SK} (hand, dorsal)
- Setting adjusted every 2 s.

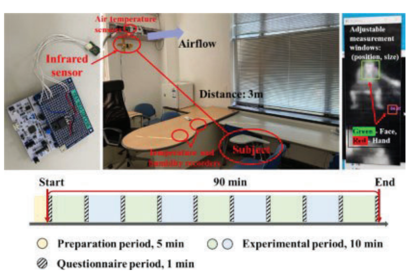


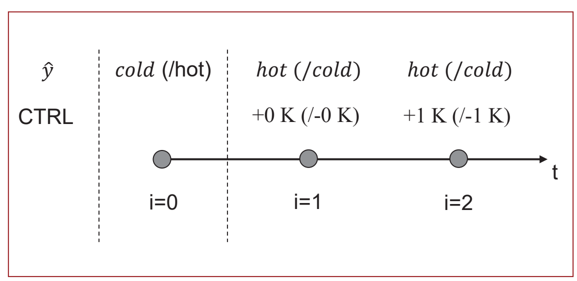
- Automatic control provided **same level of thermal comfort** as user control
- Average user control input similar to automatic control

Veselý et al., Personalized heating – comparison of heaters and control modes, Build. Environ., 2017, https://doi.org/10.1016/j.buildenv.2016.11.036.

Air conditioning control

- Single-person office with AC
- $22\ ℃ < T_{room} < 30℃$





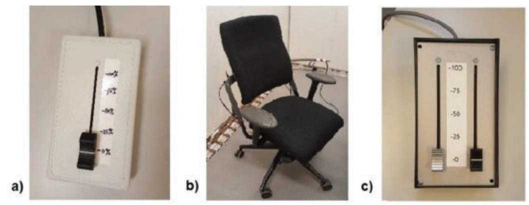
$\overline{TSV} = [-0.5, 0.5]$; $TCV = not\ always\ 'comfortable'$

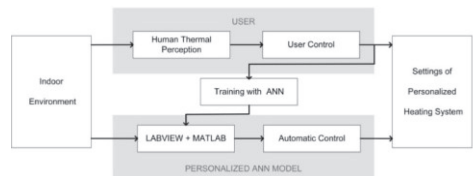
- Algorithm: RF; Input: $\overline{T_{hand}}, \overline{T_{face}}, T_{room}$; Output: $\hat{y} = TSV$; $ACC = 84\%$
- $\Delta T: -1\ K\ (\hat{y} = hot)$; $+1\ K\ (\hat{y} = cold)$; $+0\ K\ (\hat{y} = neutral)$

Yeyu et al., Development of personal comfort model and its use in the control of air conditioner, E&B, 2023, https://doi.org/10.1016/j.enbuild.2023.112900

Personal comfort model for PECS

- $20\ ℃$, 2 people, 14 test sessions (4h)
- Inputs: environmental (T_{air}, RH, $\bar{T}_r$); Output: setting of PECS
- The control voltage was used as the target of the predictive model
- Both test subjects felt comfortable throughout the tests and expressed their satisfaction with the automatic control

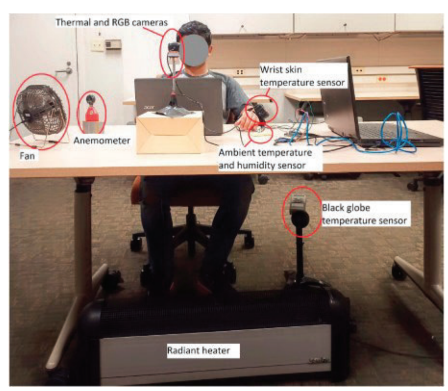




Katic et al., Neural network based predictive control of personalized heating systems, E&B, 2020, https://doi.org/10.1016/j.enbuild.2018.06.033

Personal comfort model for PECS

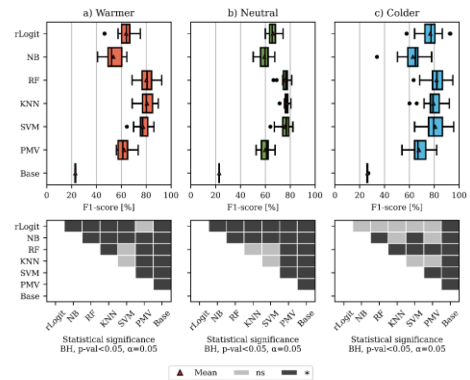
- $19\ to\ 31\ ℃$ with $1℃/10$ min, fan ($1.2\ m/s$) or heater ($1000\ W$), 0.57 clo
- PECS require separate comfort models
- Comfort models built without PECS may be enhanced by including PECS power/operation
- 2-5% increase in accuracy with environmental instead of physiological data (T_{SK})
- Model accuracy decreased with PECS (better sensing and modelling methods required)

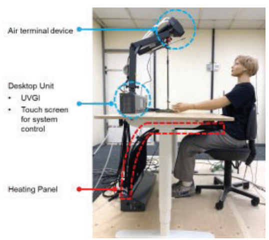


Aryal et al., Thermal comfort modeling when personalized comfort systems are in use: comparison of sensing and learning methods, B&E, 2020

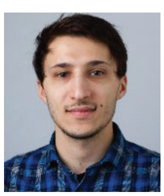
Personalised comfort model for PECS

- 18 to 28 ℃, steady-state, w/o and with PECS, 24 subjects
- Grouped according to general thermal preference
- Integrating self-assessed general thermal preference leads to higher prediction performance (11 to 18 %) than the PMV.
- Environmental indicators had the highest importance





Bogatu et al., Personalised Thermal Comfort Model for Automatic Control of a Newly Developed Personalised Environmental Control System (PECS), IAQVEC, 2023



drabo@dtu.dk

Bogatu et al., ‘Physiological sensing for thermal comfort assessment’, AIVC, 2023

Bogatu et al., “Human physiology for personal thermal comfort-based HVAC control – A review”, https://doi.org/10.1016/j.buildenv.2023.110418

ASHRAE STANDARD 241

Max Sherman, SSPC241, Vice Chair

AIVC Conference; October 2023

1

ASHRAE Standard 241-2023
Control of Infectious Aerosols

Purpose

- Requirements for control of infectious aerosols to reduce risk of airborne transmission
  - Occupiable space in existing and new buildings, additions, and major renovations
  - Non-residential, residential, and health care spaces
  - Covers outdoor air and air cleaning system design, installation, commissioning, operation, maintenance
- Specify *equivalent clean air* to be provided in *infection risk management mode*

Scope

- Based on reduction of *long range transmission* risk
- Does not establish overall requirements for acceptable indoor air quality but requires IAQ as a pre-requisite

2

2

BACKGROUND

Request from White House	• Quickly develop standard for future epidemics • Hard deadlines
ASHRAE authorizes abbreviated process	• For first version only • Expedites resources
“Tiger Team” effort	• 6 committed Working Groups. • Done in 4 months vs. more normal 4 years
ASHRAE commits to	• Normalize standard (i.e. use normal process) • Continually improve standard and fix gaps

Overview

1. Assess facility – condition and existing equivalent clean air delivered
2. Determine target equivalent clean air required by space and system
3. Determine need for additional equivalent clean air
4. Determine the best option for providing required equivalent clean air using outdoor air, particle filtration, and air cleaners tested as required, and operational measures
5. Prepare a Building Readiness Plan to document assessment and decisions
6. Perform repair and maintenance as needed and required
7. Implement upgrades if needed

Infection Risk Management Mode (IRMM)

The mode of operation in which measures to reduce infectious aerosol exposure documented in a building readiness plan are active

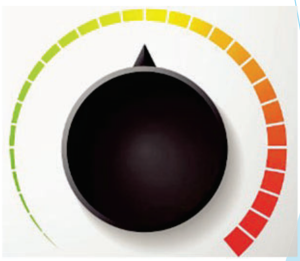
Decision on IRMM Enable / Disable: Not 241

- Public health official
- Owner
- Occupant

Why not all the time?

- Potential Energy use and cost increase
- Infection risk and consequences of infection vary over a wide range

An example of resilience applied to IAQ



Normal IRMM

5

5

Equivalent Clean Airflow (ECA)

The flow rate of pathogen-free air that, if distributed uniformly within the breathing zone, would have the same effect on infectious aerosol concentration as the sum of actual outdoor airflow, filtered airflow, and inactivation of infectious aerosols

Concept on which the entire standard depends

- Determine ECA for infection risk mitigation (ECAi)
- Determine total ECA for spaces, systems (V_{ECAi})
- Analyze options to reach target in IRMM

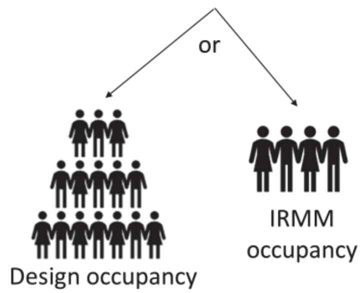
Also adopted from Epidemic Task Force guidance
(same as *equivalent* *<u>outdoor</u>* *air*)

6

6

ECAi depends on space type, number of people, activity

$$V_{ECAi} = ECAi \times P_{Z,IRMM}$$



Double table ECAi for high vocalization spaces

Occupancy Category	ECAi cfm/person	ECAi L/s/person
Correctional Facilities		
Cell	30	15
Dayroom	40	20
Commercial/Retail		
Food and beverage facilities	60	30
Gym	80	40
Office	30	15
Retail	40	20
Transportation waiting	60	30
Educational Facilities		
Classroom	40	20
Lecture hall	50	25
Industrial		
Manufacturing	50	25
Sorting, packing, light assembly	20	10
Warehouse	20	10
Health Care		
Exam room	40	20
Group treatment area	70	35
Patient room	70	35
Resident room	50	25
Waiting room	90	45
Public Assembly/Sports and Entertainment		
Auditorium	50	25
Place of religious worship	50	25
Museum	60	30
Convention	60	30
Spectator area	50	25
Lobbies	50	25
Residential		
Common space	50	25
Dwelling unit	30	15

Meeting the ECA target

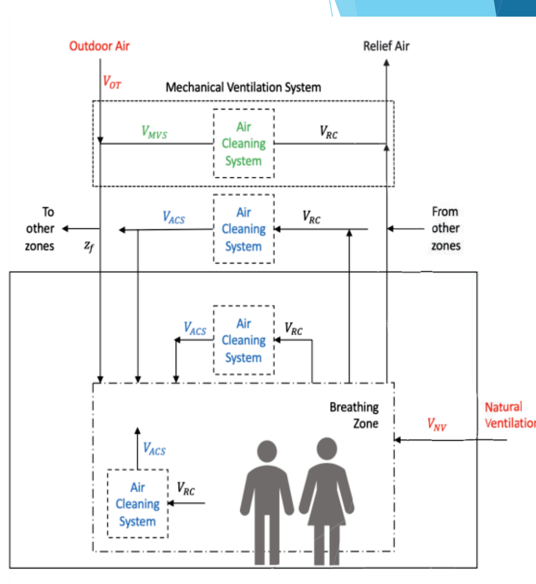
Requirement can be met by

- Outdoor airflow – mechanical/natural
- ECA from multi-zone air cleaning systems
- ECA from in-room air cleaning systems

Approach allows maximum flexibility to user

Limitations on compliance

- Must have prerequisite minimum outdoor air
- To receive credit toward meeting requirements, mechanical filters must be MERV-A 11 or higher or equivalent (ePM2.5>50%)
- MERV 11 acceptable until 1/1/2025
- Hope to raise to ePM1>50%



Air Cleaning

Reducing infectious aerosol concentration through capture and removal or inactivation

Air cleaning technologies

- Mechanical filters (including electret media)
- Germicidal ultraviolet light
- Reactive species – ionizers, photocatalytic oxidation, other oxidants

Mention of specific technologies in the standard is not endorsement!

9

9

Air Cleaning Effectiveness and Safety

Lack of information and standards related to air cleaning systems was a major problem during the COVID19 pandemic:

- Effectiveness – ability to remove or inactivate infectious aerosols
- Safety – adverse effects of direct exposure (UV-C, oxidants), secondary contaminants (particles, ozone); not required for purel mechanical filtration

Standard 241 establishes backup minimum requirements for effectiveness and safety testing in Normative Appendix A

- For when no applicable standard exists

Goal is a level playing field for all technologies

10

Special Considerations: Dwellings

Requires separation zones in case of infection	Defines enhanced ECA for higher risk occupants	Less specific on process
Infected individuals are sent home	Special populations need more protection	Owners may modify

11

11

Building Readiness Plan (BRP)

Reduced detail for dwellings

- Documents the engineering and non-engineering controls that facility systems will use for the facility to achieve its goals
- Summarizes results of assessment and planning exercises and documents measures to be implemented in IRMM
- Direct descendant of ASHRAE Epidemic Task Force guidance


ASHRAE

ASHRAE EPIDEMIC TASK FORCE

BUILDING READINESS | Updated 5-17-2022

General Information
- Building Readiness Intent
- Building Readiness Team
- Building Readiness Plan

Epidemic Conditions in Place (ECIP)
- Systems Evaluation
- Building Automation Systems (BAS)
- Ventilation per Code / Design
- Increased Ventilation above Code
- Increased Ventilation Control
- Building and Space Pressure
- Flushing Between Occupied Periods
- Equivalent Outdoor Air
- Upgrading and Improving Filtration
- Filter Droplet Nuclei Efficiency / Particle Size Expectations
- Energy Savings Considerations
- Exhaust Air Re-entrainment
- Energy Recovery Ventilation Systems Operation Considerations
- UVGI Systems
- Domestic Water & Plumbing Systems
- Maintenance Checks
- Shutdown a Building Temporarily-FAQ
- System Manual
- Reopening During Epidemic Conditions in Place

Post-Epidemic Conditions in Place (P-ECIP)
- P-ECIP: Prior to Occupying
- P-ECIP: Operational Considerations once Occupied
- P-ECIP: Ventilation
- P-ECIP: Filtration
- P-ECIP: Building Maintenance Program
- P-ECIP: Systems Manual

Additional Information
- Acknowledgements
- References
- Disclaimer

Information in this document is provided as a service to the public. While every effort is made to provide accurate and reliable information, this is advisory, is provided for informational purposes only, and may represent only one person's view. They are not intended and should not be relied upon as official statements of ASHRAE.

12

12

Assessment, planning, and implementation

- Builds on ASHRAE Epidemic Task Force Building Readiness guidance
- Applies commissioning practices to infection risk mitigation systems
- Requirements for developing the Building Readiness Plan
  - optional for dwellings
- Assessment of existing V_{ECAi} to determine need for additional controls
- Supporting information
  - Tracer particle test procedure for determining V_{ECAi} in-place (appendix)
  - Checklists for assessment and commissioning (appendix)
  - Building Readiness Plan template (appendix)
  - Equivalent clean air calculator (download at ashrae.org/241-2023)
  - Guidance on assessing energy recovery ventilators (download)
  - Guidance on preventing re-entry of contaminated air (download)

13

13

Operations

(Requirements are optional for dwellings)

- BRP on site, accessible, current
- Essential supplies stocked
- Operating modes defined:
  - Normal - occupied/unoccupied
  - IRMM - occupied/unoccupied
  - Temporary shutdown
- Temperature and humidity - maintain design set points when occupied
- Operating schedules
  - On for all occupied hours
  - No on-off control of HVAC fans
- Flushing not required between occupancy periods
- Operator training
- Occupant communication

14

14

Maintenance

Maintenance tasks and frequencies for all occupancies and system types follow ASHRAE/ACCA Standard 180 plus additional requirements →

Frequency of some checks increased for IRMM

Table 9-2 Minimum Maintenance Activity and Frequency for Additional Engineering Controls and Associated Components While in Use

Engineering Control	Inspection/Maintenance Task	Frequency
In-room air cleaners	Verify unit is in appropriate location and operating as intended per the *BRP*. Confirm that the air cleaner is operating at the speed or setting assumed in the V_{ECAi} calculation. Maintain systems and equipment and verify performance per manufacturer's instructions. Visually inspect intake for debris and clean as necessary.	Monthly
Ultraviolet (UV) germicidal irradiation	Maintain systems and verify performance and safety per manufacturer's instructions and in accordance with ANSI/IES RP-44-21 [11] and ANSI/IES RP-27.1.22 [20] or equivalent. Adjust, clean, and replace equipment as needed.	Assess quarterly or per manufacturer's recommended interval
All air cleaning systems and equipment (including in-room, in-duct, and UV air cleaners)	Maintain systems and equipment and verify performance per manufacturer's instructions. Adjust, clean, and replace equipment as needed. If equipment cannot be repaired, remove equipment from service and use a substitute engineering control to maintain V_{ECAi} in occupied space.	Assess quarterly or per manufacturer's recommended interval
Separation space	The designated temporary separation areas shall be tested for negative pressure whenever an infected individual is present.	As used

15

15

Thank You

QUESTIONS

16

Can the Wells-Riley model universally assess airborne pathogen infection risk?

Dr Benjamin Jones
Associate Professor
University of Nottingham

Dr Chris Iddon

Prof. Max Sherman

AIRBODS

1

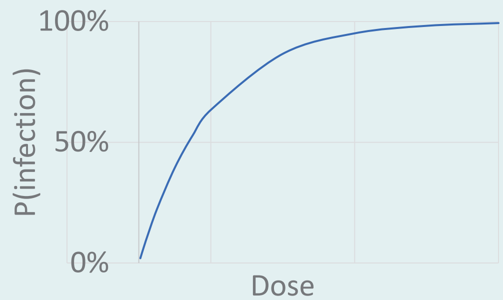
NO

AIRBODS

2

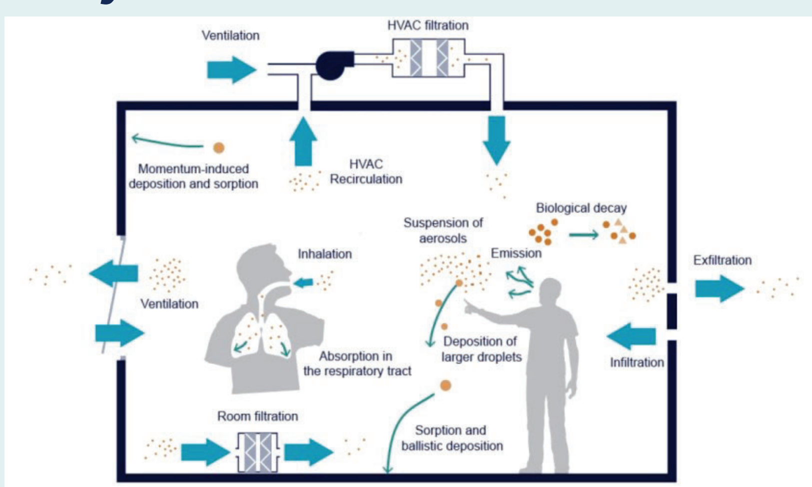
Wells-Riley model

$$P(infection) = 1 - EXP(-n)$$



AIRBODS

Virus dynamics



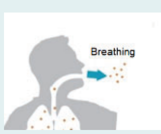
AIRBODS

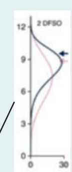
Terms

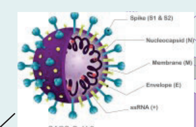
$$n = \frac{-QDq}{\phi V}$$

5

Emission



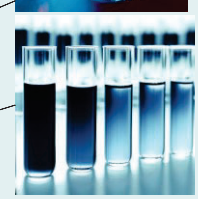




$$q \equiv kG/K$$

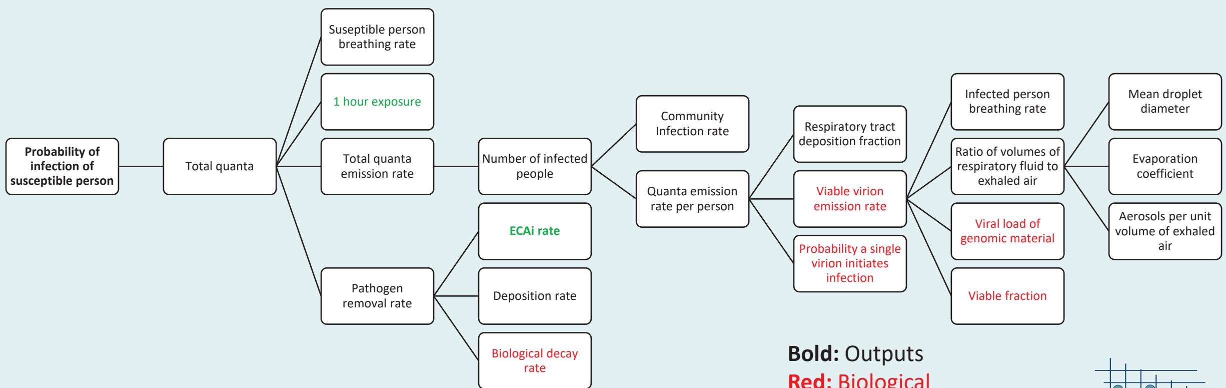
$$G = QV^*_{drop}Lv$$

$$V^*_{drop} = \frac{\pi}{6}\left(\bar{d}E\right)^3 C_{drop}$$



6

The system

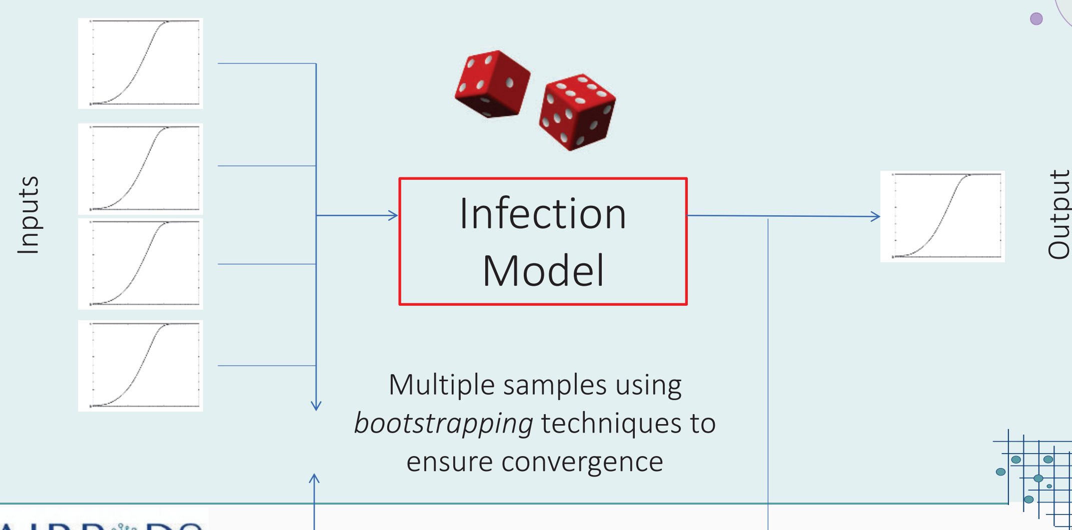


Bold: Outputs
Red: Biological
Green: Deterministic

AIRBODS

7

Variance using Monte Carlo

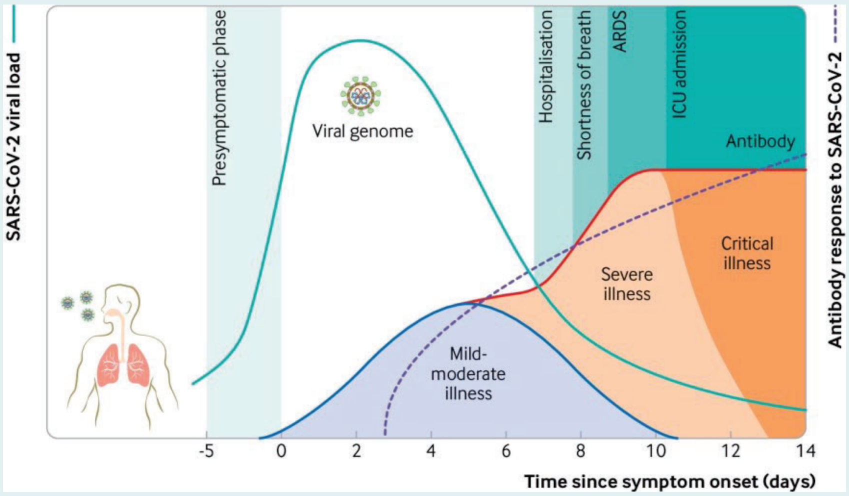


Multiple samples using *bootstrapping* techniques to ensure convergence

AIRBODS

8

Viral load

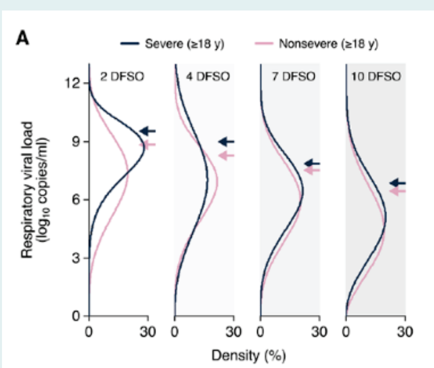


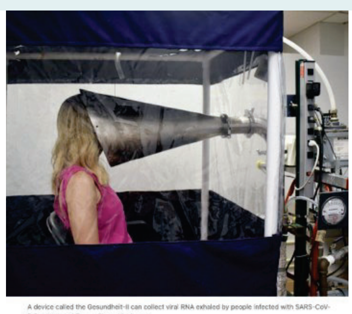
AIRBODS

Cevik, M. *et al.* (2020) 'Virology, transmission, and pathogenesis of SARS-CoV-2', *BMJ (Clinical research ed.)*, 371, p. m3862. doi: 10.1136/bmj.m3862

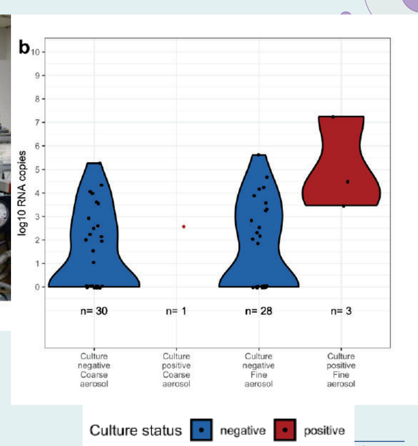
9

Viral load





Variability in respiratory viral load Lai *et al* 2022 pre-print



AIRBODS

Chen et al (2021) SARS-CoV-2 shedding dynamics across the respiratory tract, sex, and disease severity for adult and pediatric COVID-19 https://doi.org/10.7554/eLife.70458

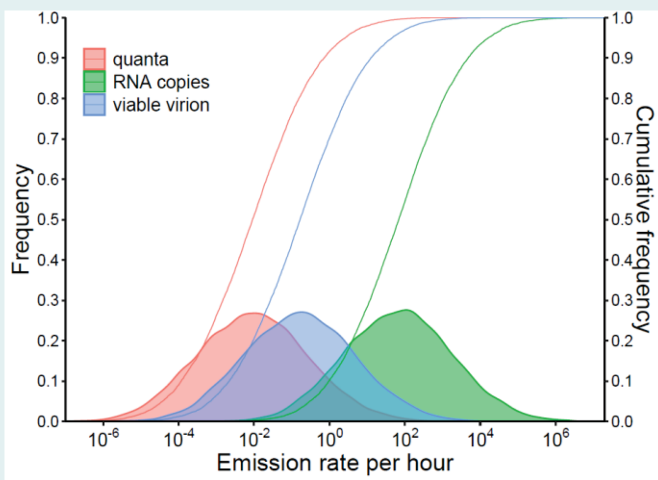
10

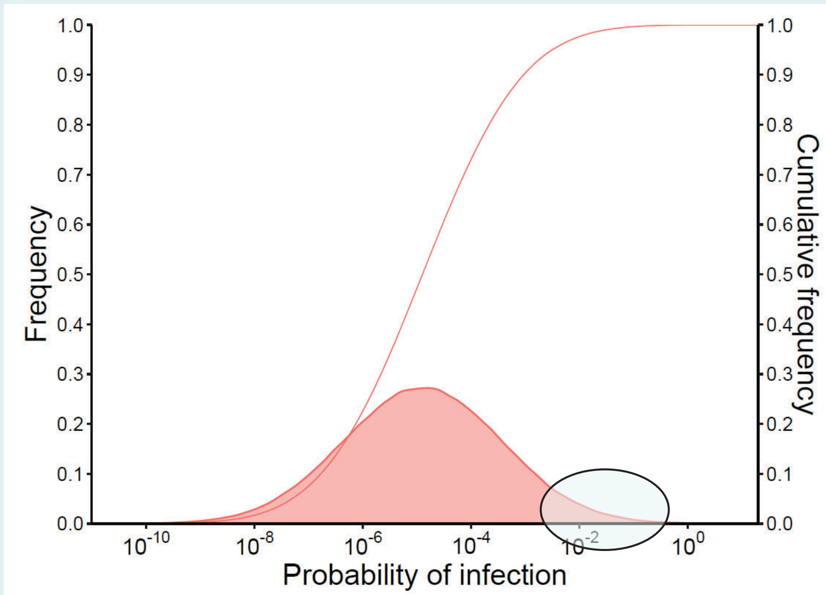
Table 1: Uncertainty in input parameters

	Variable	Values	Source
Quanta emission rate	Breathing rate, Q (m^3 h^{-1})	LN(0.56, 0.056)	(Adams 1993)
	Respiratory activity, *breathing:talking* (%)	75:23	(Morawska *et al.*,2009; Iddon *et al.* 2022)
	Aerosol concentration in exhaled air, C_{drop} (respiratory particles m^{-3})	LN(1.54×10^5,1.54×10^4)	(Morawska *et al.*,2009; Iddon *et al.* 2022)
	Mean aerosol diameter, $\bar{d}$ (m)	LN(1.91×10^{-6},1.91×10^{-7})	(Morawska *et al.*,2009)
	Aerosol evaporation factor, E	B(2.0,5.0) [2.0,5.0]	(Nicas *et al.* 2005)
	Viral load, L ($\log_{10}$ RNA copies ml^{-1})	N(7.0,1.4)	(Chen *et al.* 2021)
	Viable fraction, v	B(2.0,5.0) [10^{-4},10^{-2}]	(Killingley *et al.* 2022)
	Respiratory tract absorption fraction, k	U(0.43,0.65)	(Darquenne 2012)
	Dose constant, K	U(5,15)	(Killingley *et al.* 2022)
Scenario	Number of infected people, j	1	
	Number of occupants	50	
	Space volume, V (m^3)	1350	
	Exposure duration, D (h)	8	
	Outside airflow rate (l s^{-1} per person)	10	
	Outside air change rate, ψ (h^{-1})	1.33	
	Biological decay rate, λ (h^{-1})	LN(0.63,0.43)	(Van Doremalen *et al.* 2020)
	Surface deposition rate, γ (h^{-1})	U(0.42,0.61)	(Thatcher *et al.* 2002)

N(μ,σ), normal(mean, standard deviation); LN(μ,σ), log-normal; U(max,min), uniform; B(α,β) [min, max], beta.
Note that L needs to be converted into RNA copies per m^3 by multiplying by 10^6.

Viral load and quanta





AIRBODS

13

Problems

- Using outbreak data doesn't account for key factors that introduce significant bias into estimations
  - Number of index cases
  - Transmission pathways
  - Time varying virus dynamics
  - Inter-personal emission and immunity differences
  - Oral activity and breathing rate
- Personal quantum emission rate varies of time
- Population of individual emission rates has a broad distribution
- Do not understand the true underlying distributions
- Uncertainty is high so must be accounted for because data not enough to reduce it, unless it is cancelled

AIRBODS

14

A solution

$$P(infection) = 1 - EXP(-n)$$

When want to know when the *P(infection)* is low when

$$P(infection) \approx n$$

A simple first order % reduction in risk

$$REI = 1 - \left(\frac{\phi_{pre} N_{post}}{\phi_{post} N_{pre}}\right)$$

AIRBODS

15

The End

AIRBODS

Loughborough University UCL The University Of Sheffield. UNIVERSITY OF CAMBRIDGE The University of Nottingham LSBU

16

43rd AIVC -11th TightVent & 9th venticool Conference

FLOW DYNAMICS OF HUMAN COUGH AND MEASURING TECHNIQUES: A REVIEW

CHEN ZHANG*, PETER NIELSEN, SIMON MADSEN, LI LIU, CHUNWEN XU, ZHENGTAO AI

DEPARTMENT OF THE BUILT ENVIRONMENT, AALBORG UNIVERSITY

AALBORG UNIVERSITY
DENMARK

1

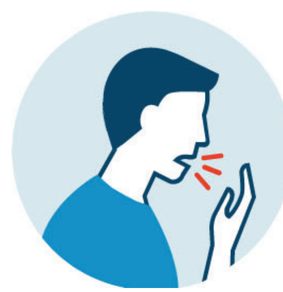
Background

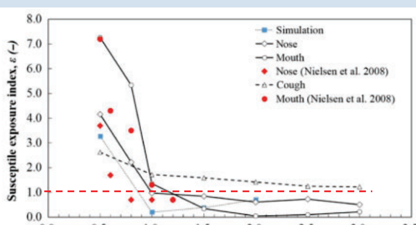
Why cough is important?

- Symptom of many respiratory infections and diseases, such as influenza, tuberculosis, COVID-19
- Critical vector in droplet and airborne transmission

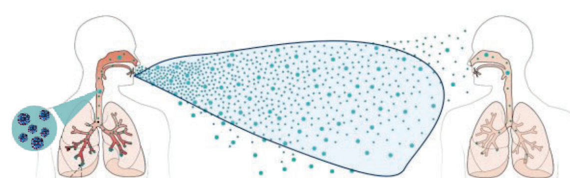
'2 meters (6-feet) rule' might not apply to situations involving increased exhalation, e.g. coughing

- Centers for Disease Control and Prevention (CDC)





[Li et al., 2016]



[Xu et al., 2022]

AALBORG UNIVERSITY
DENMARK

2

Literature review –Flow dynamics of human cough

Method | Flow characteristics | Boundary conditions

Reference	Technique	Subjects	Cough Duration [s]	Cough peak velocity [m/s] or flow rate [l/s]	Peak velocity time [ms]	Cough Volume [l]	Flow direction	Mouth geometry
Mahajan et al. 1994	s					0.5-5		
Khan et al. 2004		F)	0.					
Zhu 2006	PIV	3 (3 M)	0.			0.8-2.2 Average 1.4		
Gupta et al. 2009	Spirometer	25 (13 M and 12 F)	0.35-0.75	M:3-8.5 L/s F:1.6-6 L/s	M: 57-96 F: 57-110	M:0.4-1.6 F:0.25-1.25	θ1=15±5 °; θ2= 40±4 ° (vertical spread angle 25 °)	M:400±95 mm² F:337±140 mm²
Chao et al. 2009	PIV	11 (3 M and 8 F)		M:13.2 m/s F: 10.2 m/s Average 11.7 m/s				
Lindsley et al. 2010	Spirometer	58 (47 influenza-positive and 11 influenza-negative	0.9	Influenza-positive 7.1 l/s Influenza-negative 7.6 l/s		Influenza-positive 2.7 Influenza-negative 3.1		
Vansciver et al. 2011	PIV	29 (10 M and 19 F)	0.55	1.15-28.8 m/s Average 10.2m/s				706 mm2 (D= 30 mm)
Tang et al. 2012	schlieren imaging technique	20 (10 M and 10 F)	0.2-0.35	M:3.2–14 m/s F: 2.2–5.0 m/s;				
Kwon et al. 2012	PIV	26 (17 M and 9 F)		M: 15.3 m/s F 10.6 m/s			Vertical spread angle M: 38 ° F: 32 °	
Wang et al. 2020	PIV	4		15 m/s				
Han et al. 2021	PIV	10 (5 M and 5 F)	0.52-0.56	M:6.4-18.6 m/s F: 5.0-15.7 m/s	M: 8-35 F: 8-39		Vertical spread angle M: 15.3 ° F: 15.6 ° Horizontal spread angle M: 13.3 ° F: 14.2 °	M: 47 mm F: 39.4 mm (Mouth width)

3

Measuring techniques


[Gupta et al., 2009]


[NIST]


[Han et al., 2021]

Spirometer

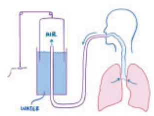
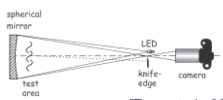
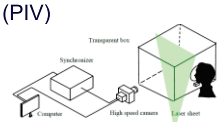
Schlieren imaging technique

Particle image velocimetry (PIV)

AALBORG UNIVERSITY
DENMARK

4

Measuring techniques

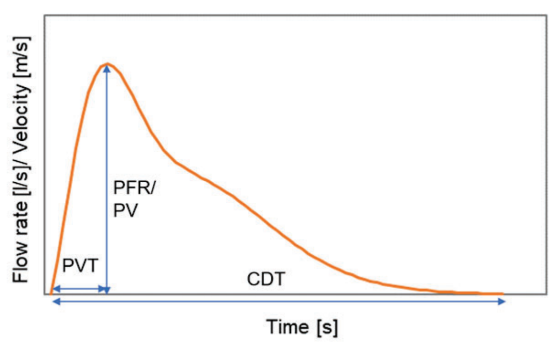
Techniques	Principle	Advantages	Disvantages
Spirometer  [Osmosis]	Poiseuille's equation $Q = f(\Delta p)$	• Widely available • Easy and low cost	• Need a mouthpiece • Disturb exhaled flow development
Schlieren imaging technique  [Tang et al., 2011]	Visualize variations in refractive index caused by density gradients	• Visualizes flow • Non-intrusive technique • No safety concern	• No direct quantitative measurements of flow velocity or flow rate • Require temperature difference between exhaled flow and surrounding
Particle image velocimetry (PIV)  [Pan et al., 2023]	Captures flow velocity by tracking the motion of tracer particles in a fluid	• Visualizes flow • Quantitative measurement • High Spatial Resolution	• Need tracer particles • High intensity laser light cause safety concern • Safety protections might constrain and disturb the exhaled flow

AALBORG UNIVERSITY DENMARK

Flow characteristics

- Peak flow rate (PFR) or peak velocity (PV)
  1.15 -28.8 m/s, mean 10~11 m/s
- Peak velocity time (PVT)
  10-100 ms, mean 50 ms
- Cough duration time (CDT)
  200 - 900 ms, mean 500 ms
- Cough expired volume (CEV)
  0.5-5 l, mean 1.4 l

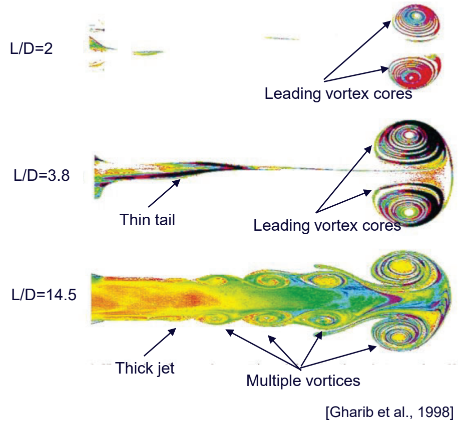
Large deviations on cough profile, due to:
- Gender
- Body mass
- Health
- Measuring techniques



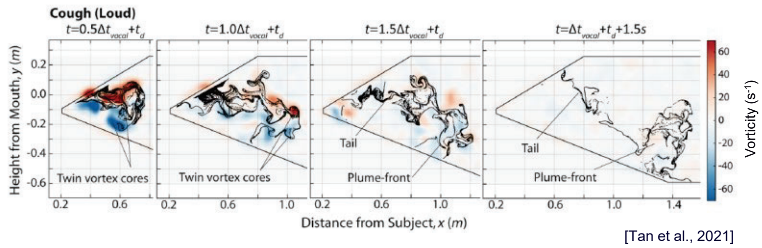
Gamma-probability distribution function

AALBORG UNIVERSITY DENMARK

Vortex Structure



Classic vortex rings

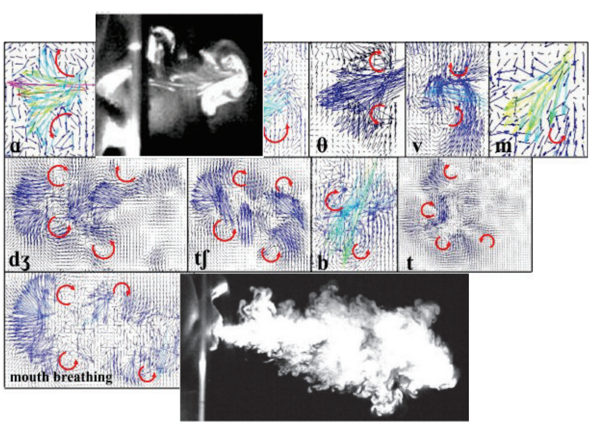


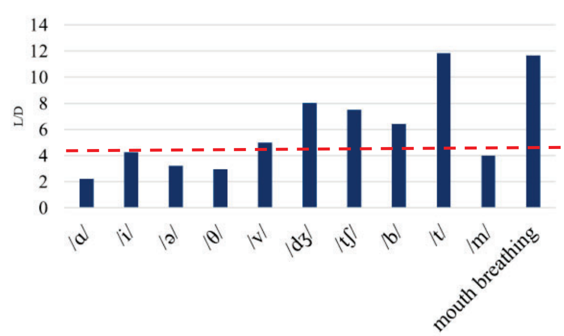
Stroke ratio(L/D)=$\frac{\textit{propagation distance}}{\textit{mouth diameter}}$ > 100

AALBORG UNIVERSITY
DENMARK

7

Vortex Structure





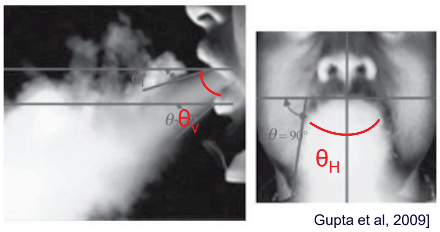
[Pan et al., 2023]

AALBORG UNIVERSITY
DENMARK

8

Flow direction

- Flow visualization



Gupta et al, 2009]

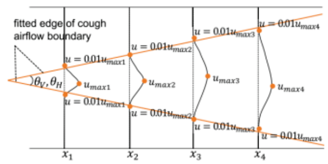
$\theta_1 = 15° \pm 5°$

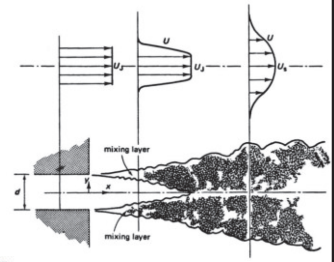
$\theta_2 = 40° \pm 4°.$

θ_V~ 25 °

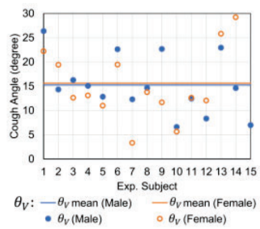
θ_H~ 0 °

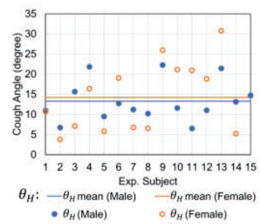
- Velocity boundary layer





[Han et al, 2021]





θ_V~ 15 °

θ_H~ 14 °

AALBORG UNIVERSITY
DENMARK

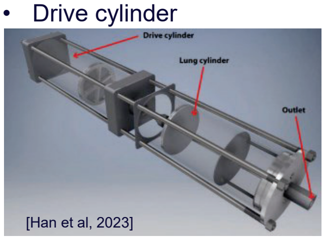
Cough simulator

Author	Year	Peak flow	Cough volume [l]	Duration [s]	Mouth opening diameter [mm]	Cough medium	Equipped with thermal manikin	Refer to human subject measurement
Bolashikov et al.	2012	10 l/s	2.5	0.5	21	CO2, 100%	Yes	-
Lindsley et al.	2013	11.4 l/s	4.2		21	Cell culture medium	No	Lindsley et al. 2010
Liu et al.	2014	6.08 m/s		1	24	Particles (0.77 µm, 2.5 µm and 7 µm)	No	-
Pantelic et al.	2015		1.4	0.5		Water 90% and glycerin 10%	Yes	Zhu et al. 2006
Cao et al.	2015	6 m/s	1.4	1		Particles (0.77 µm)	Yes	Zhu et al., 2006; Gupta et al., 2009
Licina et al.	2015	10 m/s				Mixture of water (94%) and glycerin (6%)	No	Zhu et al. 2006
Hall et al.	2022		4.2		40	Aqueous solution of 0.1% fluorescein	No	Lindsley et al. 2010
Thacher et al.	2022		1.23±0.09		25.5	Fluorescent polyethylene	Yes	Gupta et al., 2009

AALBORG UNIVERSITY
DENMARK

Cough simulator

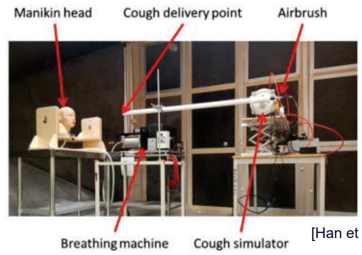
- Drive cylinder



[Han et al, 2023]

- Pressurized gas tank

- Without manikin



[Han et al, 2023]

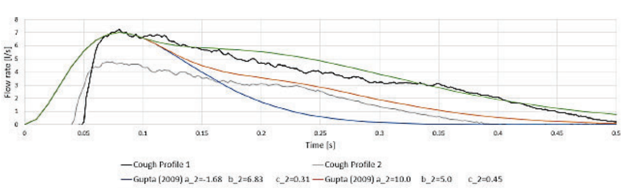
- With manikin

[PT Teknik]

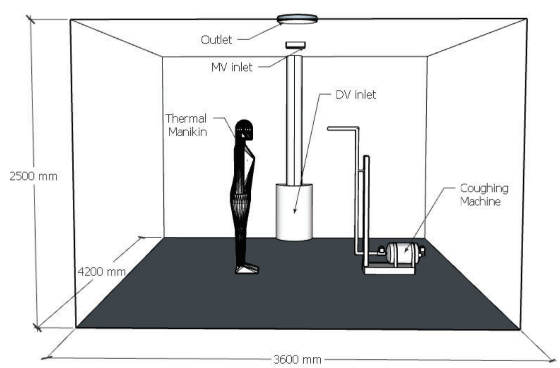
[Nielsen et al, 2008]

AALBORG UNIVERSITY
DENMARK

Cough simulator



Cough flow profile generated by the cough simulator compared with profiles from literature [Gupta et al., 2009].



AALBORG UNIVERSITY
DENMARK

Conclusions

- The airflow characteristic of human cough is normally measured by three techniques, including the **Schlieren imaging technique**, **spirometer** and **PIV**. The uncertainties of measuring techniques require further investigation.
- Cough profile can be described by a **gamma-probability distribution function**.
- Large deviations are due to subjects' **gender, age, body mass surface**, and **measuring techniques.**
- It is difficult to create a **'standard' cough profile.**
- Cough airflows can be described as an **impulsive jet**, vortex ring structures **prevent the rapid dilution of aerosol plume.**
- Development of **realistic cough simulator** is needed.

AALBORG UNIVERSITY
DENMARK

THANK YOU FOR YOUR ATTENTION!

AALBORG UNIVERSITY
DENMARK

FACULTY OF ENGINEERING
AND ARCHITECTURE

EVALUATING THE IMPACT OF AIR CLEANING AND VENTILATION OF AIRBORNE PATHOGENS AND HUMAN BIO-EFFLUENTS AT TWO PRIMARY SCHOOLS IN BELGIUM

Ghent University	Klaas De Jonge, Jelle Laverge and Arnold Janssens
VITO	Marianne Stranger, Sarah L. Paralovo, Maarten Spruyt, Borislav Lazarov
Liantis	Tom Geens
Jessa Hospital Clinical Lab	Reinoud Cartuyvels
Antwerp University Hospital	Koen Van den Driessche

1

UNIVERSITEIT GENT

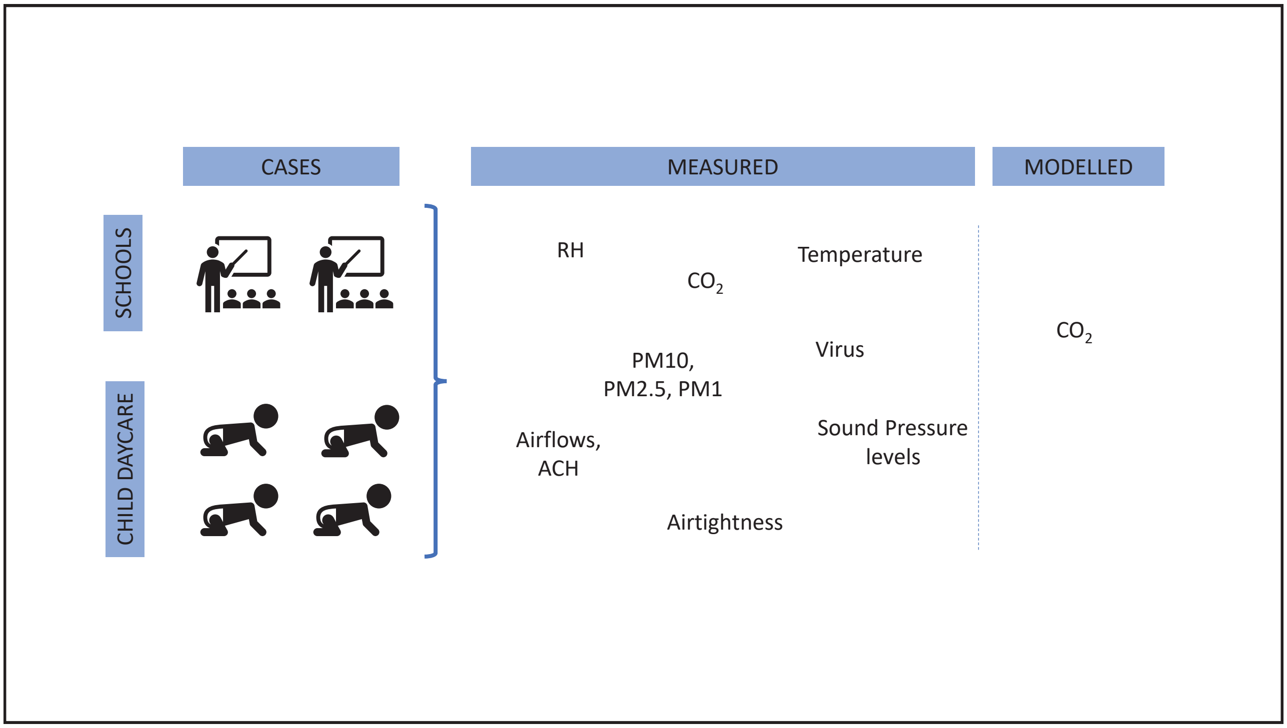
vito

jessa ZIEKENHUIS

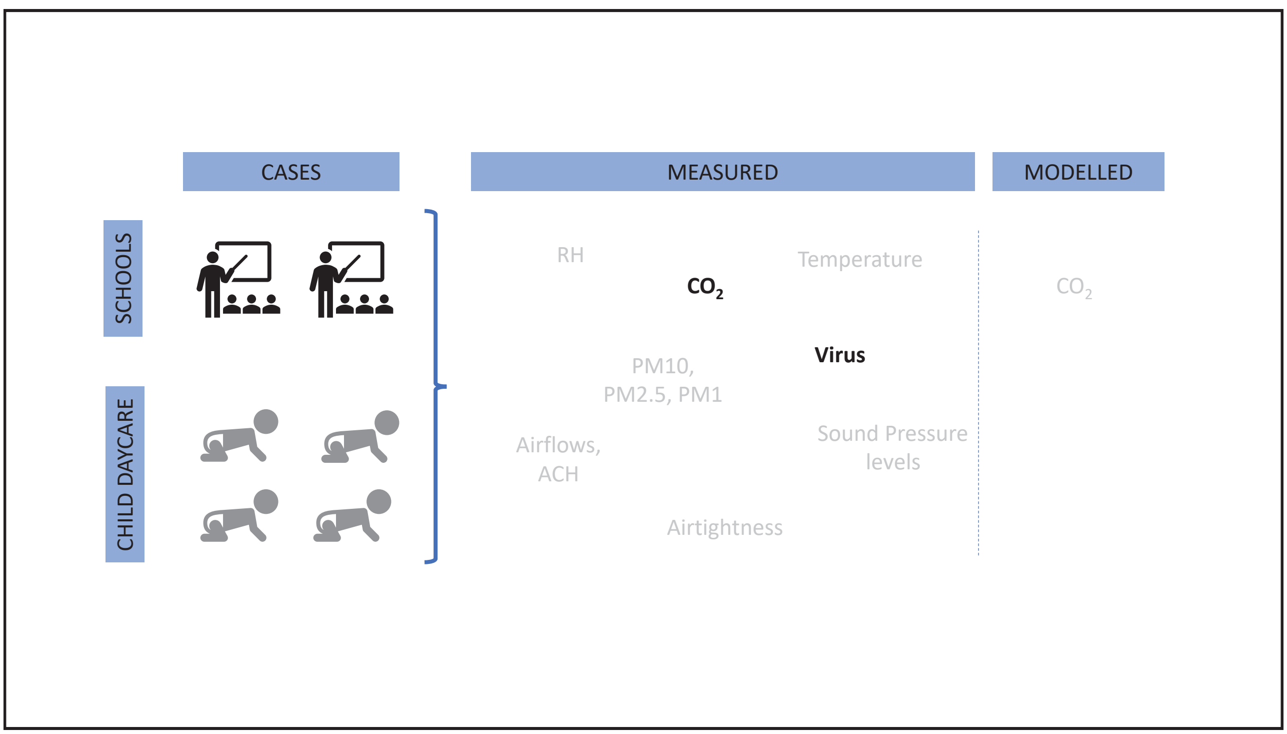
liantis

UZA

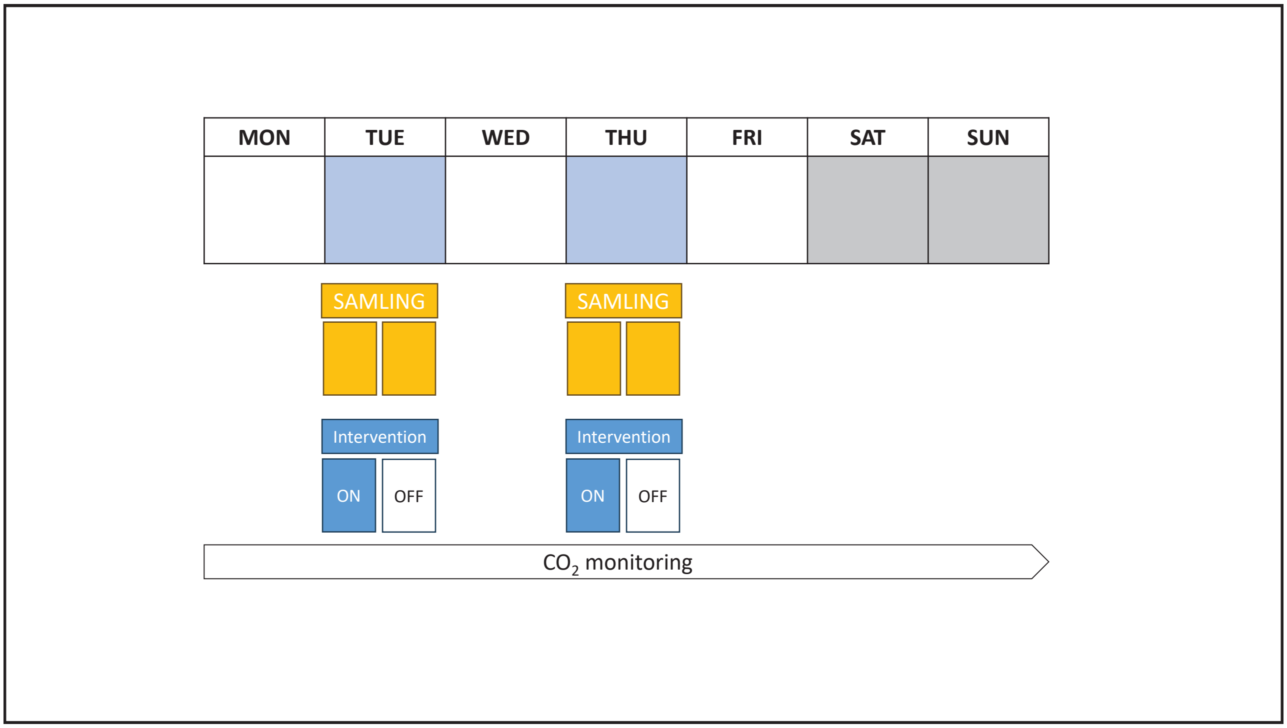
2


CASES
MEASURED
MODELLED
SCHOOLS
CHILD DAYCARE
RH
CO_2
Temperature
Virus
PM10,
PM2.5, PM1
Airflows,
ACH
Sound Pressure
levels
Airtightness
CO_2

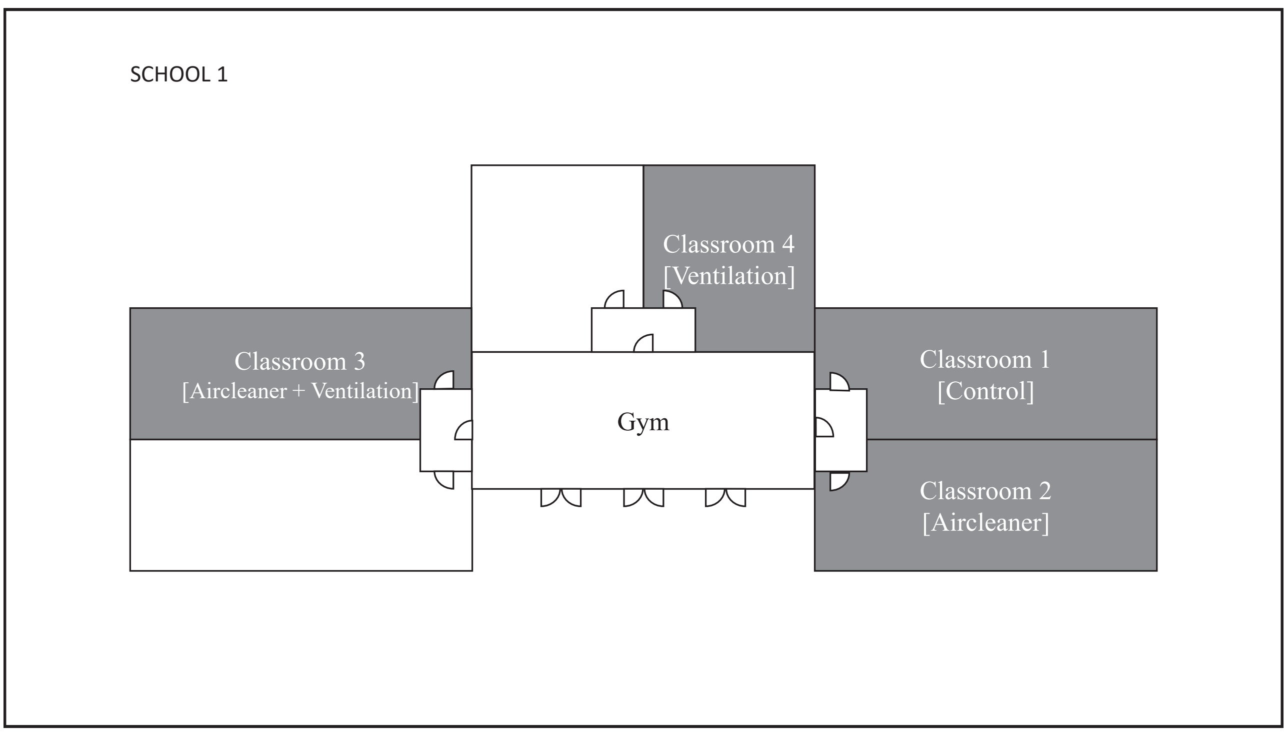
3


CASES
MEASURED
MODELLED
SCHOOLS
CHILD DAYCARE
RH
CO_2
Temperature
Virus
PM10,
PM2.5, PM1
Airflows,
ACH
Sound Pressure
levels
Airtightness
CO_2

4

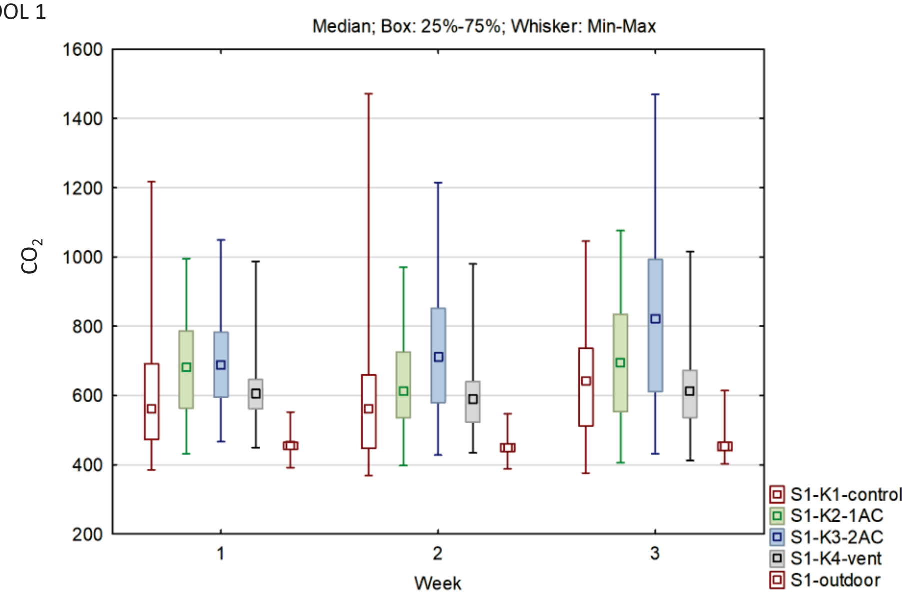

MON
TUE
WED
THU
FRI
SAT
SUN
SAMLING
SAMLING
Intervention
ON
OFF
Intervention
ON
OFF
CO_2 monitoring

5


SCHOOL 1
Classroom 4
[Ventilation]
Classroom 3
[Aircleaner + Ventilation]
Gym
Classroom 1
[Control]
Classroom 2
[Aircleaner]

6

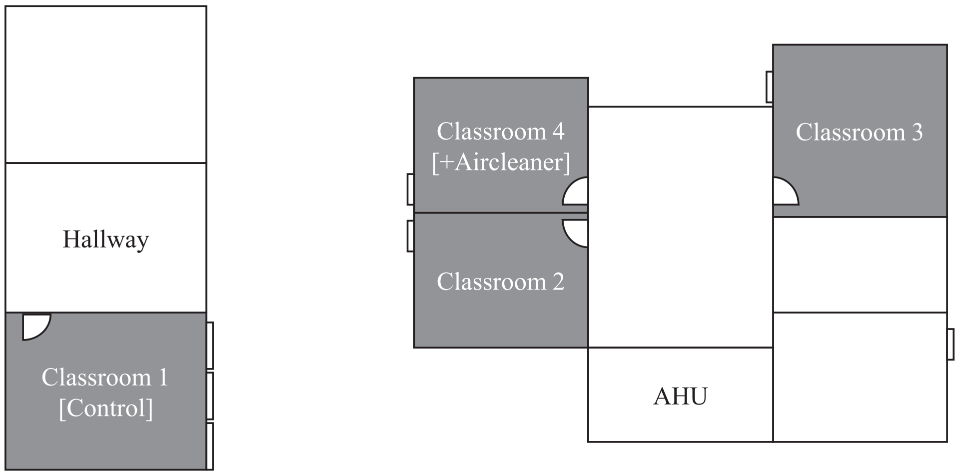
SCHOOL 1



SCHOOL 1

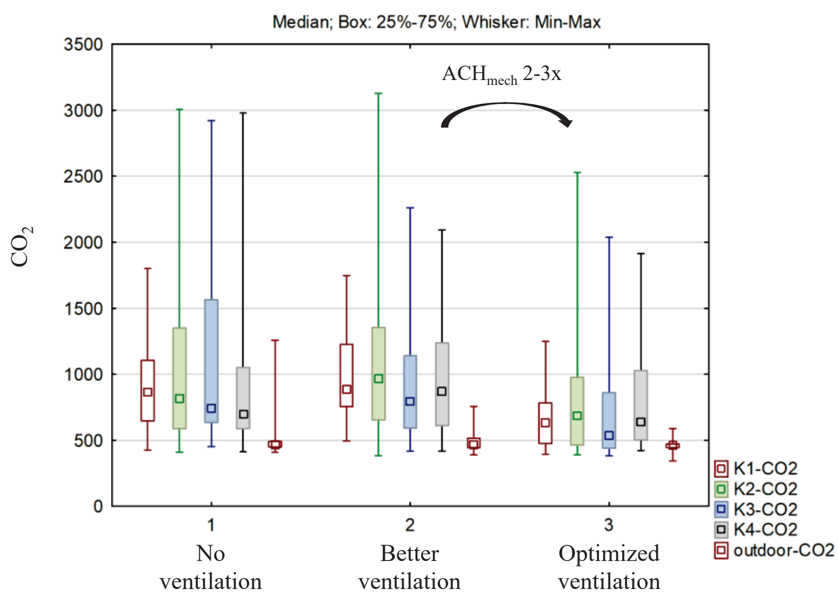
SARS-CoV-2		Tuesday		Thursday	
		Intervention ON	Intervention OFF	Intervention ON	Intervention OFF
Week 1	Class. 1 - Control			Limit (ct 39.3)	
	Class 2 - Air cleaner			Neg.	Neg.
	Class 3 - Air clean + Vent.			Limit (ct 36.9)	Limit (ct 37.0)
	Class. 4 - Vent.			Neg.	
Week 2	Class. 1 - Control	Neg.		Neg.	
	Class 2 - Air cleaner	Neg.		Neg.	Neg.
	Class 3 – Air clean + Vent.	Neg.	Limit (ct 38.7)	Neg.	
	Class. 4 - Vent.	Neg.	Neg.	Neg.	
Week 3	Class. 1 - Control	Neg.		Neg.	
	Class 2 – Air cleaner	Neg.		Neg.	Neg.
	Class 3 – Air clean + Vent.	Limit (ct 39.4)	Neg.	Neg.	Limit (ct 38.3)
	Class. 4 - Vent.	Neg.	Neg.	Neg.	

SCHOOL 2



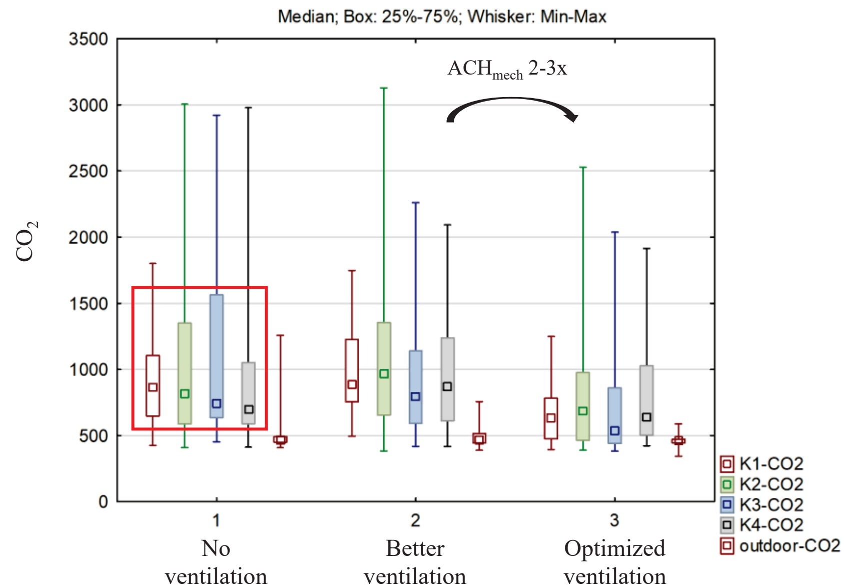
9

SCHOOL 2



10

SCHOOL 2



11

SCHOOL 2

	SARS-CoV-2		Tuesday		Thursday	
			Intervention ON	Intervention OFF	Intervention ON	Intervention OFF
Better ventilation	**Week 1**	Class. 1 - Control		Limit (ct 36.0)		Limit (ct 36.7)
		Class 2 - Mech. Vent.	Limit (ct 36.7)	Limit (ct 38.3)	Neg.	Limit (ct 38.9)
		Class 3 - Mech. Vent.		Neg.	Neg.	Limit (ct 38.5)
		Class 4 - Vent.+Air cleaner				Limit (ct 35.4)
	Week 2	Class. 1 - Control	Limit (ct 38.9)		Limit (ct 39.7)	
		Class 2 - Mech. Vent.	Neg.	Limit (ct 38.7)	POS. (ct 33.0)	
		Class 3 - Mech. Vent.	Limit (ct 40.5)		Limit (ct 37.9)	Limit (ct 36.5)
		Class 4 - Vent.+Air cleaner	Limit (ct 40.7)	Neg.	Limit (ct 38.9)	Neg.
	Week 3	Class. 1 - Control	Neg.		Limit (ct 40.4)	
		Class 2 - Mech. Vent.	Limit (ct 39.3)	Limit (ct 39.2)	Limit (ct 38.3)	Neg.
		Class 3 - Mech. Vent.	Limit (ct 38.5)		Limit (ct 37.4)	Limit (ct 38.2)
		Class 4 - Vent.+Air cleaner	Limit (ct 38.2)	Neg.	Limit (ct 40.0)	
	Maintenance and commissioning to AHU					
Optimized ventilation	**Week 4**	Class. 1 - Control	Limit (ct 39.1)		School closed	
		Class 2 - Mech. Vent.	Neg.			
		Class 3 - Mech. Vent.	Neg.	Neg.		
		Class 4 - Vent.+Air cleaner	Limit (ct 41.1)	Neg.		
	Week 5	Class. 1 - Control	Neg.		Limit (ct 37.0)	
		Class 2 - Mech. Vent.	Neg.		Limit (ct 40.0)	
		Class 3 - Mech. Vent.	Limit (ct 38.9)	Neg.	Limit (ct 38.2)	
		Class 4 - Vent.+Air cleaner	Limit (ct 39.0)	Limit (ct 37.6)	Neg.	Neg.
	Week 6	Class. 1 - Control			Limit (ct 39.5)	
		Class 2 - Mech. Vent.	Limit (ct 37.3)		Limit (ct 40.2)	Neg.
		Class 3 - Mech. Vent.	Neg.	Limit (ct 40.1)	Neg.	Limit (ct 40.0)
		Class 4 - Vent.+Air cleaner				

12

CONLUSIONS

- For both schools, **no measurable effect** of increased ventilation or air cleaning on the occurrence of SARS-CoV-2 could be **objectively observed** for these in-situ and in-use situations.
- **importance of proper commissioning and maintenance** to mechanical ventilation systems and show an overall better expected perceived indoor air quality when the ventilation system works properly
- **manual airing** through the opening of windows **can achieve the same level of expected perceived indoor air quality** if operated correctly

FACULTY OF ENGINEERING AND ARCHITECTURE

DEPARTMENT ARCHITECTURE AND URBAN PLANNING
RESEARCH GROUP BUILDING PHYSICS

REVIEW OF INTERNATIONAL STANDARDS DESCRIBING AIR CLEANER TEST METHODS

H. Scheipers, A. Janssens, J. Laverge
05/10/2023

GHENT UNIVERSITY

1

Context

- Increasing use of air cleaners
- Multiple test standards used

GHENT UNIVERSITY

Investigated standards

AHAM AC-1 (2020)
AHAM AC-4 (2022)
AHAM AC-5 (2022)

ASHRAE 52.2 (2017)
ASHRAE 145.1 (2015)
ASHRAE 145.2 (2016)
ASHRAE 185.1 (2020)
ASHRAE 185.2 (2020)

IEC 63086-1 (2020)

EN IS0 10121-3 (2022)
ISO 16000-36 (2021)

EN 16846-1 (2017)

NF B44-200 (2016)

GHENT UNIVERSITY

Investigated standards

AHAM AC-1 (2020)
AHAM AC-4 (2022)
AHAM AC-5 (2022)

ASHRAE 52.2 (2017)
ASHRAE 145.1 (2015)
ASHRAE 145.2 (2016)
ASHRAE 185.1 (2020)
ASHRAE 185.2 (2020)

IEC 63086-1 (2020)

EN IS0 10121-3 (2022)
ISO 16000-36 (2021)

EN 16846-1 (2017)

NF B44-200 (2016)

Standalone/portable air cleaners
In duct or air handling systems

GHENT UNIVERSITY

Investigated standards

AHAM AC-1 (2020)
AHAM AC-4 (2022)
AHAM AC-5 (2022)

ASHRAE 52.2 (2017)
ASHRAE 145.1 (2015)
ASHRAE 145.2 (2016)
ASHRAE 185.1 (2020)
ASHRAE 185.2 (2020)

IEC 63086-1 (2020)

EN IS0 10121-3 (2022)
ISO 16000-36 (2021)

EN 16846-1 (2017)

NF B44-200 (2016)

GHENT UNIVERSITY

Specifies the used technology
Does not specify the used technology

Investigated characteristics

Technical characteristics

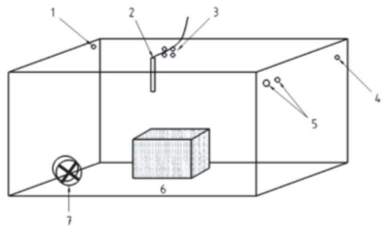
- Test method
- Definition of performance
- Duration of the test
- Test pollutants

Knowledge gaps and challenges

GHENT UNIVERSITY

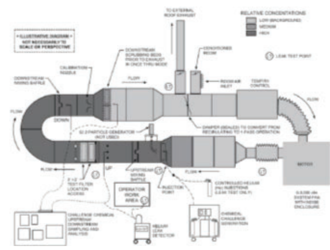
Test apparatus

Test chamber



NBN EN 16846-1 (2017)

Test duct

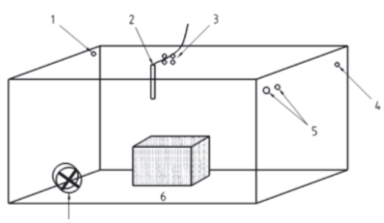


ANSI/ASHRAE 145.2-2016

GHENT UNIVERSITY

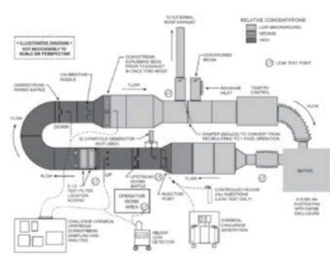
Definition of performance

Test chamber



NBN EN 16846-1 (2017)

Test duct



ANSI/ASHRAE 145.2-2016

CADR

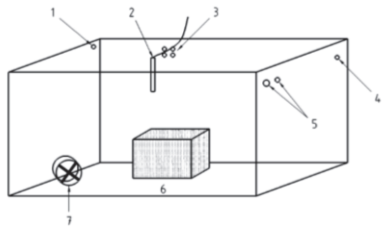
Clean Air Delivery Rate

Single pass efficiency

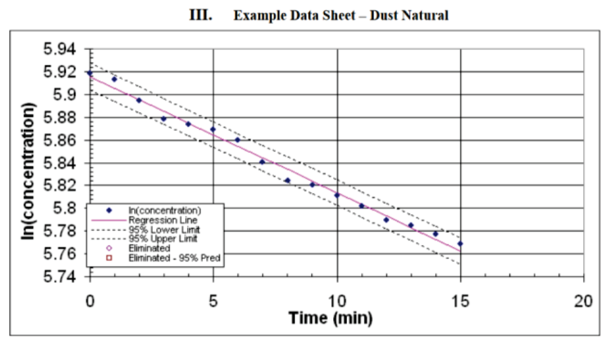
GHENT UNIVERSITY

Test apparatus

Test chamber



NBN EN 16846-1 (2017)



Decay rate (AHAM AC-1 (2020))

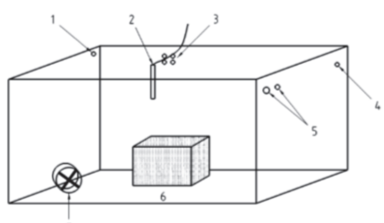
CADR

Clean Air Delivery Rate

GHENT UNIVERSITY

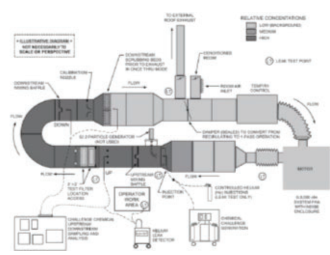
Definition of performance

Test chamber



NBN EN 16846-1 (2017)

Test duct



ANSI/ASHRAE 145.2-2016

CADR

Clean Air Delivery Rate

Single pass efficiency

GHENT UNIVERSITY

Investigated standards

AHAM AC-1 (2020)
AHAM AC-4 (2022)
AHAM AC-5 (2022)

ASHRAE 52.2 (2017)
ASHRAE 145.1 (2015)
ASHRAE 145.2 (2016)
ASHRAE 185.1 (2020)
ASHRAE 185.2 (2020)

IEC 63086-1 (2020)

EN ISO 10121-3 (2022)
ISO 16000-36 (2021)

EN 16846-1 (2017)

NF B44-200 (2016)

Test chamber + CADR
Test duct + single-pass efficiency

GHENT UNIVERSITY

Test pollutants

- VOCs, aerosols, (synthetic) dust, (acid) gases and microorganisms
- Limited scope of pollutants vs. broader range
- Different concentrations

GHENT UNIVERSITY

Investigated characteristics

Technical characteristics

- Test method
- Definition of performance
- Duration of the test
- Test pollutants

Knowledge gaps and challenges

GHENT UNIVERSITY

13

13

Knowledge gaps and challenges

~~By-products~~

- Short duration
- Non-realistic test conditions
- Specific test pollutants
- Small test chamber
- …

Real life performance?
Long-term performance?

GHENT UNIVERSITY

14

14

Conclusion

- Main differences
  - Type of air cleaner being tested
  - Test apparatus used + definition of performance
  - Test pollutants
- Knowledge gaps

GHENT UNIVERSITY

Further research

- Creation of a new test standard
  - Non-targeted analysis
  - Real life & long-term performance

GHENT UNIVERSITY

FACULTY OF ENGINEERING AND ARCHITECTURE

Hannelore Scheipers
PhD Student

RESEARCH GROUP BUILDING PHYSICS

E hannelore.scheipers@ugent.be
T +32 9 264 32 89

www.ugent.be

Universiteit Gent
@ugent
@ugent
Ghent University

GHENT UNIVERSITY

Rethinking different ventilation strategies in a post- pandemic era: a CFD assessment

Kobe University, Alicia Murga
alicia.murga@harbor.kobe-u.ac.jp

Kyushu University, Kazuhide Ito (ito@kyudai.jp)
Riken／Kobe University, Makoto Tsubokura (tsubo@tiger.kobe-u.ac.jp

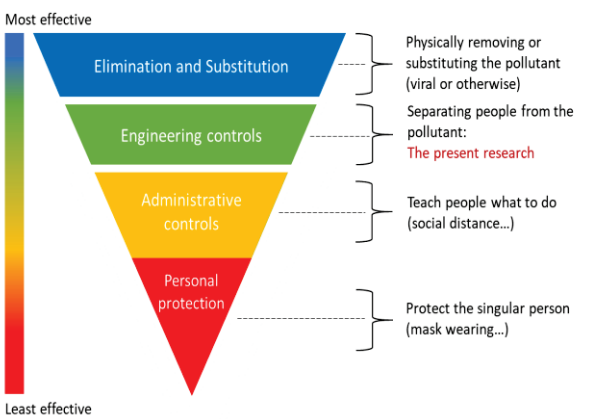
43rd AIVC -11th TightVent & 9th venticool Conference. Ventilation, IEQ and health in sustainable buildings. Copenhagen, 2023

1

Aim

- Use breathing-zone volume ventilation by CFD (RANS) to create a focus on infection control:

    purging effectiveness
    thermal comfort



Methodology

3 types of ventilation strategies:
General-volume focused: **mixing**

Advanced:
Breathing-zone focused: **stratum & impinging jet**

Airflow ASHRAE 62 $Q = (Q_p \times N) + (Oc \times A)$

Heat Load $h = Q\rho C_p \Delta T$

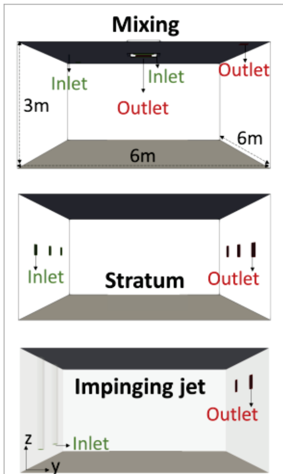
Age of Air
Scale for ventilation efficiency 3

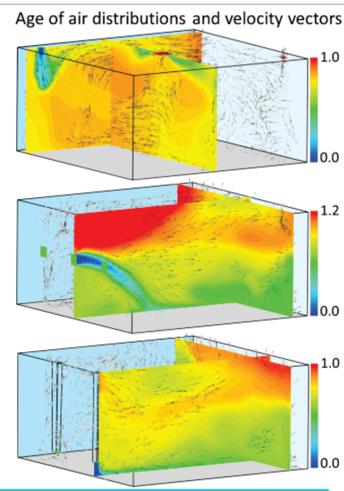
$$SVE3 = \frac{C'_x(X)}{C_s}$$

$$C_s = \frac{q}{Q}$$

2

Results and Discussion





Results in the occupied zone (0 to 1.8m)

Ventilation	Age of Air	PMV	PPD
Mixing	0.80	-0.09	5.15
Stratum	0.66	-0.28	6.63
Impinging jet	0.65	-0.49	9.92

Should current building requirements be adjusted as a prophylactic measure?

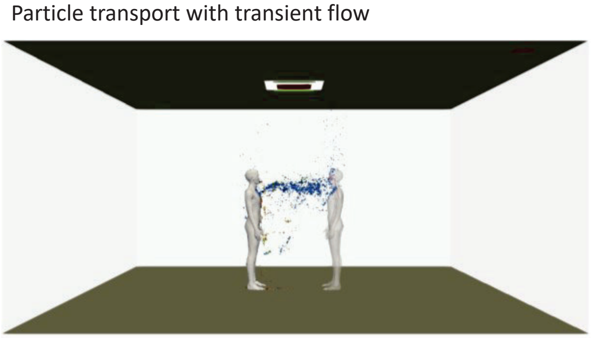
Building design → CFD simulations → Results

3

Conclusions

- ✓ Breathing-zone volume generally shows better IAQ than general-volume ventilation
- ✓ Thermal comfort lowers as purging effectiveness increases: a balance is needed
- ✓ Local considerations must be analyzed in addition to general room indexes

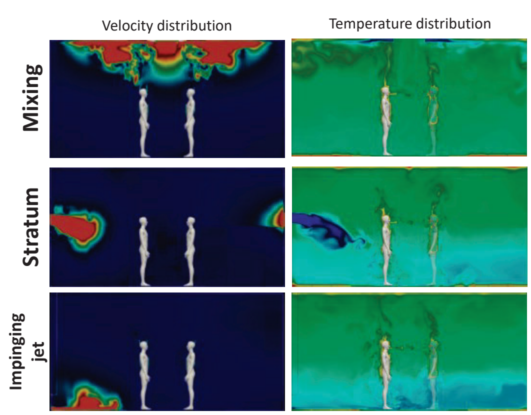
Particle transport with transient flow



Time: 20.0 sec

Current and future state

- ✓ RANS → LES
- ✓ PMV substituted by skin surface temperature
- ✓ Age of Air enhanced by particle deposition on tissue and infection risk → improved Wells-Riley



4

Acknowledgments

Fugaku computational resources were provided by the HPCI System Research Project (ID: hp210086) and "Program for Promoting Researches on the Supercomputer Fugaku" (MEXT) and used computational resources provided by RIKEN Center for Computational Science.

This research was partially supported by JST CREST "Creation of fundamental technologies by interdisciplinary research to coexist with infectious diseases including COVID-19" (Issue name: Development of the integrated risk assessment system for the viral droplet infection on a supercomputer and its social implementation), Grant Number JPMJCR20H7, Japan.

Kobe University, Alicia Murga
alicia.murga@harbor.kobe-u.ac.jp

Kyushu University, Kazuhide Ito (ito@kyudai.jp)
Riken／Kobe University,　Makoto Tsubokura (tsubo@tiger.kobe-u.ac.jp

How the COVID Pandemic and the Energy Crisis Have Influenced Indoor Environmental Conditions in non-residential Buildings

Aurora Monge-Barrio*[1], Ainhoa Arriazu-Ramos[1], María Fernández-Vigil[1], and Ana Sánchez-Ostiz[1]
1. School of Architecture, Universidad de Navarra, Spain. amongeb@unav.es

1

STUDY BASED ON ANALYSIS OF MONITORING DATA, ENERGY CONSUMPTION AND SURVEYS

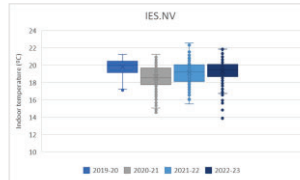
Two High Schools and a Museum naturally ventilated

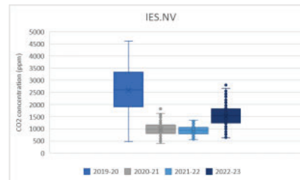
Winter	Situation	IES_NV Monitoring data	IES_PC Monitoring data	MN Monitoring data
2019-20	COVID, schools closed at March15th 2020	3-15/03/20	NA	12/19 – 2/20
2020-21	COVID Schools opened in Spain*	12/20 – 2/21	NA	12/20 – 2/21
2021-22	COVID Schools opened in Spain*	12/21 – 2/22	12/21 – 2/22	12/21 – 2/22
2022-23	Post Covid & Energy crisis	12/22 – 2/23	12/22 – 2/23	12/22 – 2/23

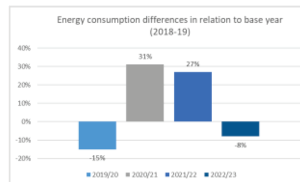
2

How the COVID Pandemic and the Energy Crisis Have Influenced Indoor Environmental Conditions in non-residential Buildings

- ALL CLASSROOMS ARE MONITORED
- STAFF AND TEACHERS AWARE OF DATA, AND ENGAGE WITH BEST PRACTICES





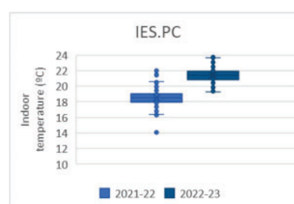


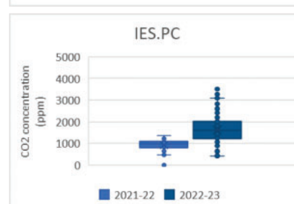
Aurora Monge-Barrio*[1], Ainhoa Arriazu-Ramos[1], María Fernández-Vigil[1], and Ana Sánchez-Ostiz[1]
1. School of Architecture, Universidad de Navarra, Spain.

Universidad de Navarra

How the COVID Pandemic and the Energy Crisis Have Influenced Indoor Environmental Conditions in non-residential Buildings

- SELECTED CLASSROOMS ARE MONITORED
- STAFF AND TEACHERS AWARE OF DATA, AND ENGAGE WITH BEST PRACTICES

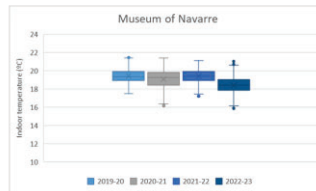


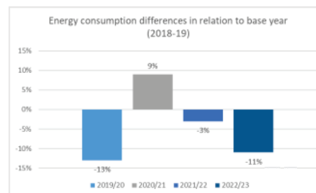


Aurora Monge-Barrio*[1], Ainhoa Arriazu-Ramos[1], María Fernández-Vigil[1], and Ana Sánchez-Ostiz[1]
1. School of Architecture, Universidad de Navarra, Spain.

Universidad de Navarra

- SELECTED ROOMS ARE MONITORED
- MAIN FOCUS ON THE CONSERVATION OF COLLECTIONS





Aurora Monge-Barrio*[1], Ainhoa Arriazu-Ramos[1], María Fernández-Vigil[1], and Ana Sánchez-Ostiz[1]
1. School of Architecture, Universidad de Navarra, Spain.

How the COVID Pandemic and the Energy Crisis Have Influenced
Indoor Environmental Conditions in non-residential Buildings

MAIN CONCLUSIONS of the study:

- NV buildings have had to balance minimum thermal comfort, high levels of ventilation and high energy costs.
- High level of CO2 concentration prior to COVID has been followed by two years of low and adequate levels for NV buildings during COVID (1000ppm)
- After the pandemic, CO2 concentration has risen due to concerns on energy costs in case studies (1500ppm)
- Indoor temperatures have been balanced during COVID with high energy consumption (30%), accepting low temperatures for the benefits of face to face learning
- The energy crisis has reduced energy consumption since pre-COVID (10%), affecting IEQ in both kinds of buildings
- The relevance of IAQ has risen through the COVID pandemic, but the perception is that "everybody" has forgotten it
- The perception of the need to a HVAC upgrade is mainly focused on the heating system and renewable energies, but not on the installation of HRV
- The study of existing NV buildings dealing with external events helps in understanding the potential and benefits of NV, which should be considered in their upgrade

Thank you!
(amongeb@unav.es)

Aurora Monge-Barrio*[1], Ainhoa Arriazu-Ramos[1], María Fernández-Vigil[1], and Ana Sánchez-Ostiz[1]
1. School of Architecture, Universidad de Navarra, Spain.

POLITÉCNICA

Unitec | Environmental Solutions Research Centre

The impact of increased occupancy on particulate matter concentrations in mechanically-ventilated residential buildings in a subtropical climate.

German Hernandez[1,2], Terri-Ann Berry[1],
Rafael Borge[2] and Dan Blanchon[1]

[1] UNITEC, Institute of Technology, New Zealand
hhernandez@unitec.ac.nz
[2] Universidad Politecnica de Madrid, Spain

43rd AIVC -11th TightVent & 9th venticool Conference, 2023

1

Outline

Objective

Background Information

- Mechanical Ventilation Systems
- Factors Affecting IAQ
- Study Location
- 2021 COVID-19 Lockdown

Methodology / Pilot Study Location

Results

Conclusions & Recommendations

2

OBJECTIVE

3

Investigate impact of high occupancy levels, caused by stay-at-home orders under a COVID-19 lockdown, on IAQ in mechanically-ventilated residential buildings.

4

RESEARCH BACKGROUND

5

Mechanical Ventilation Systems

On average, kiwis spend 70% of their time indoors.

Growing pressure to combat climate change:

- Reduce energy consumption
- Improve energy efficiency

Some Energy-efficient characteristics can negatively impact IAQ.

- Increase air exchange and reduce moisture.
- Can improve indoor air quality

6

Factors Affecting IAQ

Season & weather conditions

Building characteristics

Proximity to roads/ traffic & industry

7

Study Location

Auckland

Largest city in NZ

Population over 1.6 million (Stats NZ, 2022)

Humid, subtropical climate – warm, humid summers and mild winters (Hessell, 1988).

8

9

METHODOLOGY

10

Methodology

- 6 houses, mech ventilation
- 3-week period: L4 lockdown +/- 1 wk
- Winter period
- Low-cost monitors for indoor/outdoor AQ
- High accuracy: tested by AQ-SPEC
- Outdoor data also from council stations.

Pilot Study

- Auckland average house size 117 m^2
- 3 indoor monitors:
  - Main bedroom, second bedroom, kitchen/living space
- 1 outdoor monitor:
  - South facing
- Sensors:
  - PM2.5, PM10, Temp, RH

RESULTS & ANALYSIS

13

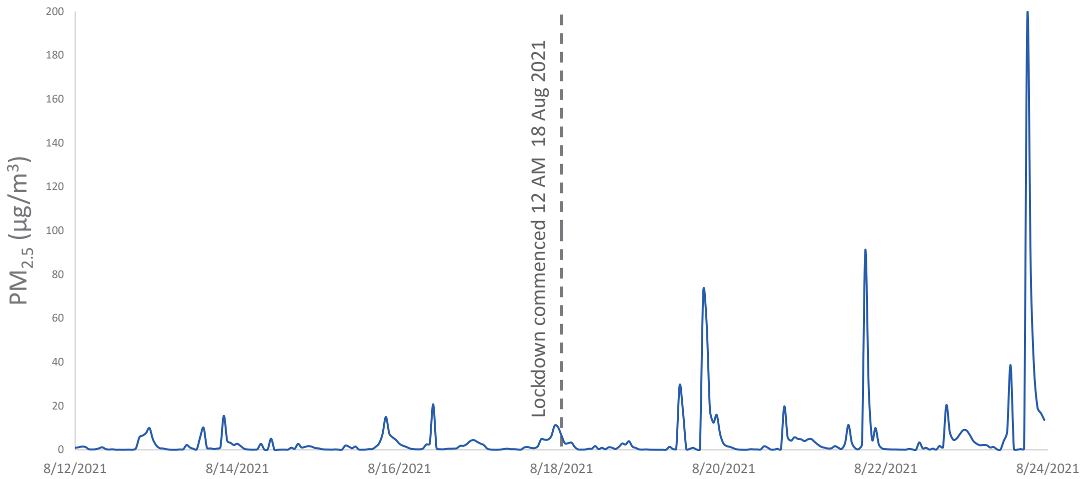
Change in Indoor $PM_{2.5}$ Concentrations

- Significant increase in 50% houses, despite mechanical ventilation.
- Only 1 house exceeded WHO guideline limit.

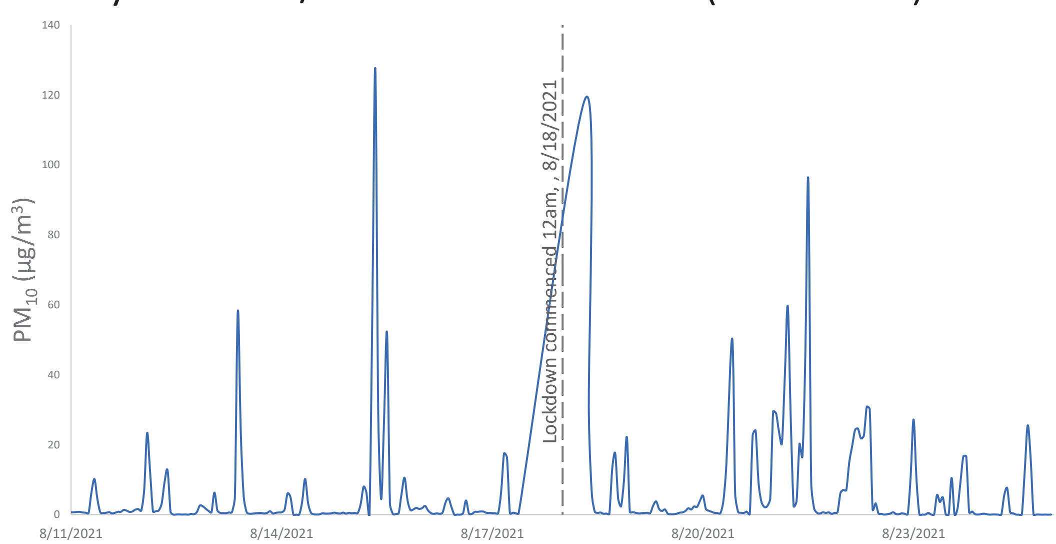
	$PM_{2.5}$ (µg/m^3)		PM_{10} (µg/m^3)	
	Pre-lockdown	During lockdown	Pre-lockdown	During lockdown
House A	0.55	0.80	0.93	0.58
House B	0.73	1.73	1.08	0.36
House C	20.62	21.21	23.51	21.50
House D	4.20	5.24	4.69	6.13
House E	4.96	8.01	5.52	6.05
House F	4.37	5.78	9.00	7.71

14

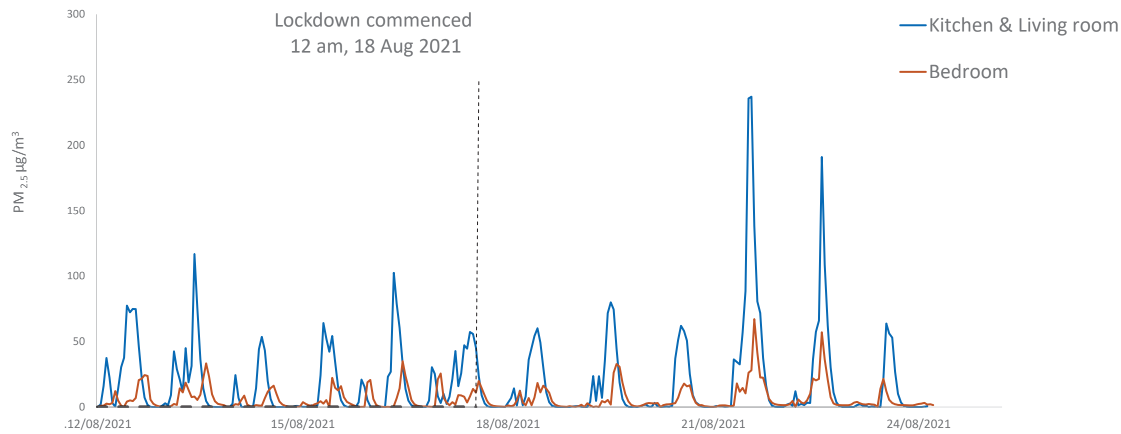
1 Week Before/After Lockdown (House D)



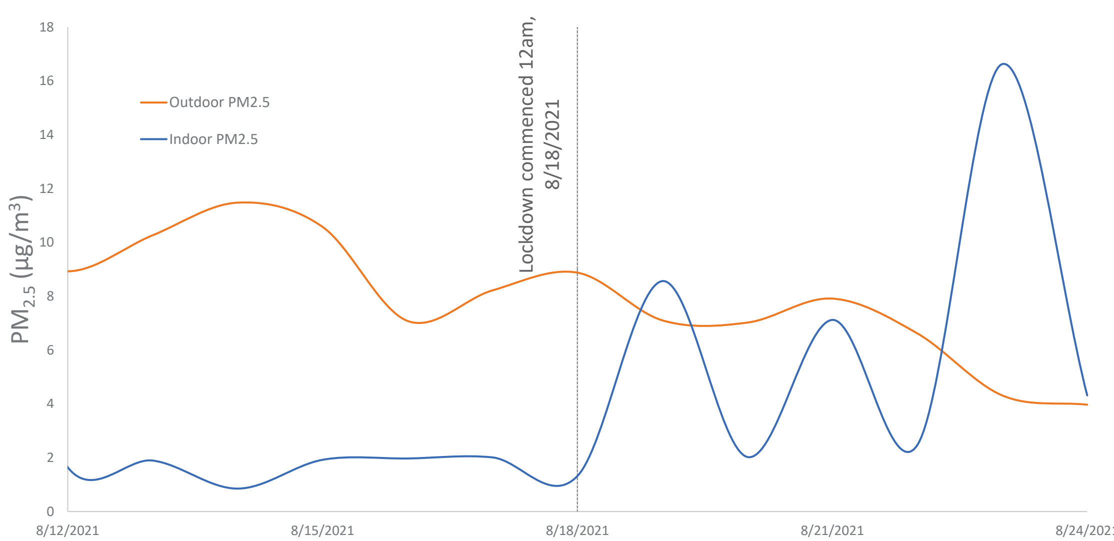
1 Day Before/After Lockdown (House E)



Indoor $PM_{2.5}$ Variability



Indoor vs Outdoor

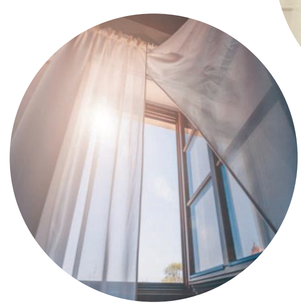


CONCLUSIONS & FUTURE STUDIES

19

Conclusions

- Outdoor $PM_{2.5}$ decreased 34%
- Indoor $PM_{2.5}$ 25% to 62% higher, suggesting internal sources.
- Importance of ventilation, especially with higher occupancy.



20

Current and Next

- Conducted Experiments in Winter 2023 and 2024
- Roof Air Quality Assessment in 2023 and 2025
- Examined Different Seasons in 2023
- Increased House Sample to 15 in 2023 and 2024
- Evaluated Sustainable Home Characteristics in 2023 and 2024
- Expanding Study to Other Cities in 2024

21

POLITÉCNICA

Unitec | Environmental Solutions Research Centre

Thank You!

German Hernandez
hhernandez@unitec.ac.nz

UNITEC, Institute of Technology, New Zealand/
Universidad Politecnica de Madrid, Spain

23

References

ASHRAE. (2019). ANSI/ASHRAE Addendum ae to ANSI/ASHRAE Standard 62.1-2016 Ventilation for Acceptable Indoor Air Quality (p. 6). https://www.ashrae.org/File%20Library/Technical%20Resources/Standards%20and%20Guidelines/Standards%20Addenda/62.1-2016/62_1_2016_ae_20190826.pdf

Chappell, P. R. (2013). THE CLIMATE AND WEATHER OF WAIKATO (2nd Edition). NIWA. https://niwa.co.nz/static/Waikato%20ClimateWEB.pdf

Dannemiller, K. C., Weschler, C. J., & Peccia, J. (2016). Fungal and bacterial growth in floor dust at elevated relative humidity levels. Indoor Air, 27(2), 354–363. https://doi.org/10.1111/ina.12313

Hessell, J. W. D. (1988). The climate and weather of the Auckland region. National Institute of Water and Atmospheric Research, NIWA.

Khajehzadeh, I., & Vale, B. (2017). How New Zealanders distribute their daily time between home indoors, home outdoors and out of home. Kōtuitui: New Zealand Journal of Social Sciences Online, 12(1), 17–31.

Maynard, R., Krzyzanowski, M., Vilahur, N., Héroux, M.-E., Weltgesundheitsorganisation, & Regionalbüro für Europa. (2017). Evolution of WHO air quality guidelines past, present and future. http://www.euro.who.int/__data/assets/pdf_file/0019/331660/Evolution-air-quality.pdf?ua=1

Misonne, D., & Eloise, S. (2021). Regulating Air Quality: the First Global Assessment of Air Pollution Legislation (No. USL-B-Université Saint-Louis).

Stats NZ. (2021). PM_{10} concentrations. https://www.stats.govt.nz/indicators/pm10-concentrations

World Health Organization (Ed.). (2000). Air quality guidelines for Europe (2nd ed). World Health Organization, Regional Office for Europe.

World Health Organization (Ed.). (2006). Air quality guidelines: Global update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide. World Health Organization.

Yoshinaga, J. (2012). Lead in the Japanese living environment. Environmental Health and Preventive Medicine, 17(6), 433–443. https://doi.org/10.1007/s12199-012-0280-z

AIVC 2023 Conference

On-site Capture efficiency of Kitchen Range Hood based on Particle Diameters and Exhaust Flow Rates

Shinhye Lee
Seoul National University
Department of Architecture and Architectural Engineering
AEPRL (Architectural Environmental Planning Research Laboratory)
ibeido@snu.ac.kr

1

Contents

2

Introduction

1 Introduction

1 Background

Cooking is one of the biggest contributors to particle concentration
→ Kitchen range hood removes the particles directly and efficiently.

1. Factors affecting the Efficiency of the Hood

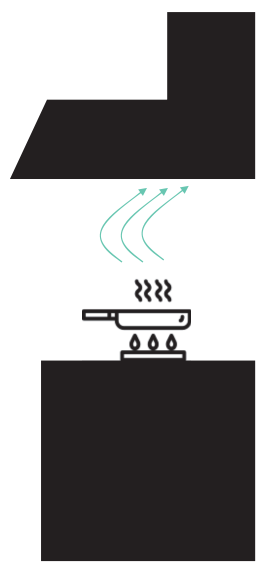
Particle Diameter

- Particles with various diameters can be generated during cooking.
  (Turning on gas, sautéing, frying)
- exhibit different CEs depend on diameter.

Exhaust rate

- Higher exhaust rate is more effective.

Kitchen range hood Capture Efficiency (CE)

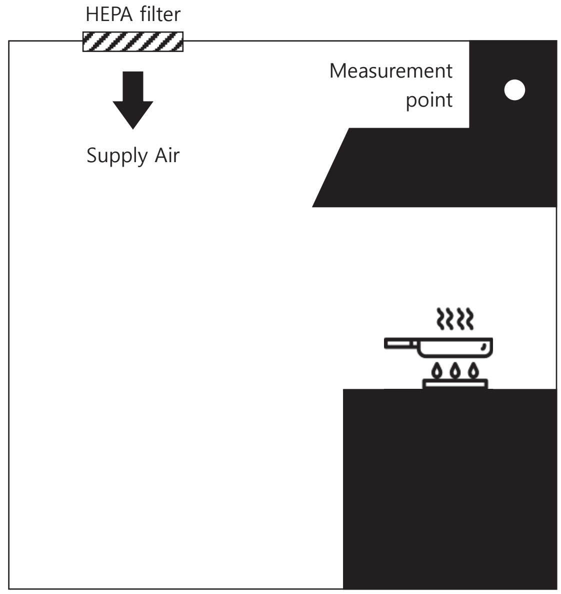


1 Introduction

1 Background

2. Limitations of evaluating CE in ordinary households

1. Difficulty to adhere to standard
   - ASTM E3087-18
     → measure concentration inside the kitchen range hood
     → measure concentration of gas
   - Measuring inside the exhaust hood is difficult.
   - Especially when it comes to measuring particles.
2. The challenge of minimizing outdoor particle infiltration
   - HEPA filter in the path of the supply air.



1 Introduction

2 Objectives of the study

1. Factors affecting efficiency of the Hood
- Particle diameter
- Exhaust rates

2. Limitations of evaluating CE in ordinary household
- Difficulty to adhere to standard
- Challenging to minimize the outdoor particles

OBJECTIVE
Compare the performance of kitchen range hoods in relation to particle diameters and kitchen exhaust rates when the kitchen is affected by outdoor air particulate concentration

Materials and Methods

1. Testbed
2. Measurement
3. Cooking procedure
4. Calculation of capture efficiency
5. Experimental cases

7

2 Material and Methods

1 Testbed

Experimental Overview

Date	January – February, 2020.
Location	A testbed in Seoul
Volume	20.1 m^3 (kitchen)

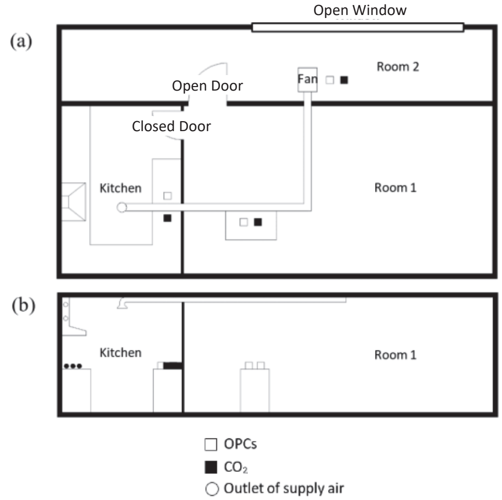
Kitchen Range hood

Type	Chimney type
Cabinets	Two cabinets installed on both side
Height	60 cm above the cooktop
Dimension	90 cm × 55 cm

Cooktop

Type	Electric cooktop
Dimension	60cm × 51 cm
Power Consumption	220 Wh/kg
Used burner	Front burner

Schematic layout of the Testbed

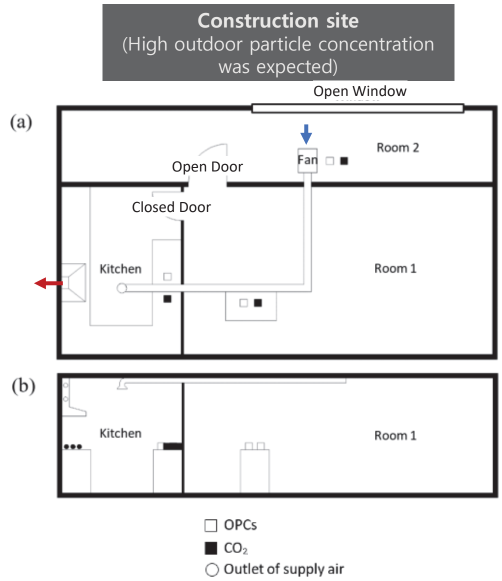


2 Material and Methods

1 Testbed

1. Construction site was 30 m away
   → High outdoor particle concentration was expected.
2. Window and door in room 2 was always opened to draw in outdoor air.
3. Fan in the room 2 supplied outdoor air to the kitchen via ductwork.
   There was no filter in the fan.
4. Pressure difference between the kitchen and room 1 was maintained near zero by adjusting the supply air volume flow rate.

→Particles generated from construction site was introducing to the kitchen.
(∵ Testbed was modeled after a typical household, not a chamber or laboratory)



2 Material and Methods

2 Measuring instruments

1. Particle counter □

Measuring location	Kitchen, Room 1, Room 2
Instrument	Optical Particle Counter (OPCs) Aerotrak 9306 (TSI)
Sampling rate	1 min

2. CO_2 concentration

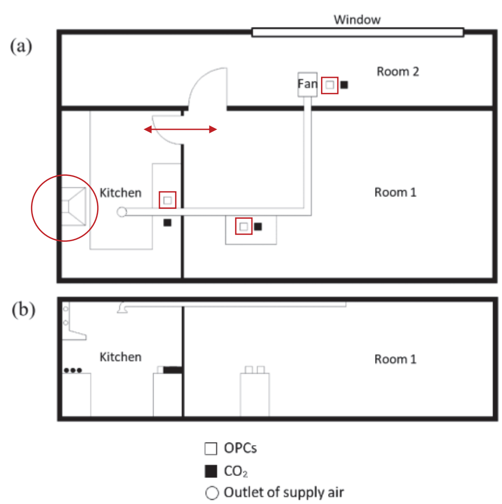
Measuring location	Kitchen, Room 1, Room 2
Instrument	MCH-383SD, Lutron Electronic

3. Pressure difference ↔

Measuring location	Kitchen and Room 1
Instrument	C310 (Kimo)

4. Volumetric flowmeter ○

Measuring location	Kitchen range hood
Instrument	420 (Testo)



2 Material and Methods

3 Cooking Procedure

Cooking ingredients

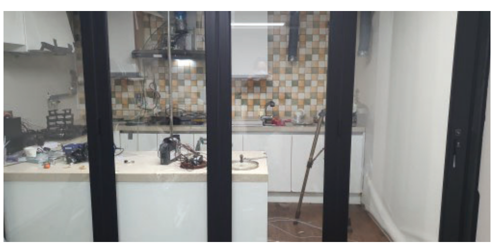
Bacon frying ∵ to ensure the even size, weight, and distribution of fat

Cooking Procedure

1. Measure flow rate of the kitchen range hood	Turn on the hood and measure the flow rate.
2. Measure the weight of the bacon	Weigh each piece of bacon before every experiments. The weight was approximately 40 g.
3. Preheat the pan	Until the surface temperature reached 210 – 230 ℃ (took about 3 min)
4. Cook bacon	For 3 min
5. Turn over the bacon	For another 2 min
6. Cover the pan and remove it from the kitchen	Prevent further particle generation
7. Wait for the concentration return to the initial concentration	
8. Clean up	Remove any oil and particles attached to the walls, cooktop, and kitchen range hood with wet tissues.

2 Material and Methods

3 Cooking Procedure



2 Material and Methods

4 Calculation of Capture Efficiency

Capture Efficiency

Ratio of the particle captured by the kitchen range hood and the particle emitted from the source.

$$CE = \frac{N_{captured}}{N_{emitted}} = 1 - \frac{V\int_{t0}^{tb}(C_{remained})dt}{V\int_{t0}^{tb}(C_{emitted})dt}$$

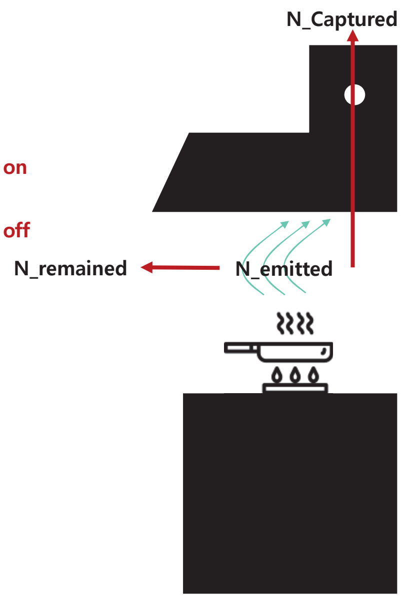
Hood on

Hood off

N_captured	• Number of particles captured during experiment → Can be obtained when the hood is on
N_emitted	• Number of particles emitted from cooking during experiment → Can be obtained when the hood is off
V	Volume of the kitchen
t_0, t_b	Initial time and the time taken to return to initial concentration

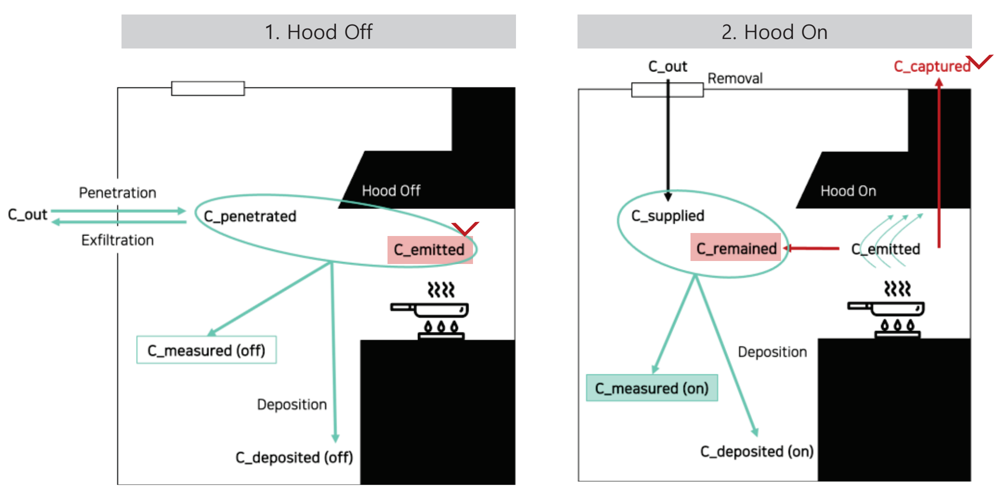
To obtain N_captured and N-emitted,

C_captured and C_emitted should be calculated beforehand.



3 CONTAM model and Validation

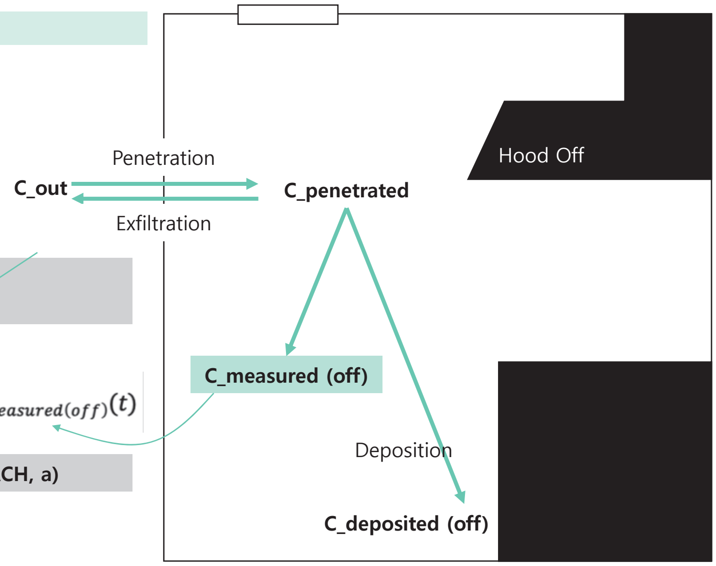
4 Calculation of Capture Efficiency



2 Material and Methods

4 Calculation of Capture Efficiency

1. C_emitted (Hood off)



Penetration Coefficient (P), Deposition rate (K)

$$\frac{dC_{measured(off)}(t)}{dt} = aPC_{room2}(t) - (a+K)C_{measured(off)}(t)$$

Air change rate per hour (ACH, a)

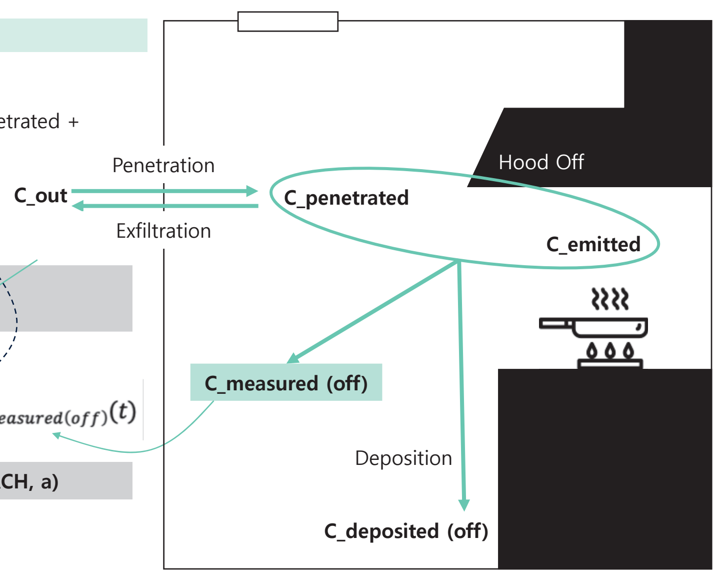
$$ACH(t) = -\frac{1}{C_{CO2}(t)}\frac{dC_{CO2}(t)}{dt}$$

2 Material and Methods

4 Calculation of Capture Efficiency

1. C_emitted (Hood off)

C_emitted = C_measured + C_deposited – C_penetrated + C_exfiltrated



Penetration Coefficient (P), Deposition rate (K)

$$\frac{dC_{measured(off)}(t)}{dt} = aPC_{room2}(t) - (a+K)C_{measured(off)}(t)$$

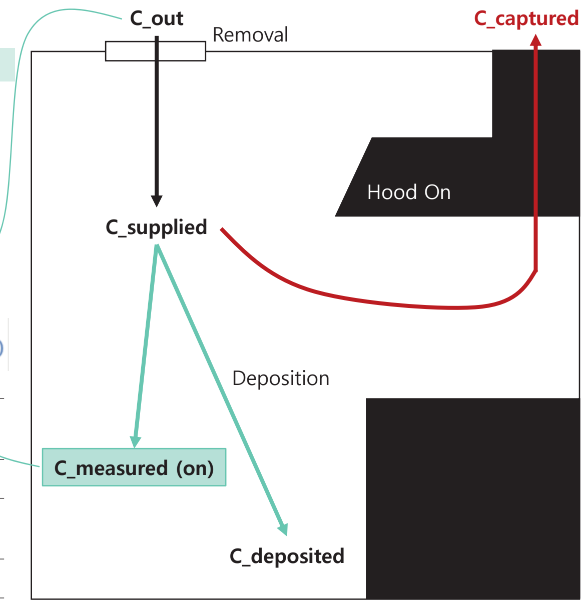
Air change rate per hour (ACH, a)

$$ACH(t) = -\frac{1}{C_{CO2}(t)}\frac{dC_{CO2}(t)}{dt}$$

2 Material and Methods

4 Calculation of Capture Efficiency

2. C_captured (Hood on)



Removal efficiency (ε), Deposition rate (K)

$$\frac{dC_{measured(on)}(t)}{dt} = (1-\varepsilon)\frac{Q}{V}C_{room2}(t) - \left(\frac{Q}{V}+K\right)C_{measured(on)}(t)$$

ϵ	Removal efficiency of the fan and duct [-]
K	Deposition rate [-]
Q	Volumetric flow rate of the supply air [m^3/h]
V	Volume of the kitchen [m^3]

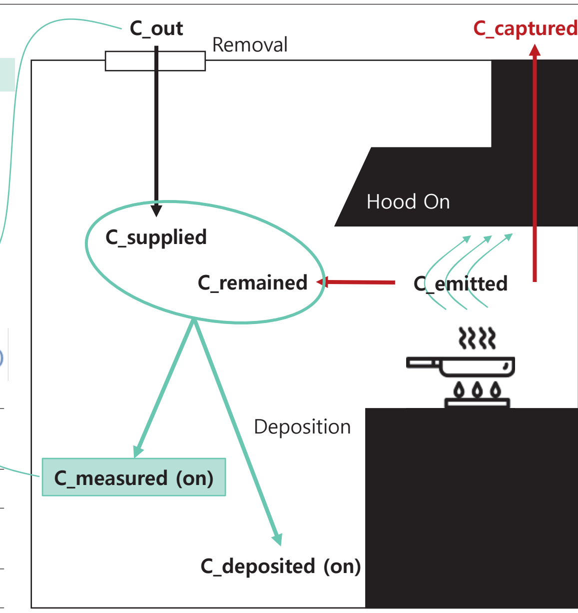
2 Material and Methods

4 Calculation of Capture Efficiency

2. C_captured (Hood on)

C_captured = C_emitted - C_remained

C_remained = C_measured + C_deposited – C_supplied



Removal efficiency (ε), Deposition rate (K)

$$\frac{dC_{measured(on)}(t)}{dt} = (1-\varepsilon)\frac{Q}{V}C_{room2}(t) - \left(\frac{Q}{V}+K\right)C_{measured(on)}(t)$$

ϵ	Removal efficiency of the fan and duct [-]
K	Deposition rate [-]
Q	Volumetric flow rate of the supply air [m^3/h]
V	Volume of the kitchen [m^3]

2 Material and Methods

5 Experimental cases

Experimental Cases

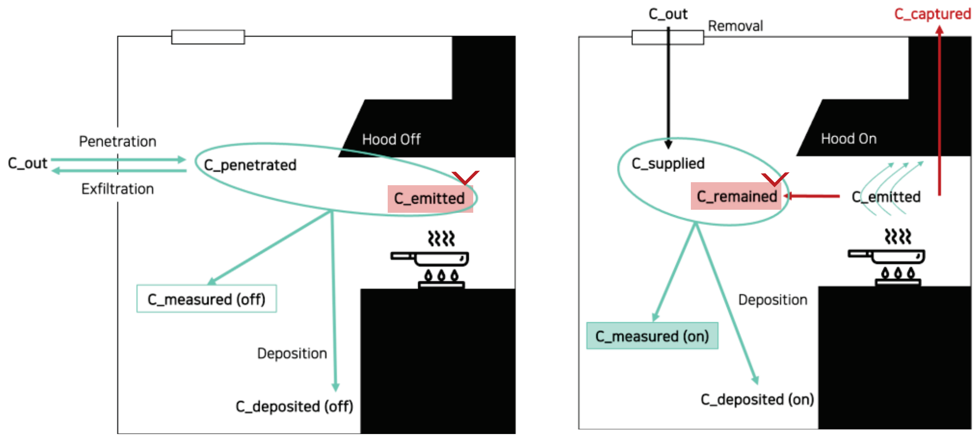
Case	Supply Fan	Exhaust Flow Rates	Repeated #	Estimated Parameters	What to obtain
Hood off	Not operated	-	2	Penetration Coefficient, Deposition Rate	C_emitted
Hood on	Operated	250 m^3/h	3	Removal Efficiency of the fan and the duct, Deposition rate	C_remained
		350 m^3/h	3		

Results

1. Estimated Particle concentration
2. Capture efficiency

3 CONTAM model and Validation

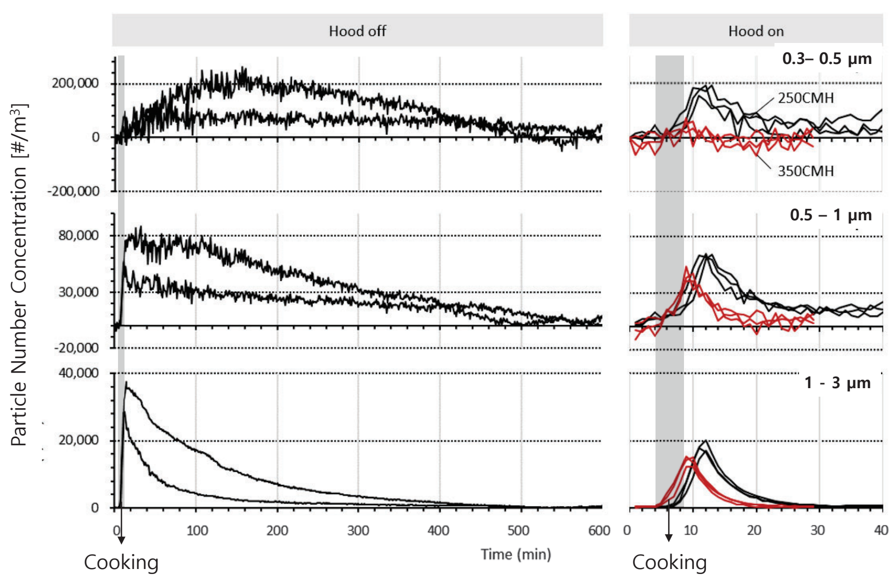
1 Calculated particle concentration



Calculated time-series C_emitted and C_remained
to compare the hood performance
based on the concentration affected by hood only.

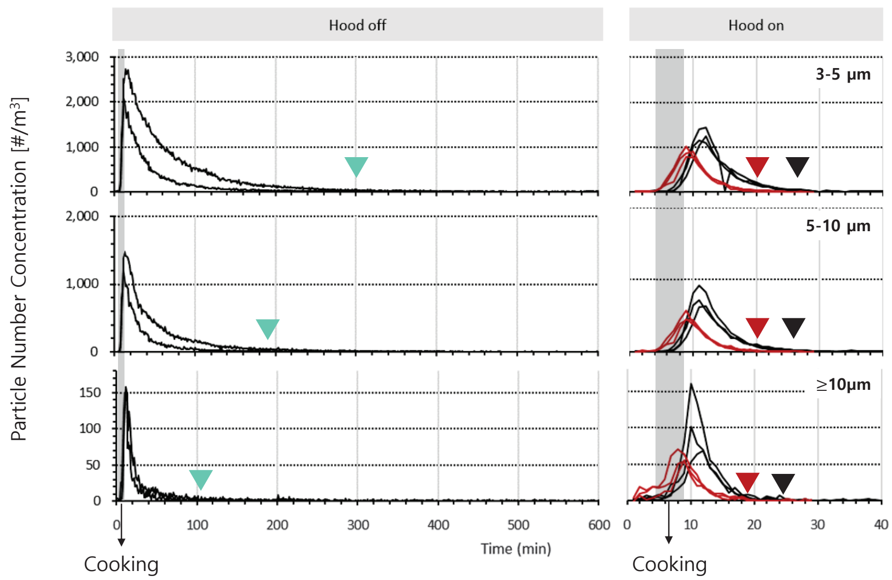
3 CONTAM model and Validation

2 Estimated particle concentration



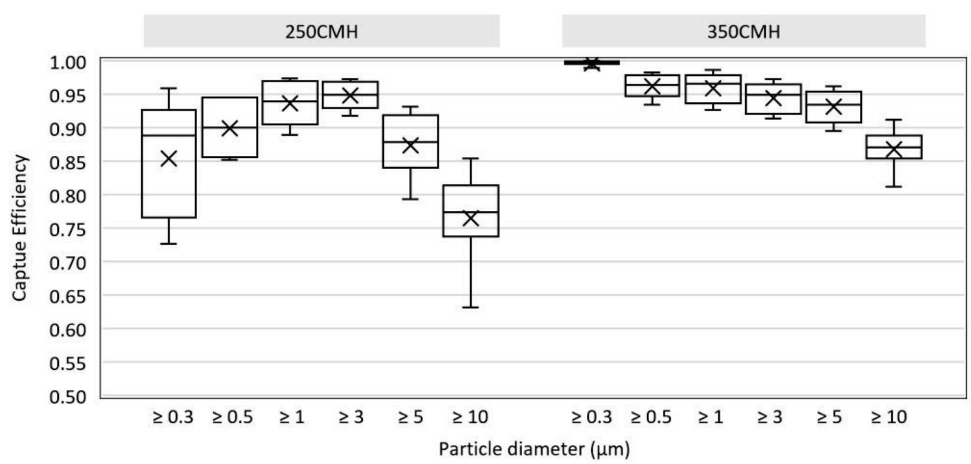
3 CONTAM model and Validation

2 Calculated particle concentration



3 CONTAM model and Validation

3 Capture efficiency



Conclusion

5 Conclusion

1 Conclusion

This study investigated the particle removal performance of a kitchen range hood depend on the particle diameters and exhaust rates, in terms of capture efficiency.
There was experimental attempt to find out the capture efficiency in a typical household setting. In this way, we had to subtract any particles besides generated from cooking.

- Kitchen range hood could reduce the time taken to return to the initial concentration by about 1/5.
- Regardless of the particle size, as the exhaust rate increased, the peak concentration and the time taken to return to the initial concentration decreased.
  This leads to the fact that larger exhaust flow rate results in better capture efficiency. (≤350 m^3/h)
- To remove particles smaller than 1μm, larger exhaust flow rate is much more effective.

5 Conclusion

2 Limitation and future studies

Limitations

- Assumed complete mixing.
  - forced well-mixing was avoid (e.g., using mixing fan) because mixing fan does not operate while typical cooking activity.

Future studies

- Compare and validate the effectiveness of the proposed method in this study using the HEPA filter

Thank you for your Attention

Shinhye Lee[1], Seongjun Park[2], Donghyun Rim[2], Donga Kang[3], Myoungsouk Yeo[1,4]
[1]Department of Architecture and Architectural Engineering, College of Engineering, Seoul National University, 08826, Seoul, Korea
[2]Architectural Engineering Department, Pennsylvania State University, 104 Engineering Unit A, University Park, PA 1680, USA
[3]School of Architecture and Architectural Engineering, University of Seoul, 02504 Seoul, Korea
[4]Institute of Construction and Environmental Engineering, Seoul National University, 08826 Seoul, Korea, msyeo@snu.ac.kr

서울대학교 NAVIEN

References

1. sources: A study conducted in the metropolitan Boston area. *Environmental health perspectives*, *108*(1), 35-44.
2. ASTM. (2023). *ASTM E3087-18*. https://www.astm.org/e3087-18.html
3. Cui, S., Cohen, M., Stabat, P., & Marchio, D. (2015). CO2 tracer gas concentration decay method for measuring air change rate. *Building and environment*, *84*, 162-169.
4. Eom, Y. S., Kang, D. H., Rim, D., & Yeo, M. (2023). Particle dispersion and removal associated with kitchen range hood and whole house ventilation system. *Building and Environment*, 109986.
5. Kim, Y.-S., Walker, I. S., & Delp, W. W. (2018). Development of a standard capture efficiency test method for residential kitchen ventilation. *Science and Technology for the Built Environment*, *24*(2), 176-187.
6. Kwon, M. H., Kim, S. M., Shim, I. K., Seo, S. Y., Won, S. R., Ji, H. A., & Park, J. (2013). A study on management of indoor air quality pollutants in kitchen air. *National Institute of Environmental Research*.
7. Lunden, M. M., Delp, W. W., & Singer, B. C. (2015). Capture efficiency of cooking-related fine and ultrafine particles by residential exhaust hoods. *Indoor Air*, *25*(1), 45-58.
8. O'Leary, C., de Kluizenaar, Y., Jacobs, P., Borsboom, W., Hall, I., & Jones, B. (2019). Investigating measurements of fine particle (PM 2.5) emissions from the cooking of meals and mitigating exposure using a cooker hood. *Indoor air*, *29*(3), 423-438.
9. Rim, D., Wallace, L., Nabinger, S., & Persily, A. (2012). Reduction of exposure to ultrafine particles by kitchen exhaust hoods: the effects of exhaust flow rates, particle size, and burner position. *Science of the Total Environment*, *432*, 350-356.
10. Singer, B. C., Delp, W. W., Price, P. N., & Apte, M. G. (2012). Performance of installed cooking exhaust devices. *Indoor Air*, *22*(3), 224-234.

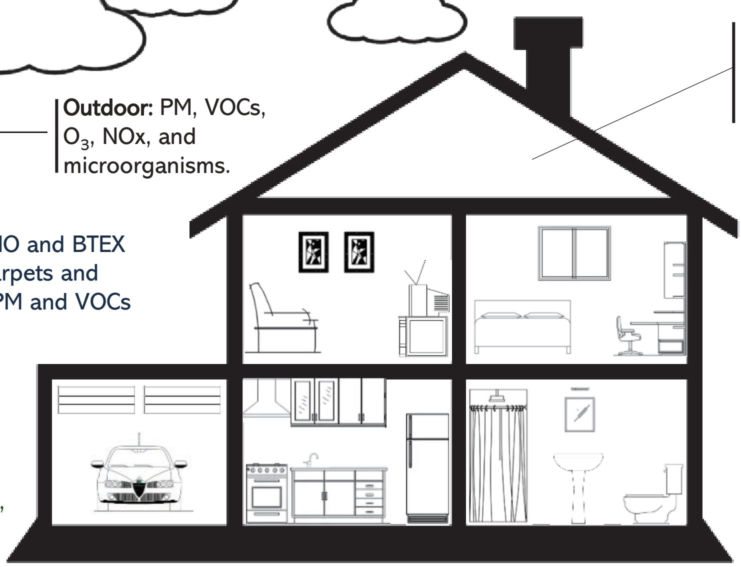
43rd AIVC Conference

MAIN INDOOR POLLUTANTS IN-KITCHEN

Daniela Mortari
Gaëlle Guyot
Nathan Mendes

Copenhagen, 2023

1



Outdoor: PM, VOCs, O_3, NOx, and microorganisms.

Building materials: HCHO and fibers from insulating materials, dust, asbestos and VOCs.

Living room: HCHO and BTEX from furniture, carpets and airfreshner, CO, PM and VOCs from fireplace.

Bedroom: CO_2 and moisture from occupant metabolism, VOCs from furniture and personal care products, O_3 from eletronic devices.

Garage: PM, NOx, CO and VOCs from car exhaust. VOCs from paints, adhesives, solventes, so on.

Bathroom: mold, microorganisms and moisture. VOCs from cleaning products, cosmetics and personal care.

Kitchen: CO, PM and VOCs from cooking and VOCs from cleaning products.

Adapted from González-Martín et al., 2021

2

2

COOKING PROCESS

- ✓Type of stove/fuel
- ✓Procedure
- ✓Type of food

TYPE OF STOVE/FUEL

- ✓ Challenge: Great **diversity of customs** within each country;
- ✓ 3 billion people cook using open fires or simple stoves:

wood, charcoal, animal dung, crop waste, coal, and kerosene.

WHO (2022)

12 major cities (5 houses each),

+

4 global regions:

→

natural gas (NG), liquefied petroleum gas (LPG), kerosene, ethanol, electric + different combinations

Kumar et al., 2022

TYPE OF STOVEN/FUEL

Fuel	Main emissions	Authors
Natural gas (NG)	CO_2, CO, steam, NO, NO_2, CH_2O, CH_4 and PM	(Lebel et al., 2022; Singer et al., 2017; Zheng et al., 2022)
Liquefied petroleum gas (LPG)	CO_2, CH_4, CO, SO_2, NO, NO_2, PM_{10}, $PM_{2.5}$ and HC	(Oke et al., 2020; Permadi et al., 2017)
Charcoal	CO_2, CH_4, N_2O, PM_{10}, $PM_{2.5}$, SO_2, CO, NOx, black carbon (BC), organic carbon (OC), non-methane volatile organic compounds (NMVOC)	(Permadi et al., 2017)
Ethanol	CO, CO_2, $PM_{2.5}$	(Chomanika et al., 2022)
Kerosene	CO_2, CH_4, N_2O, PM, SO_2, CO, NOx, BC, OC, NMVOC	(Permadi et al., 2017)
Coal	CO_2, CH_4, PM, SO_2, CO, NOx, BC, OC, NMVOC	(Permadi et al., 2017)
Raw wood-based fuel	CO_2, H_2O, NO, NO_2, SO_x, CO, CH_2O, PM and VOCs	(Kuye and Kumar, 2023)

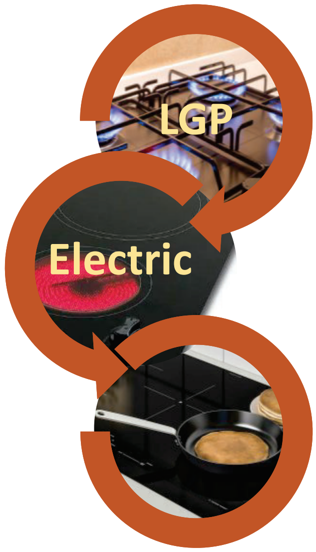
TYPE OF STOVE/FUEL

Kenya Ceramic Jiko (KCJ) (photo source: Njenga et al., 2017)

Fuel	Charcoal	Ethanol briquettes
Consumption (g of fuel per kg of cooked food (g/kg)	665	453
CO emissions rate (g/min)	20.71	0.029
$PM_{2.5}$ emissions rate (mg/min)	1398.03	0.0931

(source: Chomanika et al., 2022)

TYPE OF STOVE/FUEL



- ✓ CO, CO_2, NO, NO_2, and TVOC were reduced by around 40%, 26%, 86%, 42% and 48%, respectively (Zhao and Zhao (2018)
- ✓ CO_2 emissions reached 3500 ppm to LGP stove while the concentrations to induction and electric stove were near 500 ppm
- ✓ The CO concentration reached 23 ppm to LGP stove and was lower than 4 ppm to induction and electric stove

(Martínez-Gómez et al., 2016)

PROCEDURE

Reported methods: boiling, grilling, steaming, stewing, braising, stir-frying, pan-frying, deep-frying and roasting (Zhao and Zhao, 2018)

Main results: frying and grilling produce more PM than boiling and steaming food, especially if the food is Maillard browned or charred

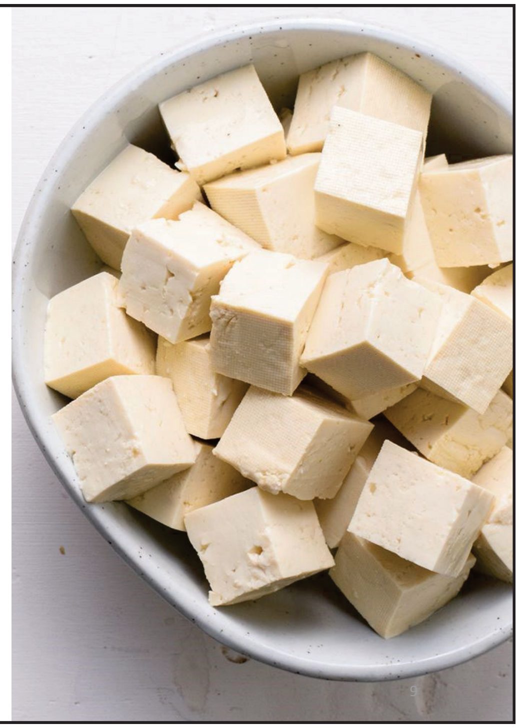
- Type of pan and the use of seasonings also affect the indoor air pollutants

$PM_{2,5}$ AVERAGE MASS CONCENTRATIONS

- ✓ **Steaming:** 65,7±7.6 µg/m^3
- ✓ **Boiling:** 81.4±9.3 µg/m^3
- ✓ **Stir-frying:** 120±13 µg/m^3
- ✓ **Pan-frying:** 130±15 µg/m^3
- ✓ **Deep-frying:** 190±20 µg/m^3.

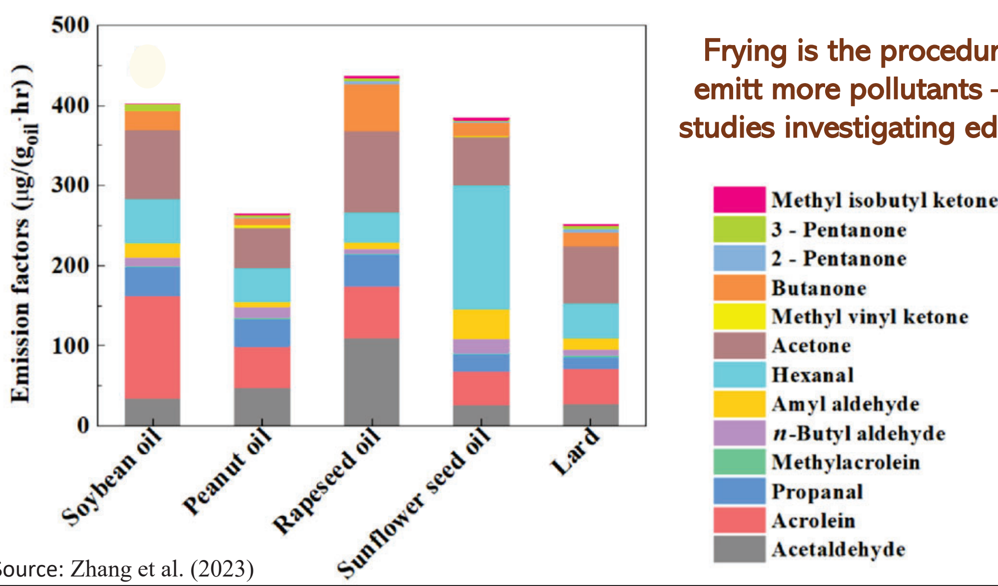
During the cooking process of 150 g of tofu

Balasubramanian 2008 (apud Zhao and Zhao 2018)



9

TYPE OF FOOD – EFFECT OF EDIBLE OILS



Source: Zhang et al. (2023)

Frying is the procedure that emitt more pollutants – many studies investigating edible oils

10

10

TYPE OF FOOD – COMPLETE MEALS

Chinese cuisine (Zhang et al. (2023)
4 different meals
13 aldehydes and ketones
acetaldehyde
558.41- 12329.93 µg/m^3

Latin cuisine (Alves et al., 2021)
4 different meals
Carbonyl and PM_{10}
PM_{10} 24.3 – 73.1 µg/m^3
Formaldehyde 31.3 – 36.9 µg/m^3

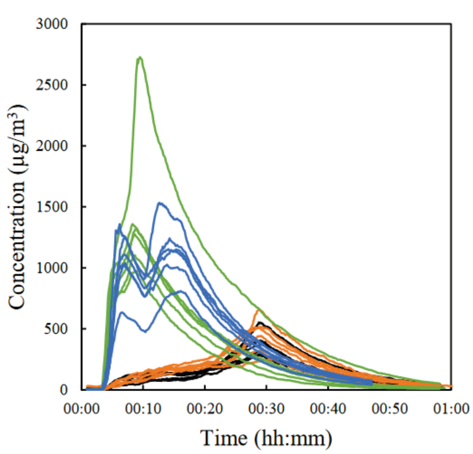
Japanese cuisine (Saito et al., 2014)
5 grilled proteins
PAHs
0.0039 – 78 µg/m^3

Dutch cuisine (O'Leary et al., 2019)
4 different meals
$PM_{2.5}$
0.62 – 3.2 mg/min

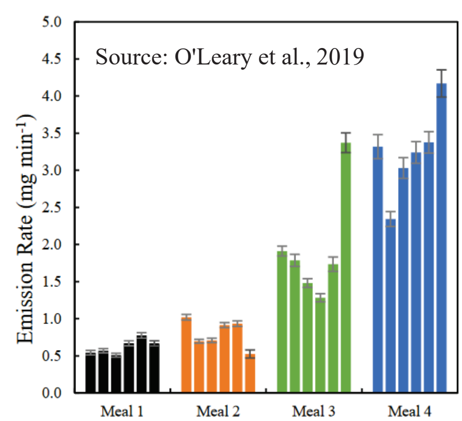
11

TYPE OF FOOD – COMPLETE MEALS

- 1 Chicken fillet and French fries
- 2 Chicken fillet and boiled potatos
- 3. Pasta Bolognese
- 4. Stir-fry – vegetables, chicken and noodles



e) All Meals



f) $PM_{2.5}$ Emission rates

12

12

DISCUSSION

- Various contaminants exceeded the maximum threshold concentrations defined by the World Health Organization (WHO) based on health effects.
- In different cultures the cooking process is repeated three or more times a day, every day, and in many situations, performed daily by the same person.
- More than 3 million people die annually worldwide due to illnesses caused by fumes and toxins released during cooking processes .
- While source reduction is a key in reducing avoidable pollution, ventilation is a key in reducing unavoidable pollution, such as cooking emissions.
- Challenge: Manual activation (USA: > 80% of houses built after 2003 have the devices)

13

CONCLUSIONS

- **Ventilation** appears as a key in reducing inevitable pollution.
- However, when it is **manually activated**, its use is decreased and only 30% of households reports to use the devices.
- This decrease also indicates the lack of knowledge of cooking pollutant hazards.
- In this context, **smart ventilation** associated with **education** on cooking pollutants is promising in improving IAQ.

14

THANK YOU FOR YOUR ATTENTION!

UNIVERSITÉ SAVOIE MONT BLANC

LOCIE

PUCPR GRUPO MARISTA

La Région Auvergne-Rhône-Alpes

CAPES

LST

Cerema

daniela.mortari@univ-savoie.fr

15

15

THANK YOU FOR YOUR ATTENTION!

MORTARI, Daniela

GUYOT, Gaëlle

MACHADO, Denner

BATISTELA, Marcos

MENDES, Nathan

16

16

REFERENCES

González-Martín, J., Kraakman, N.J.R., Pérez, C., Lebrero, R., Muñoz, R., 2021. A state–of–the-art review on indoor air pollution and strategies for indoor air pollution control. Chemosphere 262, 128376. https://doi.org/10.1016/j.chemosphere.2020.128376

Zhang, S., Ai, Z., Lin, Z., 2021. Novel demand-controlled optimization of constant-air-volume mechanical ventilation for indoor air quality, durability and energy saving. Applied Energy 293, 116954.

Zhao, Y., Zhao, B., 2018. Emissions of air pollutants from Chinese cooking: A literature review. Build. Simul. 11, 977–995. https://doi.org/10.1007/s12273-018-0456-6

Chomanika, K., Vunain, E., Mlatho, S., Minofu, M., 2022. Ethanol briquettes as clean cooking alternative in Malawi. Energy for Sustainable Development 68, 50–64.

O'Leary, C., de Kluizenaar, Y., Jacobs, P., Borsboom, W., Hall, I., Jones, B., 2019. Investigating measurements of fine particle (PM2.5) emissions from the cooking of meals and mitigating exposure using a cooker hood. Indoor Air 29, 423–438.

Pantelic, J., Son, Y.J., Staven, B., Liu, Q., 2023. Cooking emission control with IoT sensors and connected air quality interventions for smart and healthy homes: Evaluation of effectiveness and energy consumption. Energy and Buildings 286, 112932.

Sun, L., Singer, B.C., 2023. Cooking methods and kitchen ventilation availability, usage, perceived performance and potential in Canadian homes. J Expo Sci Environ Epidemiol 33, 439–447.

REFERENCES

Kumar, P., Hama, S., Abbass, R.A., Nogueira, T., Brand, V.S., Wu, H.-W., Abulude, F.O., Adelodun, A.A., de Fatima Andrade, M., Asfaw, A., Aziz, K.H., Cao, S.-J., El-Gendy, A., Indu, G., Kehbila, A.G., Mustafa, F., Muula, A.S., Nahian, S., Nardocci, A.C., Nelson, W., Ngowi, A.V., Olaya, Y., Omer, K., Osano, P., Salam, A., Shiva Nagendra, S.M., 2022. CO2 exposure, ventilation, thermal comfort and health risks in low-income home kitchens of twelve global cities. Journal of Building Engineering 61, 105254.

Kuye, A., Kumar, P., 2023. A review of the physicochemical characteristics of ultrafine particle emissions from domestic solid fuel combustion during cooking and heating. Science of The Total Environment 886, 163747.

Lebel, E.D., Finnegan, C.J., Ouyang, Z., Jackson, R.B., 2022. Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. Environ. Sci. Technol. 56, 2529–2539.

Singer, B.C., Pass, R.Z., Delp, W.W., Lorenzetti, D.M., Maddalena, R.L., 2017. Pollutant concentrations and emission rates from natural gas cooking burners without and with range hood exhaust in nine California homes. Building and Environment 122, 215–229.

Zheng, Z., Zhang, H., Qian, H., Li, J., Yu, T., Liu, C., 2022. Emission characteristics of formaldehyde from natural gas combustion and effects of hood exhaust in Chinese kitchens. Science of The Total Environment 838, 156614.

Oke, D.O., Fakinle, B.S., Sonibare, J.A., Akeredolu, F.A., 2020. Evaluation of emission indices and air quality implications of liquefied petroleum gas burners. Heliyon 6, e04755.

REFERENCES

Permadi, D.A., Sofyan, A., Kim Oanh, N.T., 2017. Assessment of emissions of greenhouse gases and air pollutants in Indonesia and impacts of national policy for elimination of kerosene use in cooking. Atmospheric Environment 154, 82–94.

Zhang, W., Bai, Z., Shi, L., Son, J.H., Li, L., Wang, L., Chen, J., 2023. Investigating aldehyde and ketone compounds produced from indoor cooking emissions and assessing their health risk to human beings. Journal of Environmental Sciences 127, 389–398.

Liu, Q., Son, Y.J., Li, L., Wood, N., Senerat, A.M., Pantelic, J., 2022. Healthy home interventions: Distribution of PM2.5 emitted during cooking in residential settings. Building and Environment 207, 108448.

Alves, C.A., Vicente, E.D., Evtyugina, M., Vicente, A.M.P., Sainnokhoi, T.-A., Kováts, N., 2021. Cooking activities in a domestic kitchen: Chemical and toxicological profiling of emissions. Science of The Total Environment 772, 145412.

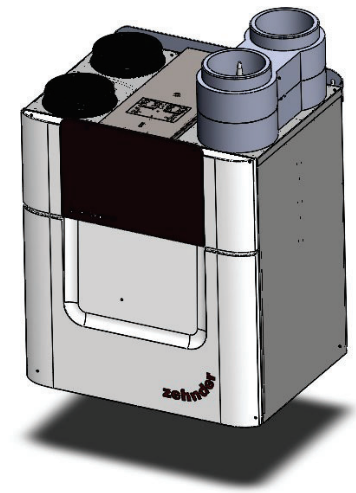
Saito, E., Tanaka, N., Miyazaki, A., Tsuzaki, M., 2014. Concentration and particle size distribution of polycyclic aromatic hydrocarbons formed by thermal cooking. Food Chemistry 153, 285–291.

19

AIVC Conference 2023 in Copenhagen

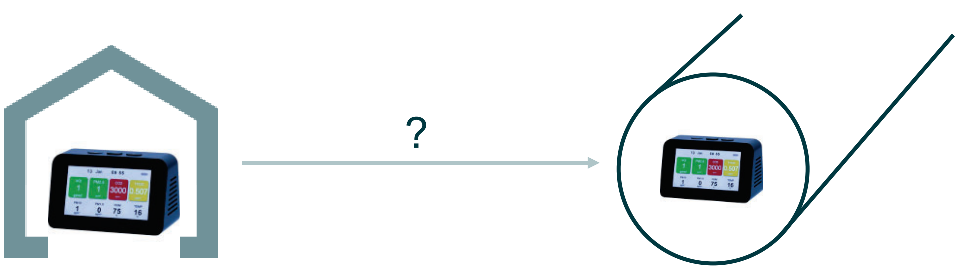
Fine dust (PM) measurement in ducts of balanced ventilation systems

Bart Cremers (in cooperation with Jan de Vries)
Knowledge Consultant Ventilation technologies



Introduction: PM measurement in ducts

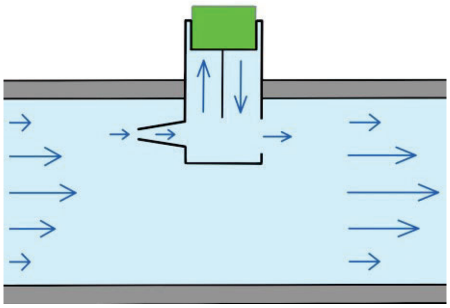
All currently available particulate matter (PM) sensors are designed to measure in slow-moving air (<1m/s).



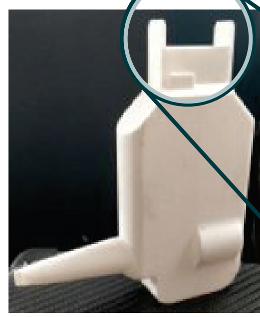
always the best climate

Technology of measurement in ducts

zehnder



1. isokinetic sampling of air
2. slowing down below 1 m/s
3. traversing PM sensor



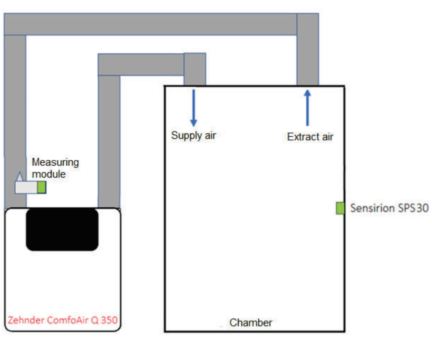
Rapid prototype
without PM sensor

detail, with PM sensor

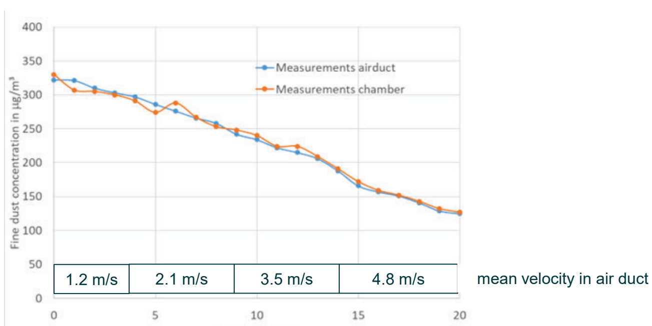
Measurement in ducts compared to measurement in chamber

zehnder

Experimental setup



Typical decay pattern of incense smoke

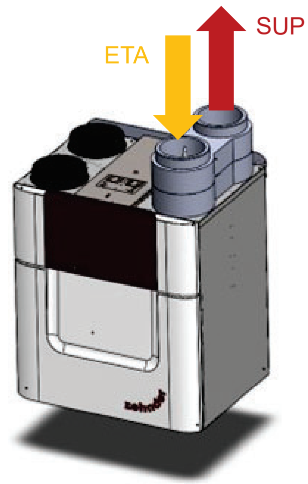


PM measurement in ducts can reproduce the values as measured in a test chamber (difference 2% to 4%)

Measurement in ducts of balanced ventilation system

Measurement of PM2.5 in extract air duct and in supply air duct

- Measurement in extract air is average of all rooms with extract
- Measurement in supply air is filtered outdoor air
- Measurement in supply air is after heat recovery,
  so in less variable thermal conditions



always the best climate

Test in three operational balanced ventilation units in three locations in NL

always the best climate

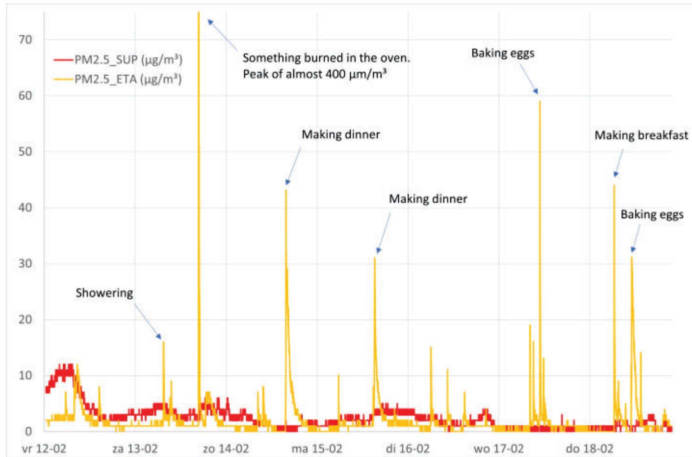
Test in Helmond (NL)

Extract

- large fine dust peaks caused by cooking
- small fine dust peaks caused by showering and steam ironing

Supply

- Small variation of fine dust values in supply air (because of outdoor variation)



7 always the best climate

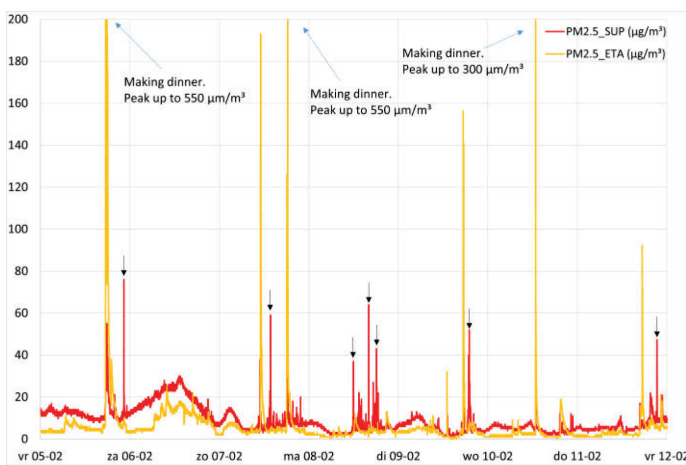
Test in Lettele (NL)

Extract

- large fine dust peaks caused by cooking

Supply

- Fine dust peaks in supply air are caused by re-intake of exhaust air by a wood stove with unfavourable winds
- Elevated levels in supply air lead to elevated levels in extract air, therefore indoor levels are result of indoor sources and outdoor sources (and ventilation rate)



8 always the best climate

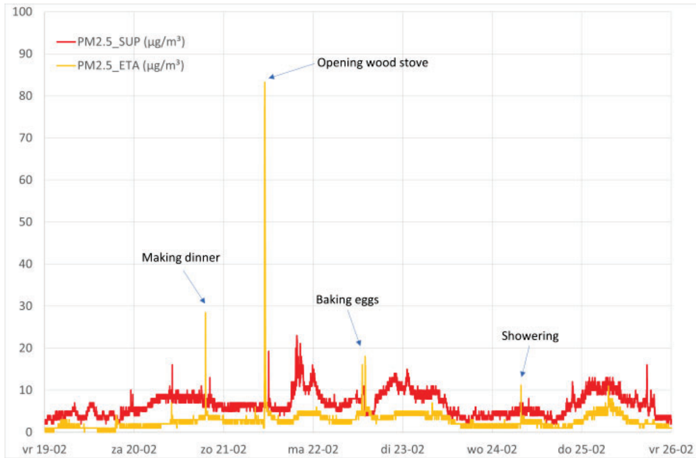
Test in Zwartsluis (NL)

Extract

- large fine dust peaks caused by cooking (lower values because of good cooking hood)

Supply

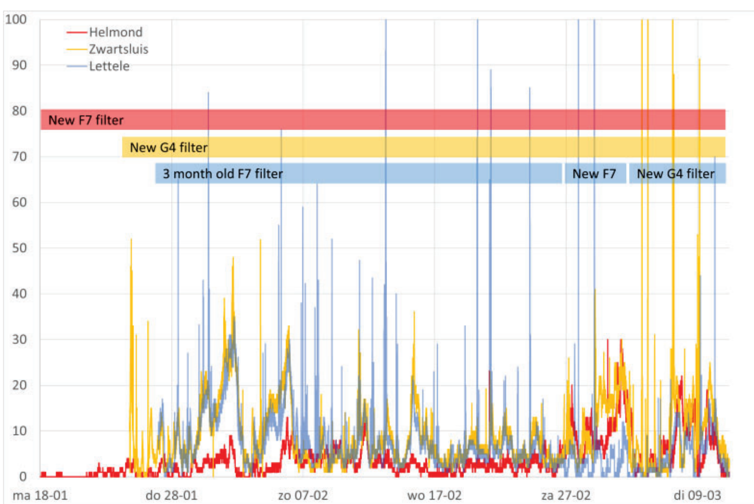
- Fine dust peaks in supply air are caused by re-intake of exhaust air by a wood stove with unfavourable winds



9

always the best climate

Comparing fine dust in supply air at three locations in NL



- similar pattern of fine dust values in all three locations
- ePM1/F7 filter of 3 months or older does not filter efficiently anymore
- influence of filter type (ePM1/F7 or Coarse/G4) and filter age (new or old

10

always the best climate

Conclusions

- Fine dust concentrations coming from outside of the house can be measured qualitatively in the supply air duct, with the measurements depending on
  - outside activity, and
  - the filter type and filter age

- Fine dust concentrations coming from inside the house can be measured qualitatively in the extract air duct, with the measurements depending on
  - type/duration of inside activities, and
  - the amount of air-extraction per room

OLLSCOIL NA GAILLIMHE
UNIVERSITY OF GALWAY

43rd AIVC - 11th TightVent & 9th venticool Conference

The Impact of Deep Energy Renovations on Indoor Air Quality and Ventilation in Irish Dwellings (ARDEN)

*Hala Hassan, Asit Kumar Mishra, Hilary Cowie, Emmanuel Bourdin, Brian McIntyre, Marie Coggins**

University
ofGalway.ie

OLLSCOIL NA GAILLIMHE
UNIVERSITY OF GALWAY

Outline/Agenda

- Background
- Study objective & methodologies
- Preliminary results - Indoor air pollutants and ventilation measured
- Conclusions

University
ofGalway.ie

Ollscoil na Gaillimhe
University of Galway

seai Sustainable Energy Authority of Ireland

- Evaluate the impact of deep energy retrofit on IAQ and thermal comfort in a sample of Irish dwellings.
- Assess the performance of the mechanical ventilation systems installed as part of the retrofit

University ofGalway.ie

Ollscoil na Gaillimhe
University of Galway

Irish Residential Sector

- 27% energy use
- 28% of Ireland's total energy emissions
- Strong tradition using fossil fuels
- Irish homes use 7% more energy and emit 60% more CO2 than average EU home

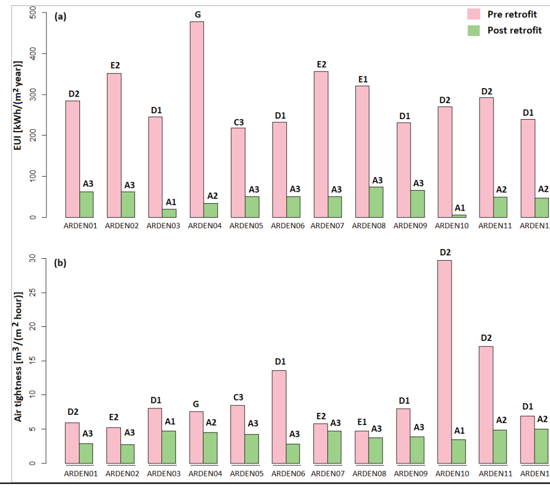
University ofGalway.ie

Ollscoil na Gaillimhe
University of Galway

Participating Dwellings

seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND

- N=26 (N=11)
- SEAI Deep Retrofit pilot programme
- 14 – 59 years old constructions
- 3 yr + post retrofit
- Non-smoking
- Detached/semi-detached, Cavity wall
- Floor area approx. 50 – 283 m^2



5

Ollscoil na Gaillimhe
University of Galway

Pollutants of interest and measuring equipment

6

Ollscoil na Gaillimhe
University of Galway

Particulate Matter $PM_{2.5}$
TSI AM520 monitor

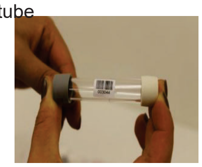
(Monitored for 3 days)

Formaldehyde
UMEX 500 badge

(3 days)

Nitrogen Dioxide (NO2)
Passive tube

(3-4 weeks)



Carbon dioxide (CO2)
Carbon monoxide (CO)
Total Volatile Compounds (TVOCs)
Temperature
Relative Humidity
GrayWolf

(Monitored for 3 days)

BTEX
TD passive tubes

(3-4 weeks)

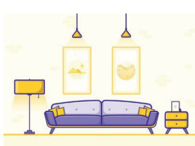
Radon
closed alpha-track detector (*Radtrak*)

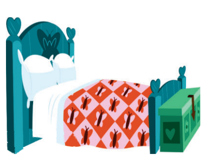
(3 months)

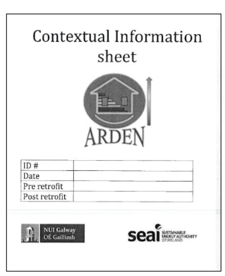
University ofGalway.ie

Ollscoil na Gaillimhe
University of Galway

Environmental Survey, Questionnaire, Occupant Diary






Contextual Information sheet
ARDEN
ID #
Date
Pre retrofit
Post retrofit
NUI Galway OÉ Gaillimh
seai

IN THE MAIN LIVING ROOM Did any of the following happen? (Please tick all that apply)	DAY ONE							
	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Windows opened								
Coal/Wood/Peat fire burning								
Candles/incense burning								
Gas hob used								
Electric cooker used								
Toaster/grill used								
Extractor fan on								
Cleaning/polishing								
Vacuum cleaner used								
Pets were present								
4 or more people were present								
Wall or window vents present open/closed								

University ofGalway.ie

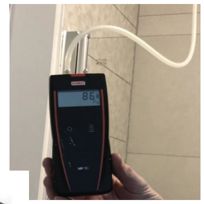
Ollscoil na Gaillimhe
University of Galway

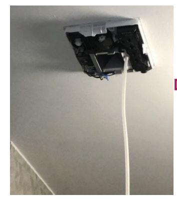
Ventilation

DCV (n=9)
- Humidity controlled
- Manometer (KimoMP50)
- Ventilation extracts in wet rooms(kitchen/bathrooms/utility)

MVHR (n=2)
- Flowfinder
- Air extract and supply terminals

ACH
- Bedroom CO_2 steady-state data





University
ofGalway.ie

Ollscoil na Gaillimhe
University of Galway

Preliminary results

University
ofGalway.ie

Results – Effect of Retrofit on Indoor Air Pollutants

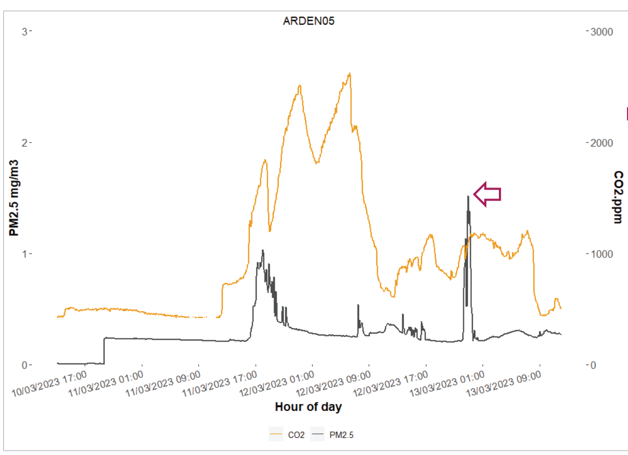
OLLSCOIL NA GAILLIMHE
UNIVERSITY OF GALWAY

	Pre- Retrofit		Post-retrofit	
	Bedrooms	Living rooms	Bedrooms	Living rooms
$PM_{2.5}$ [µg m^{-3}]	11.2 (7.5,16.7)*	9.9 (6.6,14.7)	27.3 (18.3,40.8)	24.0 (16.1,35.8)
CO_2 [ppm]	960 (860,1060)	825 (725, 925)	903 (803, 1003)	768 (668, 868)
Temperature [°C]	19.2 (18.5,19.8)	19.7 (19.0,20.3)	21.4 (20.7,22.1)	21.9 (21.2,22.6)
Relative Humidity [%]	53.8 (51.1,56.5)	52.5 (49.8,55.2)	50.3 (47.6,53.0)	49.0 (46.3,51.7)

* Least-square means (LCL,UCL)

$PM_{2.5}$ and occupants activities

OLLSCOIL NA GAILLIMHE
UNIVERSITY OF GALWAY



- Average 24-hr post-retrofit:
  Bedrooms: 4.8 – 318 µg/m³
  Living rooms: 3.1 – 258 µg/m³
- Highest 24-h average (318 µg/m³) detected at **ARDEN05** bedroom
- Peak in 2nd night (1,518 µg/m³)
- Door closed, pets present in room over-night
- Under-ventilated (ACH = 0.3 h^{-1})
- No ensuite ~ no extract vent
- One extract in bathroom – faulty reading

Ventilation

13

OLLSCOIL NA GAILLIMHE
UNIVERSITY OF GALWAY

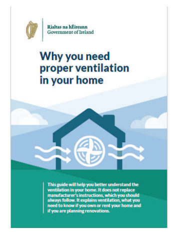
Ventilation – reported issues

- Poor maintenance
- Visible dust on vents/fan blocked
- Noise
- 25% homes reported no handover post-retrofit
- In most cases lack of understanding of the systems

14

Since ARDEN Commenced

- Technical Guidance Document (TGD) F - Ventilation (2019) to the Irish Building Regulations
  - ➢ requirement for a third party to validate that ventilation system has been installed, balanced and commissioned to achieve the design flow rates
- Presence control indicators to indicate to occupant that system is operating correctly and if fault occurred
- National Promotion Campaign (video/guidance brochure) to raise awareness on the importance of proper ventilation in homes
- NSAI S.R.54 currently under review
  - ➢ more emphasis on IAQ



Conclusions

- Higher concentrations of some IAPs detected in bedrooms and living rooms
- Warm temperatures detected in bedrooms and living rooms during summer time
  - Promote natural ventilation/more airing
- Public awareness with regard to IAPs
- Need for further studies on occupant behavior and it's impacts on IAQ and ventilation

Acknowledgement

- Project participants
- ARDEN project team, Dr Marie Coggins (University of Galway), Dr Nina Wemken (University of Galway), Dr Asit Kumar Mishra (UCC), Hilary Cowie (Institute of Occupational Medicine Edinburgh)
- Sustainable Energy Authority of Ireland – Brian McIntyre, Conor Hanniffy
- Irish Department of Housing, Local Government and Heritage – Dr Emmanuel Bourdin

This project has been funded by the Sustainable Energy Authority of Ireland under the SEAI Research, Development & Demonstration Funding Programme 2019, Grant number 18/RDD/204.

Ollscoil na Gaillimhe
University of Galway

SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Ollscoil na Gaillimhe
University of Galway

Thank *you !*

University
*of*Galway.ie

Questions ?

Ollscoil na Gaillimhe
University of Galway

PLEIAQ Cerema CLIMAT & TERRITOIRES DE DEMAIN ubbink

Financial impact of leaky ductwork in buildings – a calculation tool to raise awareness

AIVC 2023 CONFERENCE COPENHAGEN

5TH OCTOBER 2023

NOLWENN HUREL - PLEIAQ

VALÉRIE LEPRINCE – CEREMA

MARCUS LIGHTFOOT - UBBINK

1

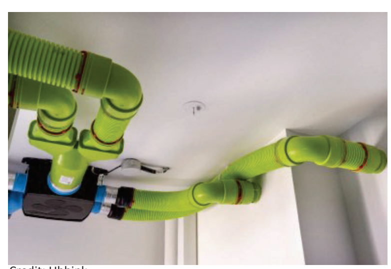
Introduction

"Build tight, ventilate right"

- Buildings more and more airtight (less energy losses)
- Mechanical ventilation systems to ensure a good IEQ

But in practice: ductwork leakages issues

- Low awareness
- Consequences on energy use and/or IAQ



Credit: Ubbink

→ **Objective:** Development of a **simple tool** to estimate the **financial impact of leaky ductwork** in buildings over their whole life

2

Model for the leakage impact calculation

Calculation tool

Case studies

Fan energy use

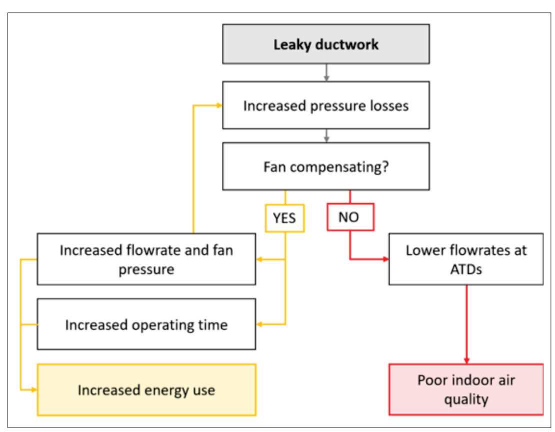
Electrical fan power:

Pressure → Δp_{AHU}, Flowrate → Q_{AHU}, efficiency → η

$$P_{AHU} = \frac{\Delta p_{AHU} \times Q_{AHU}}{\eta \times 3600}$$

Assumption:

Full compensation of leakage



Pressure losses

Friction losses:

Friction factor, Length, Velocity, Diameter

$$\Delta p_f = \frac{1000 f L}{D_h} * \frac{\rho V^2}{2}$$

Dynamic losses :

Total loss coeff., Velocity

$$\Delta p_t = \frac{C \rho V^2}{2}$$

Total pressure loss in the ductwork:

$$\Delta p_{loss} = \left(\frac{1000 f L}{D_h} + \sum C\right)\left(\frac{\rho V^2}{2}\right)$$

Electrical overconsumption

Fan power difference (with/without leakage) : $\Delta P_{AHU,real} = P_{AHU,real} - P_{AHU,0}$

Fan power with leakage

$$\mathrm{P}_{\mathrm{AHU,real}} = \frac{\Delta \mathrm{p}_{AHU,real} \times Q_{AHU,real}}{\eta \times 3600}$$

Fan power without leakage

$$\mathrm{P}_{\mathrm{AHU,0}} = \frac{\Delta \mathrm{p}_{AHU,0} \times Q_{AHU,0}}{\eta \times 3600}$$

Fan pressure with leakage

$$\Delta \mathrm{p}_{AHU,real} = \Delta \mathrm{p}_{\mathrm{ATD}} + (\Delta \mathrm{p}_{AHU,0} - \Delta \mathrm{p}_{\mathrm{ATD}}) \times \frac{Q^2_{AHU,real}}{Q^2_{AHU,0}}$$

Fan flowrate with leakage

$$Q_{AHU,real} = Q_{AHU,0} + Q_{l,real}$$

Leakage flowrate

$$Q_{l,real} = A_{du} \times C_l \times \Delta p_{a,du}^{0.65} \times 3600$$

Average pressure in ductwork

$$\Delta \mathrm{p}_{\mathrm{a,du}} \approx \frac{\Delta \mathrm{p}_{\mathrm{ATD}} + \Delta \mathrm{p}_{\mathrm{AHU,0}}}{2}$$

Assumption : Constant pressure assumed in the ductwork: average Fan – ATD without leakage

Model for the leakage impact calculation

Calculation tool

Case studies

ubbink

Calculation tool - Ductwork airtightness impact on energy use

PLEIAQ

Version : 1.0 **Date :** June 2023 **By :** PLEIAQ

Color code		
		Value to be completed
		Value calculated (do not modify)
		Cell to be ignored

Inputs

Ventilation system:	Balanced	EXHAUST			SUPPLY	
		Data	Estimation	Unit	Data	Estimation
Flowrate at the fan/AHU (designed):		225		m3/h	225	
Pressure at the fan/AHU (designed):		110		Pa	110	
Pressure at the ATD:		10		Pa	10	
Power of the fan/AHU (designed):		26		W	26	
Ductwork area:	calculation		14,72	m²		14,72
Annual operating time:	estimation		8760	h/year		
National cost of a kWh:		0,28		€/kWh		
Years of operation:	known	80		years		

Results

Airtightness classes		Annual energy overcons.		Leakage cost	
Prev. name	New name	Value (kWh)	% fan cons.	Annual	Total
3A	-	452	99%	126 €	10 117 €
2,5A	ATC 6	361	79%	101 €	8 095 €
1,5A	-	199,5	43,8%	56 €	4 469 €
A	ATC 5	127,5	28,0%	36 €	2 855 €
B	ATC 4	40,1	8,8%	11,2 €	898 €
C	ATC 3	13,1	2,9%	3,7 €	294 €
D	ATC 2	4,3	1,0%	1,22 €	97 €
-	ATC 1	1,4	0,3%	0,40 €	32 €

Estimated values

Ductwork area

EXHAUST ductwork 14,72 m²

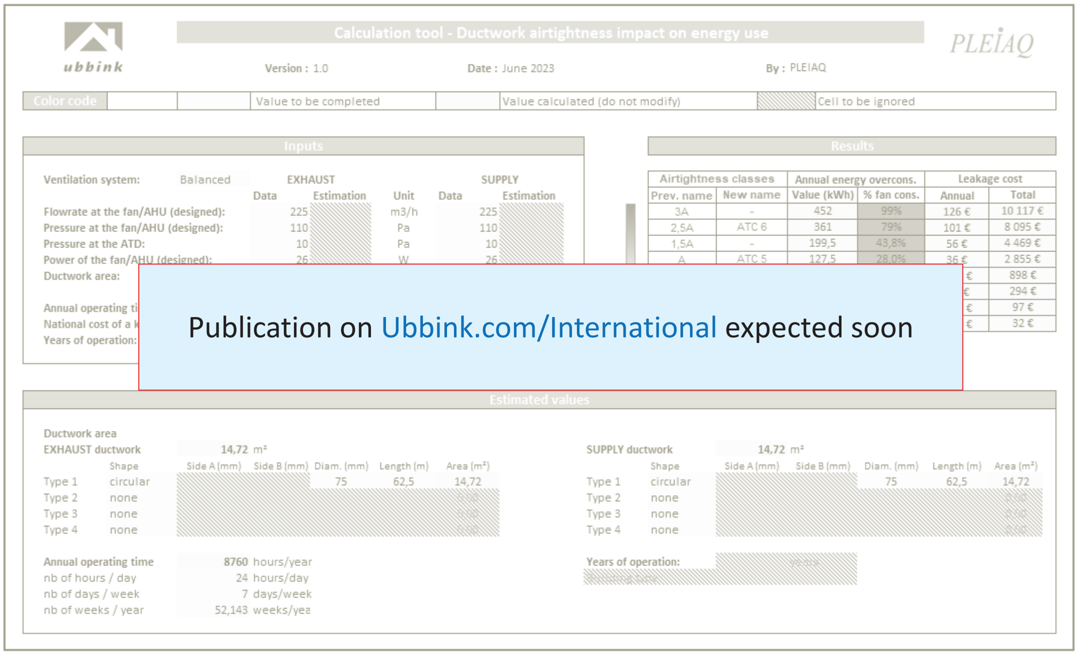
	Shape	Side A (mm)	Side B (mm)	Diam. (mm)	Length (m)	Area (m²)
Type 1	circular			75	62,5	14,72
Type 2	none					
Type 3	none					
Type 4	none					

SUPPLY ductwork 14,72 m²

	Shape	Side A (mm)	Side B (mm)	Diam. (mm)	Length (m)	Area (m²)
Type 1	circular			75	62,5	14,72
Type 2	none					
Type 3	none					
Type 4	none					

Annual operating time	**8760**	hours/year
nb of hours / day	24	hours/day
nb of days / week	7	days/week
nb of weeks / year	52,143	weeks/yea

Years of operation:



Calculation tool - Ductwork airtightness impact on energy use

ubbink | Version : 1.0 | Date : June 2023 | By : PLEIAQ | PLEIAQ

Color code | | Value to be completed | | Value calculated (do not modify) | | Cell to be ignored

Inputs

Ventilation system:	Balanced	EXHAUST			SUPPLY	
		Data	Estimation	Unit	Data	Estimation
Flowrate at the fan/AHU (designed):		225		m3/h	225	
Pressure at the fan/AHU (designed):		110		Pa	110	
Pressure at the ATD:		10		Pa	10	
Power of the fan/AHU (designed):		26		W	26	
Ductwork area:						
Annual operating ti						
National cost of a k						
Years of operation:						

Results

Airtightness classes		Annual energy overcons.		Leakage cost	
Prev. name	New name	Value (kWh)	% fan cons.	Annual	Total
3A	-	452	99%	126 €	10 117 €
2,5A	ATC 6	361	79%	101 €	8 095 €
1,5A	-	199,5	43,8%	56 €	4 469 €
A	ATC 5	127,5	28,0%	36 €	2 855 €
				€	898 €
				€	294 €
				€	97 €
				€	32 €

Estimated values

Ductwork area

EXHAUST ductwork 14,72 m²

	Shape	Side A (mm)	Side B (mm)	Diam. (mm)	Length (m)	Area (m²)
Type 1	circular			75	62,5	14,72
Type 2	none					
Type 3	none					
Type 4	none					

SUPPLY ductwork 14,72 m²

	Shape	Side A (mm)	Side B (mm)	Diam. (mm)	Length (m)	Area (m²)
Type 1	circular			75	62,5	14,72
Type 2	none					
Type 3	none					
Type 4	none					

Annual operating time	8760	hours/year
nb of hours / day	24	hours/day
nb of days / week	7	days/week
nb of weeks / year	52,143	weeks/yea

Years of operation:

Publication on Ubbink.com/International expected soon

Model for the leakage impact calculation

Calculation tool

Case studies

Case studies: 4 houses & 1 school

Medium-sized house (House 1)
- heat recovery
- diameter: 75 mm
- length: 125 m

Medium-sized house (House 2)
- heat recovery
- 6 m of DN160 mm
- 40 m of DN 125 mm

Large house (House 3)
- heat recovery
- diameter: 75 mm
- length: 200 m

Large house (House 4)
- **Extract only**
- Pressure at ATD: 70 Pa
- Area : 7,4 m²

	House 1	House 2	House 3	House 4	School (1 AHU)	
	Exh./Sup.	Exh./Sup.	Exh./Sup.	Exh.	Exh.	Sup.
Fan flowrate (m³/h)	225	225	300	100	13500	11855
Fan pressure (Pa)	110	110	160	150	130	130
Pressure ATD (Pa)	10	10	10	70	43	35
Fan power (W)	26	26	49	15.4	4701	4143
Ductwork area (m²)	14.72	9.36	23.6	7.4	317	279
Operating time (h/y)	8760				1140*	

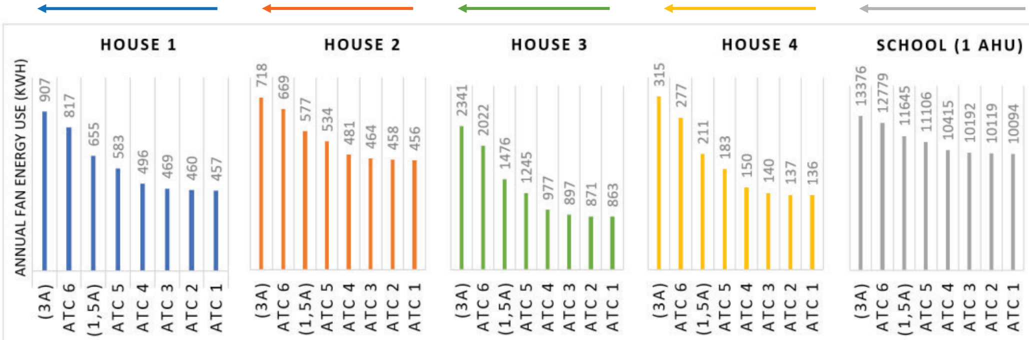
* 2000 hours (10 h/d; 5 d/w; 40 w/y) x 57% due to CO_2 regulation (value from the Avis Technique of the ventilation system)

School : 1 of the 10 AHU of a 4500 m² French school (500 students) – PromevenTertiaire project

Annual energy use

Additionnal annual energy use due to ductwork leakage (Class 3A):

+ 451 kWh (**99%**) + 263 kWh (**58%**) + 1482 kWh (**173%**) + 180 kWh (**133%**) + 3293 kWh (**33%**)



Annual and total cost of ductwork leakage

Airtight. classes		House 1		House 2		House 3		House 4		School (1 AHU)	
Prev.	New	Annual	Total	Annual	Total	Annual	Total	Annual	Total	Annual	Total
3A	-	126 €	10 117 €	73,5 €	5 881 €	415 €	33 199 €	50,4 €	4 035 €	922 €	73 772 €
2,5A	ATC 6	101 €	8 095 €	59,7 €	4 772 €	326 €	26 071 €	39,8 €	3 182 €	755 €	60 415 €
1,5A	-	55,9 €	4 469 €	33,9 €	2 713 €	173 €	13 834 €	21,3 €	1 706 €	437 €	34 999 €
A	ATC 5	35,7 €	2 855 €	22,0 €	1 760 €	108 €	8 655 €	13,4 €	1 073 €	287 €	22 924 €
B	ATC 4	11,2 €	898 €	7,1 €	565 €	33,1 €	2 645 €	4,1 €	331 €	93,3 €	7 463 €
C	ATC 3	3,7 €	294 €	2,3 €	186 €	10,7 €	856 €	1,3 €	107 €	30,8 €	2 468 €
D	ATC 2	1,22 €	97 €	0,77 €	62 €	3,53 €	282 €	0,44 €	36 €	10,26 €	820 €
-	ATC 1	0,40 €	32 €	0,26 €	21 €	1,17 €	94 €	0,15 €	12 €	3,41 €	273 €

Conclusions

Simple tool developed to estimate the financial impact of leaky ductwork

→ Help to raise awareness on the ductwork leakage issue

→ Encourage the installation of airtight ductwork systems

Case studies for 4 houses and 1 AHU of a school:

Very leaky ductwork (Class 3A) induce:

- an increase of fan energy use ranging between **58%** and **173%** for the 4 single-family houses (180 to 1482 kWh) and of **33%** for the school AHU (3293 kWh).
- a financial impact for 80 years of operation ranging between **4.0 k€** to **33.2 k€** for the 4 single-family houses and reaching **74 k€** for the school AHU (out of the 10 AHU).

→ **Significant financial impact for all type of buildings, including single-family houses**

Publication of the tool on Ubbink/International expected soon

→ Send me **an email** to be informed: nolwenn.hurel@pleiaq.net

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Decoding 30 Years of Insights: Conclusions from ISIAQ's Landmark Webinar Series on Indoor Air Quality and Climate

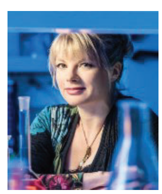
1

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Board of Directors - Voting Members


Ying Xu,
President


Kerry Kinney,
President Elect

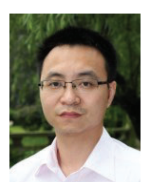

Kati Huttunen,
VP Policy


Benjamin Hanoune,
VP Research


Qihong Deng,
Vice President, Practice


Dustin Poppendieck,
Secretary


James McGrath,
Treasurer


Weiwei Liu,
Treasurer Elect

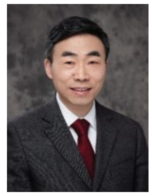
2

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

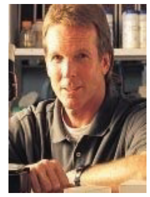
Non-voting Members

Corinne Mandin,
Past President

Yuguo Li,
ISIAQ Journal



Yinping Zhang,
President of the
Academy of Fellows



Richard Shaughnessy,
Coordinator of STCs

Lada Hensen,
Coordinator of Chapters

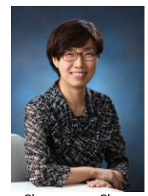
Rita Lam,
Student Representative

Martin Täubel,
Relations with
Other Societies

Tengfei Zhang,
President
HB2023-Asia

Marcel Schweiker,
President
HB2023-Europe

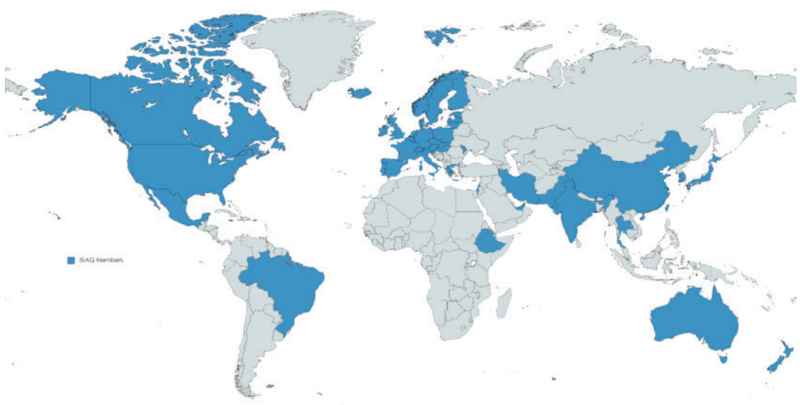
Nadia Boschi,
Trustee



Chungyoon Chun,
Trustee

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

50 countries represented and growing!



769	264	9	15	15
INDIVIDUAL MEMBERS	STUDENT MEMBERS	AFFILIATE MEMBERS	EARLY CAREER MEMBERS	CORPORATE MEMBERS

ISIAQ

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Conferences

INDOOR AIR

Held in even-numbered years; rotation between Asia/Pacific Rim – Europe/Africa – America

HEALTHY BUILDINGS

Held in odd-numbered years; regional conferences; targeted to practice

5

ISIAQ

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

2023 Conferences

HEALTHY BUILDINGS EUROPE 2023
BEYOND DISCIPLINARY BOUNDARIES

June 11-14, 2023
Aachen, Germany

HEALTHY BUILDINGS ASIA 2023

July 16-19, 2023
Tianjin, China

6

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

2024 Conference

18TH CONFERENCE OF THE INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY & CLIMATE

INDOOR AIR 2024

July 7-11, 2024 ✿ Honolulu, Hawaii, USA

INDOOR AIR 2024

7

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

ISIAQ Conferences

8

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Scientific and Technical Committees (STCs)

Roles of STCs:

- **To review and report new and emerging research directions in indoor air sciences** to be published in the ISIAQ newsletter or submitted to the ISIAQ journal
- **To organize symposiums and workshops** during ISIAQ conferences
- All individuals are **welcome to request to join** any STCs.

9

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

9 Scientific and Technical Committees (STCs)

STC11 Source, monitoring and evaluation: chemical pollutants *(55 members)*
Chairperson: Ying Xu, Tsinghua University, China
STC12 Source, monitoring and evaluation: aerosols *(20 members)*
Chairperson: Chair: Brandon E. Boor, Purdue University, USA
STC13 Microbes in indoor environments *(15 members)*
Chairperson: Ju-Hyeong Park, NIOSH/CDC, USA
STC21 Ventilation *(33 members)*
Chairperson: Brent Stephens, Illinois Institute of Technology, USA
STC22 Air cleaning *(36 members)*
Chairperson: Alireza Afshari, Aalborg University, Denmark
STC31 Health effects and epidemiology *(31 members)*
Chairperson: Yuexia Sun, Tianjin University, China
STC32 Environmental/climate impacts *(18 members)*
Chairperson: Zhiwen Luo, California Department of Public Health, USA
STC33 Thermal comfort *(25 members)*
Chairperson: Yingxin Zhu, Tsinghua University, China
STC34 IEQ Guidelines *(13 members)*
Chairperson: Ulla Haverinen-Shaughnessy, The University of Oulu, Finland

10

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Indoor Air Journal

- Wiley-owned *Indoor Air* journal had been the official journal of ISIAQ for 30 years.
- In late 2022, Wiley would transition *Indoor Air* to an Open Access journal as part of their new partnership with Hindawi.
- ISIAQ decided not to enter any association with Wiley-Hindawi publishing
- *Indoor Air* is no longer the "official journal" of ISIAQ.
- ISIAQ chose Elsevier publishing
- **A new ISIAQ-owned journal, *Indoor Environments*, will be launched this year**

11

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Library of Specialized Webinars

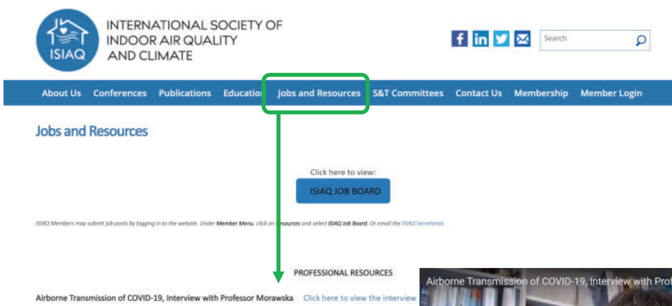
ISIAQ Members have access to our library of specialized webinars. Recent webinars include:

- The Recognition of Airborne Transmission of Infectious Diseases
- Managing buildings in the era of COVID-19
- Health and contamination: New perspectives for the future
- A Modular Mechanistic Framework for Assessing Human Exposure to Chemicals in Materials, Products and Articles – Next Steps
- Cleaning for Health: Viruses / Biological Contamination on Surfaces and How to Meet the Challenges to Achieve Effective Cleaning
- Assessing Human Exposure to Chemicals in Materials, Products and Articles: A Modular Mechanistic Framework

12

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Leading the Field



Past President Lidia Morawska was selected by Time Magazine as one of the one hundred most influential people in the world in 2021. See our interview with her on our website.

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Promoting Knowledge with IEQ Global Alliance

ISIAQ and the Indoor Environmental Quality Global Alliance (IEQ-GA) have partnered to create a unique monthly show called **Indoor Environments: Global Research to Action**

This new video show & podcast explores at how research can be translated to practice on a variety of topics related to indoor environments.

Watch the replays on:

https://global.healthyindoors.com/c/indoor-environments/

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Student Activities

- **Mentorship programme**: ISIAQ brings together students and mentors in the IAQ field. All ISIAQ members are eligible to participate.
- **Student Conference Support Awards** are available to ISIAQ student members for each conference.
- The Indoor Air conference includes **Summer School** sessions preceding the conference, available to any students that wish to participate.

15

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Student and Early Career Professionals Webinar Series

ISIAQ has launched a webinar series aimed at providing resources for student and early career professionals. Recent talks include:

- Transitioning from Academia to Industry
- Careers in Academia: How to land the perfect PhD and Post-doc position at your dream institution
- Research and Careers in the Indoor Environment: Learn how ISIAQ can help you

16

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

ISIAQ Chapters

5 national chapters:

FISIAQ (Finland)
ISIAQ.nl (the Netherlands)
SWESIAQ (Sweden)
NIO (Norway)
ISIAQ.is (Iceland)

- Activities at national level
- Meetings (sharing experience) during ISIAQ conferences
- ISIAQ welcomes applications for new chapters!

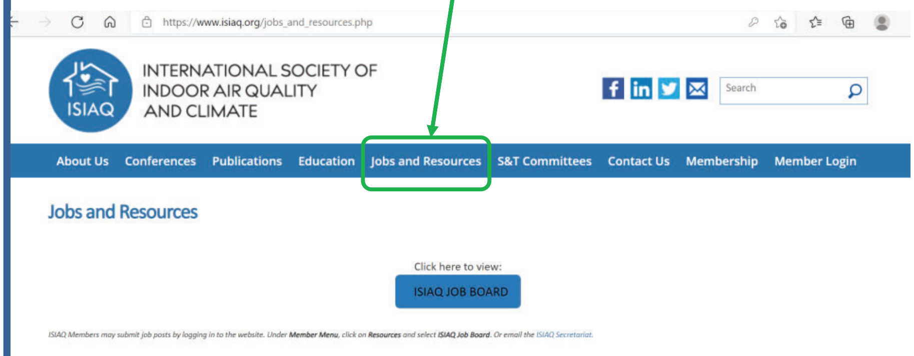
INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Online Resources

- **Quarterly newsletter** with updates on ISIAQ conferences, chapters activities, webinars in replay, publication of new reports or PhD thesis.
- **IEQ Guidelines Database**: ISIAQ STC 34 has developed a database to share worldwide IEQ guidelines. The database is accessible through the new website, www.ieqguidelines.org. On the database page, you will have access to the entire database in a tabular format where you can search, sort, and filter by any fields available. On the map page, you will have access to the national guidelines by country on an interactive map.

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Online Resources: Job Board



19

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Opportunities for Membership

ISIAQ has several tiers of membership available:

Ordinary Members - $135

Early Career Members - $70

Student Members - $30

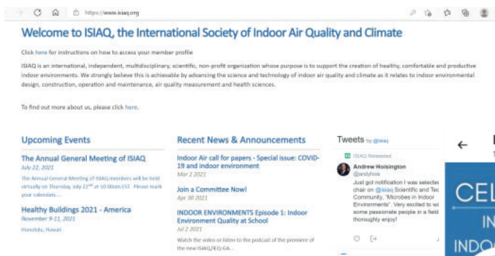
Affiliate Members - $30

20

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Connect with ISIAQ

Connect with us through our website, our social media, and LinkedIn



LinkedIn

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

30th Anniversary Webinar Series

To celebrate ISIAQ's 30 years, we took the opportunity to consider what we know/what are the main milestones of the past research, and what are now the major challenges for the coming years.

ISIAQ organized a webinar series. Each webinar brought together key researchers who had a major contribution to indoor air sciences and who played an important role within our society, and young brilliant researchers who are preparing the future of research in our field.

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Webinar 1. 30+ Years of Knowledge Creation: Indoor Air 1991-2021

William W. Nazaroff

Distinguished Professor Emeritus

University of California, Berkeley, USA

Marina Vance

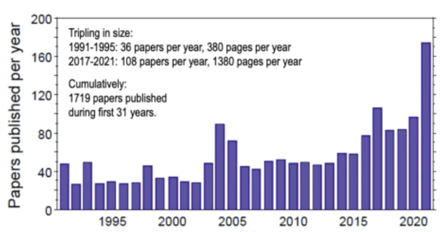
Assistant professor

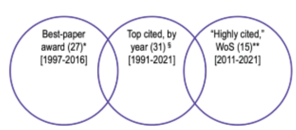
University of Colorado Boulder, USA

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Indoor Air — an international, multidisciplinary, research journal

- Established in 1991
- Aims and Scope: provide a healthy and comfortable environment for building occupants
- Steady growth in scale and influence
- **64 key papers — identify 7 major topics (1991-2021)**





INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Topic 1: Offices: Ventilation, Volatile Organic Compounds, and Sick-Building Syndrome

Office environment → Ventilation system & rate / VOCs exposure → Sick-Building Syndrome

Topic 2: Dampness, mold, microbiome, and health

- Moisture and dampness → prevalence of fungi ↔ occupants (adverse health risks)
- Microbes chemically alter indoor air

Topic 3: Indoor environment quality in schools, student achievement

- Degraded indoor environmental quality in schools might adversely affect student learning.

Topic 4: Biomass cookstoves and health

- Cooking over an open flame using solid fuels causes high air pollution exposures with severe adverse health effects

25

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Topic 5: Infections disease transmission

- Routes and mechanism for transmission/spread of infectious disease
- Large boosts: SARS epidemic of 2002–2004, COVID-19 pandemic

Topic 6: Thermal Comfort

- The predicted mean vote (PMV) model created by Fanger in the late 1960s, is used worldwide to assess thermal comfort

Topic 7: Residential air quality

- Residences — where we spend most of our time
- High baseline VOCs
- Advanced measurement technology
- Sleeping environment — quality of sleep, ability to concentrate

26

ISIAQ

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Four themes remain vigorous

- Dampness, mold, microbiomes, and health
- Indoor environmental quality in schools and student achievement
- Infectious disease transmission
- Residential air quality

+

New themes

- Climate change adaptation and mitigation in indoor environments
- IEQ improvements through advanced sensing and personalized controls
- Autoimmune, autoregulatory, and cognitive disorders as influenced by indoor exposures to endocrine disrupting chemicals

Five principles to achieve good IAQ

1) Minimize indoor emissions
2) Keep it dry
3) Ventilate well
4) Protect against outdoor pollution
5) Satisfy occupant needs

ISIAQ

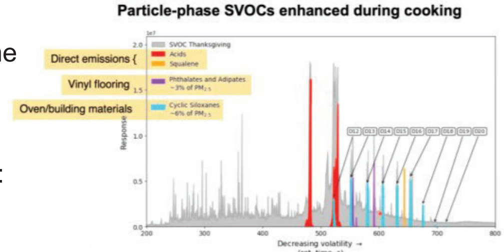
INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

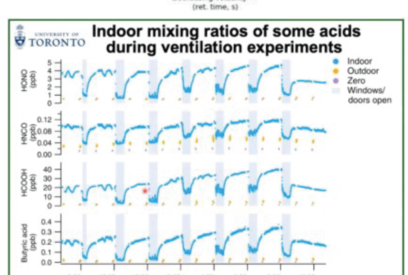
Examples of recent collaborative work related to three of Bill's five principles

The HOMEChem study: home observations of microbial and environmental chemistry

1. Minimize indoor emissions: particulate matter, SVOCs
2. Ventilate well
3. Protect against outdoor pollution

Particle-phase SVOCs enhanced during cooking





Wang et al. (2020) Sci Adv

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Webinar 2. What We Know and What We Should Know About Indoor Environmental Quality

Pawel Wargocki

Associate Professor

Technical University of Denmark

Brandon Boor

Associate Professor

Purdue University, USA

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

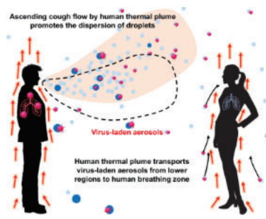
IAQ and its contribution to health and comfort became a significant topic of investigation 30 years ago. Topics of initial research included:

- Formaldehyde/Radon
- Sick building syndrome
- Volatile organic compounds
- Allergies
- Thermal comfort
- Bioaerosols

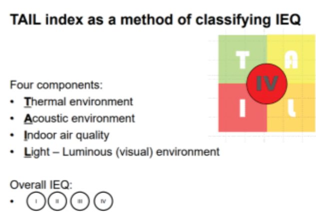
INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Areas of research to push the field forward:

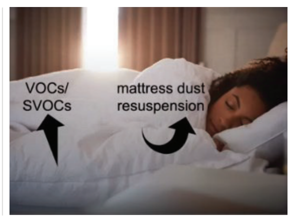
- Identification of new and potential pollutants (toxicity, transport, level)
  - Human bio-effluents
  - Nano-size particles
  - Persistent organic pollutants
- Building resilience to climate change, low carbon requirement, pandemic
- Establishment of the consensus indices or metric for IEQ
- Focus on sensitive population, e.g., the elderly and infants
- Sleep IAQ and its relationship with health



(Sun et al., 2021)



(Wargocki et al., 2021)



31

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Webinar 3. Dermal - the often-overlooked exposure route

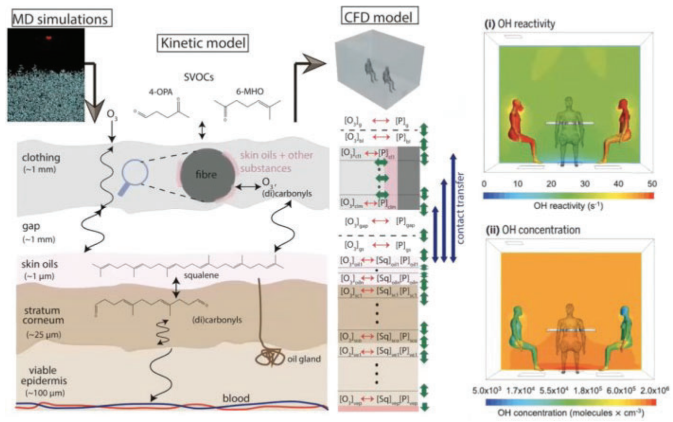
Charles Weschler
Adjunct Professor
Rutgers University, USA

Manabu Shiraiwa
Professor
University of California, Irvine, USA

32

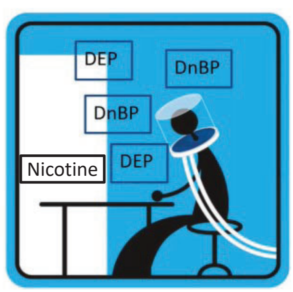
INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

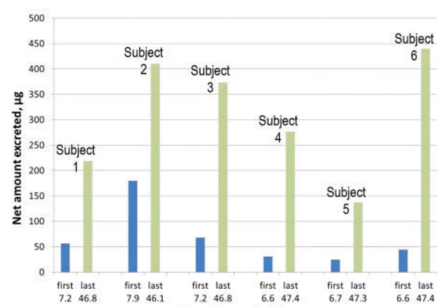
While traditionally ozone was thought to be the major oxidant indoors, recent studies have found that skin is a source of OH radicals indoors.



INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Experiments: dermal uptake from air

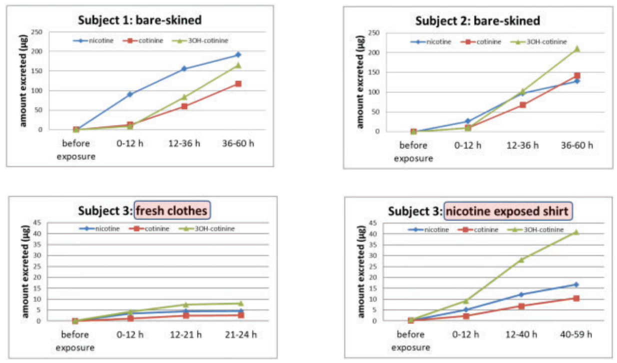




- Relatively large dermal uptake from air or clothing has been measured for DEP, DnBP, and nicotine etc.
- Skin is a reservoir – delivery continues after exposure ends

Weschler et al., 2015; Morrison et al., 2016

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE



- Modeling indicates that dermal uptake is substantial for some SVOCs (e.g., parabens, synthetic musks, chlorpyrifos, Texanol)
- Looking to the future, long-term measurements and big data sets are needed to connect indoor air pollutants to specific health effects

Bekö et al., 2017

35

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Webinar 4. Winter is coming: challenges for indoor air sciences in times of energy crisis, pandemics & climate change

Tunga Salthammer

Professor

Fraunhofer WKI, Germany

Wenjuan Wei

Research Scientist

Scientific and Technical Centre for Building, France

36

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Current challenges facing indoor air sciences include insufficient insulation, viral load in indoor environments, and the impact of climate change on indoor air quality and ventilation.

Potential solutions exist, such as mobile air cleaners, manual ventilation, and permanently installed fans to reduce risks of infection, heat, and pollutants. However, testing is needed to check for efficacy and safety from harmful byproducts.

Better communication channels are needed to share scientific results with the public.

37

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Webinar 5. From Research to Practice: Past Successes and Remaining Gaps

Nadia Boschi

Director

Sustainability Italy & Continental Europe Lendlease, Italy

James McGrath

Assistant Professor

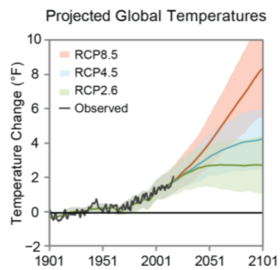
Maynooth University, Ireland

38

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Lifestyle trends of increasing urbanism, increasing population, aging demographics, increased stress, and a sedentary lifestyle all contribute to a considerable amount of time spent indoors.

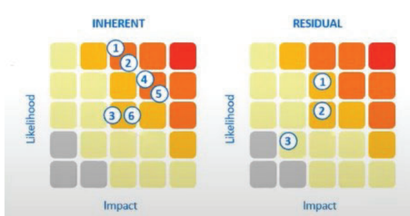
Sustainability and climate change must be considered as strategies to promote indoor air quality.

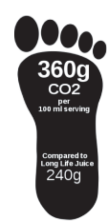


Ban tobacco smoke in apt/condo buildings (still allowed in some states)	Compartmentalization to prevent odor or unwanted air transfer (e.g stop garage air pollutants)
Local exhaust	Eliminate lead and mitigate asbestos and radon
Switch to 100% renewable energy supply (H/C/E)	Retrofit favoring the installation of controlled mechanicalventilation systems
Install windows with trickle air vents	Install CO2 monitor

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Communication of risks and opportunities is important – for example, a labeling system could allow consumers to assess health risks and make informed choices among building materials and consumer products used.





INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Webinar 6. The long history of airborne infection transmission: why don't we use the knowledge we have

Lidia Morawska

Professor

Queensland University of Technology, Australia

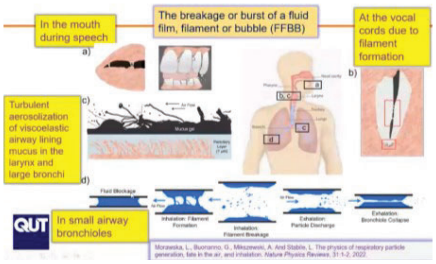
Kristen Coleman

Assistant Professor

University of Maryland School of Public Health, USA

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

We are a source of respiratory particles, which are small (the vast majority are <10 µm), light (can stay suspended in the air) and may contain viruses.



July 2020: It is time to address airborne transmission of COVID-19.

239 scientist from 34 countries

7 July 2020:
"The World Health Organization acknowledged "*evidence emerging*" of *the airborne spread of the novel coronavirus*, after a group of scientists urged the global body to update its guidance on how the respiratory disease asses between people.."

https://www.who.int/emergencies/diseases/novel-coronavirus-2019?gclid=Cj0KCQjwupD4BRD4ARIsABJMmZ8q1ZRt8YGVLpxFC C2XUZXthfPK0jsS9PI44_f2ClYOZ15JdAY5eDQaAiH5EALw_wcB

ISIAQ

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

The closing webinar of the series discussed the importance of ventilation, the use of mechanical manipulation and germicidal UV air disinfection, and the need for regulations and guidelines to ensure indoor air quality standards are met.

There is considerable work on health and the aerosolization of human and animal pathogens at the animal interface, which could potentially lead to the rapid spread of novel viruses being done, which should continue to inform developments moving forward.

ISIAQ

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

2024 Conference

18TH CONFERENCE OF THE INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY & CLIMATE

INDOOR AIR 2024

July 7-11, 2024 Honolulu, Hawaii, USA

INDOOR AIR 2024

INTERNATIONAL SOCIETY OF INDOOR AIR QUALITY AND CLIMATE

Thank you for your attention!

https://isiaq.org/

University of Nottingham
UK | CHINA | MALAYSIA

AIVC 2023

Smart Ventilation, IAQ, & Health

Benjamin Jones

1

University of Nottingham
UK | CHINA | MALAYSIA

Recent AIVC publications

ANNEX 5 EBC

AIVC Technical Note 72
Ventilation Requirements and Rationale behind. Standards and Regulations of dwellings, office rooms and classrooms

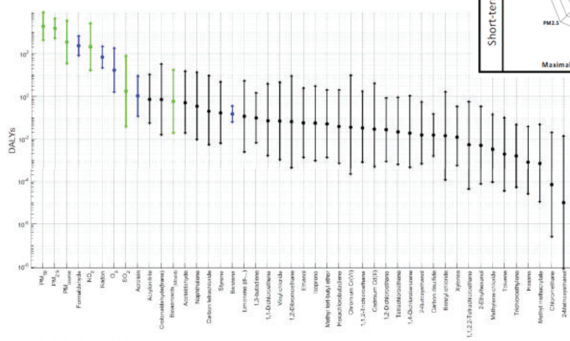
April 2023

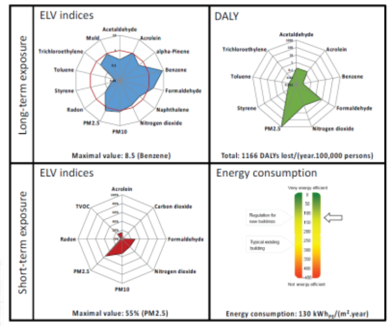
Main Authors
Willem de Gids, ventguide, Netherlands
Wouter Borsboom, TNO, Netherlands

2

University of Nottingham
UK | CHINA | MALAYSIA

IAQ and Health

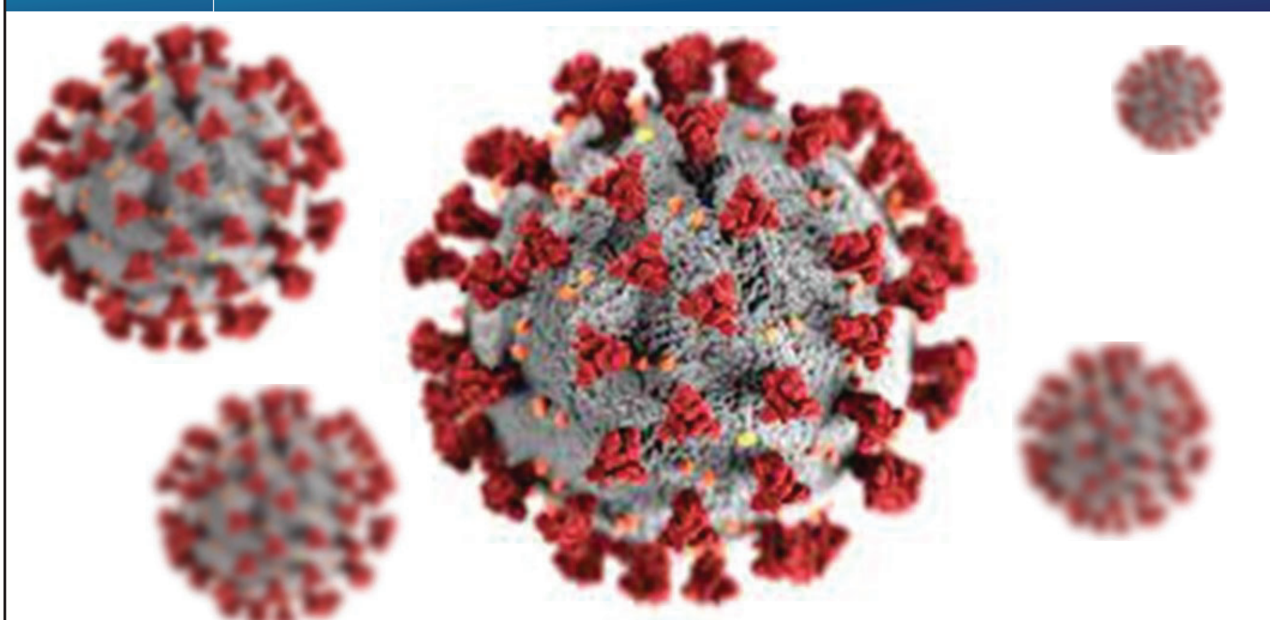




3

University of Nottingham
UK | CHINA | MALAYSIA

Disease Transmission



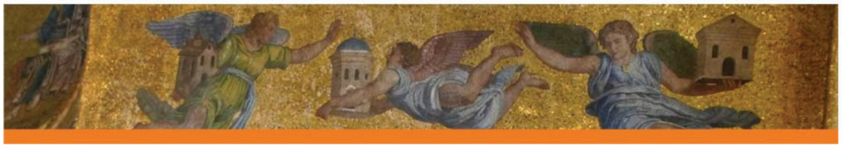
4

University of Nottingham
UK | CHINA | MALAYSIA

Annex 78 – Gas Phase Air Cleaners

IEA EBC HOME   LINKS   SEARCH   SITE MAP   EBC-LOGIN

EBC
Energy in Buildings and Communities Programme



HOME   ABOUT   SUBTASKS   PUBLICATIONS   PARTICIPANTS   NEWS   MEETINGS   MEMBER AREA

IEA EBC Annex 78 - Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications

The proposed Annex should bring researchers and industry together to investigate the possible energy benefits by using gas phase air cleaners (partial substitute for ventilation) and establish procedures for improving indoor air quality or reduced amount of ventilation by gas phase air cleaning. The project shall also establish a test method for air cleaners that considers the influence on the perceived air quality and substances in the indoor air.

ANNEX INFO & CONTACT

Status: Ongoing (2018 - 2023)

OPERATING AGENTS

Bjarne Olesen
Technical University of Denmark
Kongens Lyngby
DENMARK
Email

Dr. Pawel Wargocki
Technical University of Denmark
Kongens Lyngby
DENMARK
Email

5

6

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

SUMMARY OF AIRTIGHTNESS TRACKS

Valerie Leprince

October 5th, 2023

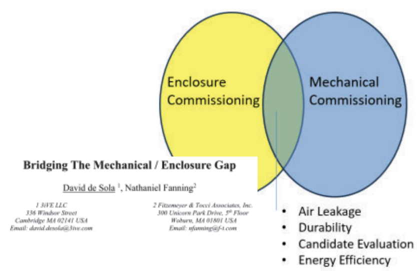
1

SUMMARY OF AIRTIGHTNESS TRACKS

- Airtightness, still a growing concern around the world
  - Yes airtightness matters!
  - New update on regulations and programs
- But how to evaluate it?
  - Blowerdoor test – benchmark solution but still a topic of research
  - New alternative methods
  - Predictive methods?

2

Airtightness, still a growing concern around the world



On the importance of airtightness…

Yes building and ductwork airtightness matters!

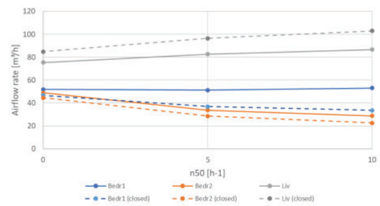
It impacts on:

- System sizing
- The quality of ventilation

Impact of the building airtightness and natural driving forces on the operation of an exhaust ventilation system in social housing in Chile.

Gilles Flamant*[1,2], Waldo Bustamante[1], Arnold Janssens[2], and Jelle Laverge[2]

Poor building airtightness induces under-ventilated bedroom with exhaust only systems!



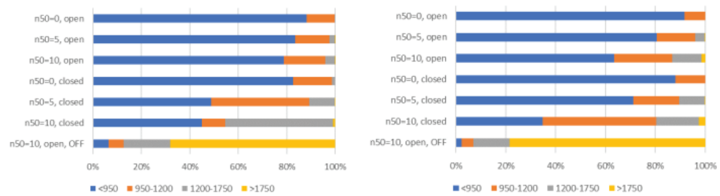


Figure 11: Percentage of time spent in four CO_2 concentration (ppm) classes for the father (left) and child_1 (right).

RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN

Financial impact of leaky ductwork in buildings – a calculation tool to raise awareness

Nolwenn Hurel[1*], Valérie Leprince[2] and Marcus Lightfoot[3]

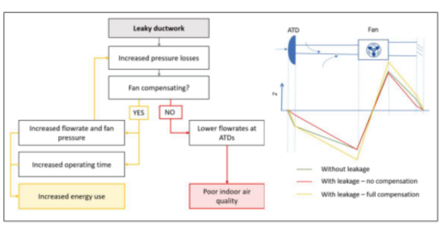


Figure 1- Impact of leaky ductwork

Simple calculation tool for building designers to evaluate the **impact of ductwork airtightness on fan energy use** for houses

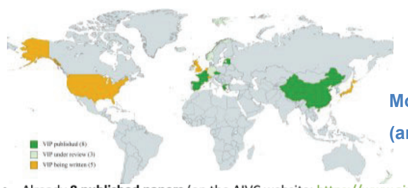
- If the fans fully compensate for leakage, the annual energy use **increase for a very leaky ductwork** (3A) compared to an airtight one ranges **between 58% and 173%** for the 4 single-family houses, and is of 33% for the school AHU.

Figure 2 - Calculation tool (for the case study of house 1)

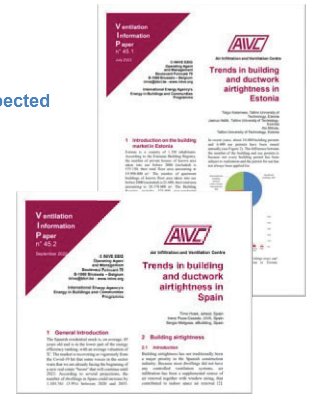
Table 4 - Annual and total (for 80 years of operation) cost of ductwork leakage according to the ductwork airtightness level for the 5 case studies

Airtight. classes		House 1		House 2		House 3		House 4		School (1 AHU)	
Prev.	New	Annual	Total	Annual	Total	Annual	Total	Annual	Total	Annual	Total
3A	-	126 €	10 117 €	73,5 €	5 881 €	415 €	33 199 €	50,4 €	4 035 €	922 €	73 772 €
2,5A	ATC 6	101 €	8 095 €	59,7 €	4 772 €	326 €	26 071 €	39,8 €	3 182 €	755 €	60 415 €
1,5A	-	55,9 €	4 469 €	33,9 €	2 713 €	173 €	13 834 €	21,3 €	1 706 €	437 €	34 999 €
A	ATC 5	35,7 €	2 855 €	22,0 €	1 760 €	108 €	8 655 €	13,4 €	1 073 €	287 €	22 924 €
B	ATC 4	11,2 €	898 €	7,1 €	565 €	33,1 €	2 645 €	4,1 €	331 €	93,3 €	7 463 €
C	ATC 3	3,7 €	294 €	2,3 €	186 €	10,7 €	856 €	1,3 €	107 €	30,8 €	2 468 €
D	ATC 2	1,22 €	97 €	0,77 €	62 €	3,53 €	282 €	0,44 €	36 €	10,26 €	820 €
-	ATC 1	0,40 €	32 €	0,26 €	21 €	1,17 €	94 €	0,15 €	12 €	3,41 €	273 €

RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN



More publications expected (around 16 countries)



- Already **8 published papers** (on the AIVC website: https://www.aivc.org/collection-keys/vip)
  - Estonia (VIP 45.1)
  - Spain (VIP 45.2)
  - Czech Republic (VIP 45.3)
  - Belgium (VIP 45.4)
  - Latvia (VIP 45.5)
  - France (VIP 45.6)
  - Greece (VIP 45.7)
  - China (VIP 45.8)

Update on regulations on airitightness

- **VIP Content**
  For both BUILDING and DUCTWORK airtightness, it details :
  - **national requirements and drivers**: airtightness indicator, requirements in the regulation, energy programs, airtightness justifications, sanctions, etc.;
  - if it is included in the **energy calculations** and how;
  - the **airtightness test protocol**: qualification for the testers, guidelines, requirements on measuring devices;
  - **tests performed**: tested buildings/ductworks, database, evolution with time;
  - **guidelines** to build airtight buildings/ductworks.

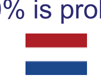
RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN

Summary of Airtightness tracks – AIVC 2023
Valérie Leprince

KEY REQUIREMENTS IN COUNTRIES

In Norway 

- "All new buildings shall be tested"
  - $n_{50} \leq 0.6$ /h for all dwellings
  - Less than 100% is probably measured in practice..

In Netherland 

- Measurement according NEN 2686 (that mostly follow EN ISO 9972)
- The Building Decree demands based on building volume
  - < 500 m^3 : qv10 = 0.2m3/s (200 l/s) as qv10 value
  - > 500 m^3 : qv10 kar = qv10 (500/Vb)

RÉPUBLIQUE FRANÇAISE Cerema CLIMAT & TERRITOIRES DE DEMAIN

Summary of Airtightness tracks – AIVC 2023
Valérie Leprince

8

KEY REQUIREMENTS IN COUNTRIES

In Spain

- Window permeability regulation since 1975
- For the envelope (only for dwellings >120m²)
  - n_{50}<6 (for V/A<=2) and n_{50}<3 for V/A>=4
- 2 options for justification: measurement or calculations

$$n_{50} = 0.629 \cdot \frac{C_0 \cdot A_0 + C_h \cdot A_h}{V}$$

In Latvia

- Mandatory airtightness requirements (in q_{50}) for all new buildings but no mandatory testing

In Montenegro

- Requirement
  - without mechanical ventilation ACH50=3 h−1
  - with mechanical ventilation ACH50=1.5 h−1
- No mandatory test
- Changing windows successfully divided by 9 the airtightness in a dwelling!!

How to evaluate airtightness?

Blowerdoor test according ISO 9972

Is it the perfect solution?

ISO 9972: FAN PRESURIZATION METHOD

- Describes measurement procedure and calculation methods for determining airtightness
- To obtain comparable and credible results, it needs to be
  - **Reliable** and valid for different kinds of buildings
  - **Reproducible** under challenging environmental conditions
  - **Applicable** in any conditions
  - **Consistent** with other standards
- Recent scientific works + more experience in field testing → **need to improve parts of ISO 9972!**

Poza-Casado et al. (2020)

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN ISO 9972

September 2015

ICS: 91.120.10

Supersedes EN 13829:2000

English Version

**Thermal performance of buildings —
Determination of air permeability of buildings —
Fan presurization method**
(ISO 9972:2015)

Performance thermique des bâtiments —
Détermination de la perméabilité à l'air des bâtiments —
Méthode de pressurisation par ventilateur
(ISO 9972:2015)

Wärmetechnisches Verhalten von Gebäuden —
Bestimmung der Luftdurchlässigkeit von Gebäuden —
Differenzdruckverfahren
(ISO 9972:2015)

REVISION OF ISO 9972

Mid-2023:
Proposition of new versions for issues ready to revise

End 2023:
Proposition of new versions with conducted research

From 2024:
Revision on ISO level

On 2023 September 28th
ISO TC163, SC1 Committee agreed to launch the revision of ISO 9972!

Resolution 347 (2/2023, Atlanta 2023-09-28)
ISO/TC 163/SC 1 agrees to create an Ad-Hoc group "Air tightness of buildings" to develop the preliminary work item ISO 9972, *Thermal performance of buildings — Determination of air permeability of buildings — Fan pressurization method*. Mr. Utsumi is appointed as the Ad-Hoc group leader.

P-members approving:	**12**
P-members disapproving:	**0**
P-members abstains:	**0**

The decision was *unanimous*

RÉPUBLIQUE FRANÇAISE
Cerema
CLIMAT & TERRITOIRES DE DEMAIN

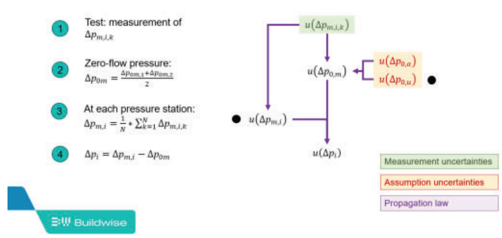
On the integration of envelope pressure inhomogeneity and autocorrelation in fan pressurization uncertainty analysis

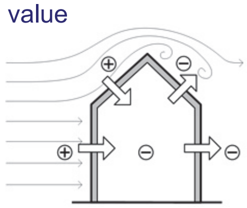
Martin Prignon[1]

Repeatability to test the **autocorelation**
- Neither fully correlated nor fully uncorrelated
- Needs to be taken into account for uncertainty calculation

Inhomogeneity
- Could be included as uncertainty term taking into account the maximum and the minimum value

Two novelties in the uncertainty estimation process





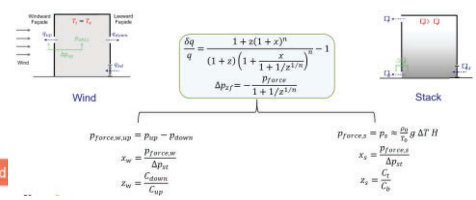
Objective: Having less uncertainty in the uncertainty calculation!

RÉPUBLIQUE FRANÇAISE
Cerema
CLIMAT & TERRITOIRES DE DEMAIN

FLOW ERROR ANALYSIS: ISO 9972 & ZERO-FLOW CONSTRAINTS

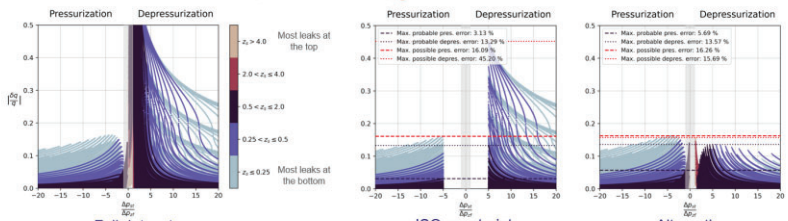
Benedikt Kölsch, Valérie Leprince, Adeline Mélois, Bassam Moujalled

UNDERSTANDING ZERO-FLOW PRESSURE



Alternative constraints to ISO 9972 ones exist to measure high-rise buildings!

Stack measurement position of Δp_0



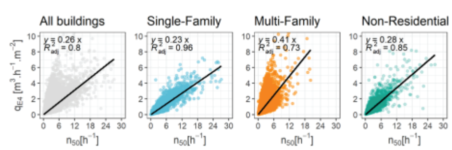
Full dataset | ISO constraints | Alternative

→ Fully pres/depres building with a margin of 10 Pa!

Statistical analysis of the correlations between buildings air permeability indicators

Bassam Moujalled[1,2*], Benedikt Kölsch[1,3], Adeline Mélois[1,2], Valérie Leprince[3]

Correlations between five indicators (**specific air leakage rates q_{E4} / q_{E10} / q_{E50} and air change rates n_{10} / n_{50}**) have been calculated



- Correlations between q_{E4} and n_{50} depending on building type and building compactness

Correlation	Building type	Correlation depending on building type and building compactness			Correlation depending on building type		General correlation	
		Compact.	Reg. coef.	Conf. Int. 95%	Reg. coef.	Conf. Int. 95%	Reg. coef.	Conf. Int. 95%
q_{E4} = Coef * n_{50}	Single-Family houses	(0.07,0.78]	0.264 (r^2=0.965)	[0.264,0.265]	0.228 (r^2=0.964)	[0.228,0.228]	0.26 (r^2=0.801)	[0.26,0.261]
		(0.78,0.83]	0.23 (r^2=0.983)	[0.23,0.231]				
		(0.83,0.88]	0.219 (r^2=0.984)	[0.218,0.219]				
		(0.88,2]	0.2 (r^2=0.977)	[0.2,0.2]				
	Multi-Family apartments	(0.02,0.29]	0.91 (r^2=0.929)	[0.906,0.914]	0.409 (r^2=0.728)	[0.407,0.41]		
		(0.29,0.46]	0.517 (r^2=0.958)	[0.516,0.519]				
		(0.46,0.70]	0.33 (r^2=0.966)	[0.329,0.331]				
		(0.70,1.94]	0.237 (r^2=0.964)	[0.236,0.238]				
	Non-Residential buildings	(0.08,0.64]	0.418 (r^2=0.9)	[0.412,0.423]	0.284 (r^2=0.851)	[0.282,0.287]		
		(0.64,0.78]	0.276 (r^2=0.971)	[0.274,0.278]				
		(0.78,0.85]	0.233 (r^2=0.973)	[0.231,0.234]				
		(0.85,6.52]	0.192 (r^2=0.936)	[0.19,0.194]				

Correlation analysis between ACH50 and Air permeability considering the floor area of a residential buildings

Su-Ji Choi[1], and Jae-Hun Jo[*2]

Classification of dwellings into 3 categories (Small, Medium and Large)

The average s/v ratio for small is 1.11, medium is 1.05, and large is 1.02, with ratios closer to 1 as the floor area increases

- More reasonable to evaluate the airtightness by air permeability (q_{E50}),
  - smoother change in airtightness value
  - consider the effect of leakage rate through the envelope

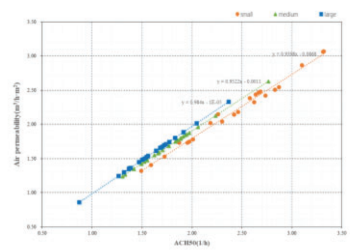


Figure 6: Correlation of ACH50 and air permeability

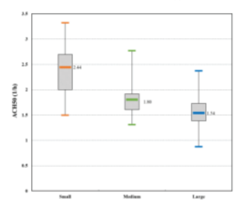


Figure 3: ACH50 by floor area

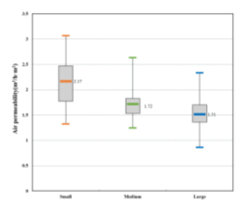


Figure 4: Air permeability by floor area

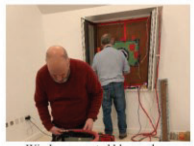
Alternative methods

Are they reliable and implementable on site?

Pulse tests in highly airtight Passivhaus standard buildings

Xiaofeng Zheng*[1], Luke Smith[2], and Christopher Wood[1]

Complete 40L Pulse setup



Window mounted blower door

New setup adapted to very tight building: smaller tank to avoid saturation and leave a sufficient decay period

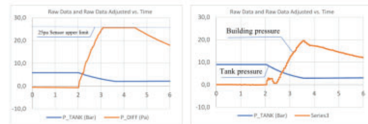


Figure 2: Example of unsuccessful pulse tests in highly airtight dwellings

On 11passive houses results in line with BLD test

- Average difference between the 2 methods
  - 0.0003m3/h/m²@4Pa (11%)
  - 0.12 @50Pa

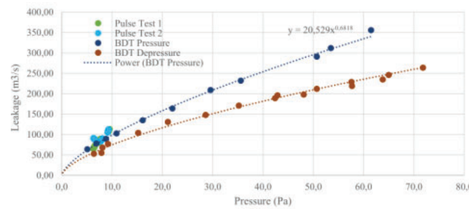


Figure 6: Property 004 blower door fan test power law extrapolation, with poor agreement between the pressurisation and depressurisation curves

Acoustic method for measurement of airtightness – field testing on three different existing office buildings in Germany

Björn Schiricke*[1], Benedikt Kölsch[2]

Figure 2: Measurement setup: pair of loudspeakers inside (left), microphone array or acoustic camera outside (centre), visualization of the loudest noise sources on the facade (right).

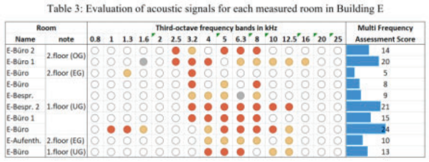
Do not necessitate large volumes of air movement through the building envelope,

- Test under naturally occurring unpressurized conditions.

Do not rely on closed volume

- Test during the construction or renovation

Table 3: Evaluation of acoustic signals for each measured room in Building E



Quantification of leakage

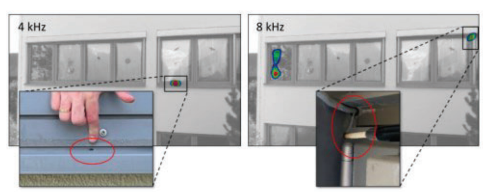


Figure 4: Examples of confirmed plausibility for air leakage as cause for sound peaks in room 106 (building D, east facade)

Predictive methods

Is it really possible to predict airtighness?

Airtightness predictive model from measured data of residential buildings in Spain

Irene Poza-Casado*[1], Pilar Rodríguez-del-Tío[2], Miguel Fernández-Temprano[2], Miguel Ángel Padilla-Marcos[1], and Alberto Meiss[1]

In Spain, maximum envelope permeability values but 2 solutions to justify it

- pressurization tests (rarely done)
- Use of reference values … which were proved to be inaccurate

The predictive model developed

- explains 42.9% of the variability of the response
- contain 12 main effects and 2 interactions.

➢ Not to replace airtightness test

➢ But useful for decision-making process before building construction or retrofitting actions

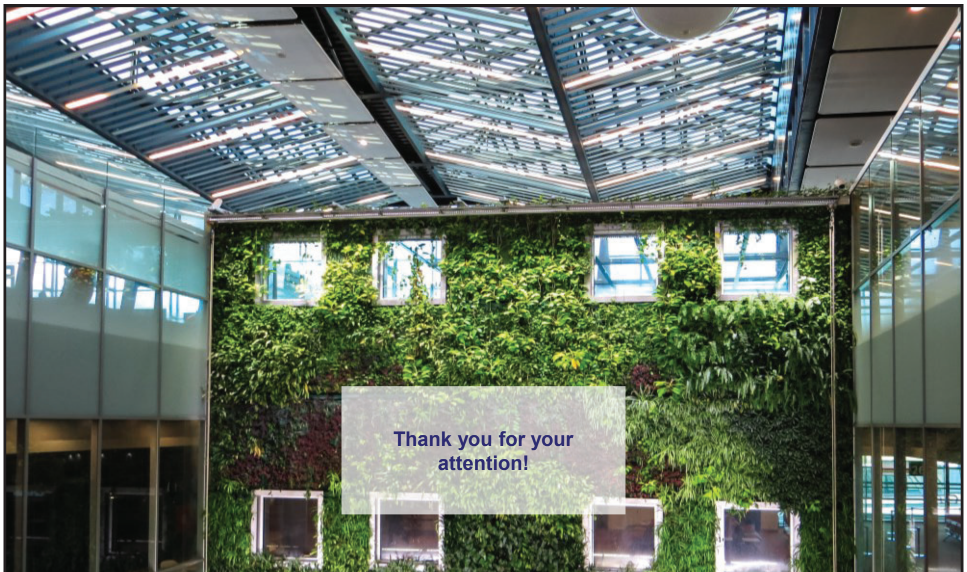
Table 5: Equation of the final GLM predictive model for airtightness.

Parameter	Coefficient	Parameter	Coefficient
Intercept	0.273	Shutter position. P04	0a
Retrofitting state. Original	0.137**	False ceiling. FC0	-0.313***
Retrofitting state. Retrofitted	0a	False ceiling. FC1	-0.264***
Climate zone. A3	0.346**	False ceiling. FC2	0a
Climate zone. B4	0.545***	Typology. Multifamily	0.412**
Climate zone. C1	0.273	Typology. Single-family	0a
Climate zone. C2	0.630***	Heating system. No heating	0.074
Climate zone. C3	0.053	Heating system. Underfloor heating	-0.041
Climate zone. D2	0.575***	Heating system. Ducts	0.261***
Climate zone. α3	0a	Heating system. Other systems	0.173
Period of construction. Before 1980	-0.329***	Heating system. Heating units	0a
Period of construction. Since 1980	0a	Number of bathrooms. 0	0.610**
Window permeability. Class 0 or 1	0.596***	Number of bathrooms. 1	0.347***
Window permeability. Class 2	0.322***	Number of bathrooms. 2	0.183
Window permeability. Class 3	0.255***	Number of bathrooms. 3	0.090
Window permeability. Class 4	0a	Number of bathrooms. 4 or 5	0a
Window material. Steel	0.071	Share of windows	0.045***
Window material. Aluminium	0.074	Share of opaque envelope	0.003
Window material. Wood	0.298***	Period of construction. Before 1980 * Share of opaque envelope	0.010***
Window material. PVC	0a	Period of construction. After 1980 * Share of opaque envelope	0a
Shutter position. P01	0.195*	Typology. Multifamily * Share of opaque envelope	-0.009**
Shutter position. P02	0.144**	Typology. Single-family * Share of opaque envelope	0a
Shutter position. P03	-0.123		

a. This parameter is set to 0 as it corresponds to the reference class of the variable.
* stands for p-value ≤ 0.1, ** for p-value ≤ 0.05 and *** for p-value ≤ 0.01

$$Y = \beta_0 + \sum_{i=1}^{p} \beta_i X_i + \sum_{i<j} \tau_{ij}(X_i X_j) + \varepsilon$$

where: Y is the response variable to be predicted, X_i with i=1,…,p are the explanatory variables, β_i are the main effects of the explanatory variables on the response, τ_{ij} are the first-order interactions among variables X_i and X_j, and ε are the random independent homoscedastic normal perturbations. For the qualitative explanatory variables, the usual decomposition in dummy indicator variables has been considered.


Thank you for your
attention!

Summing up
Resilient ventilative cooling

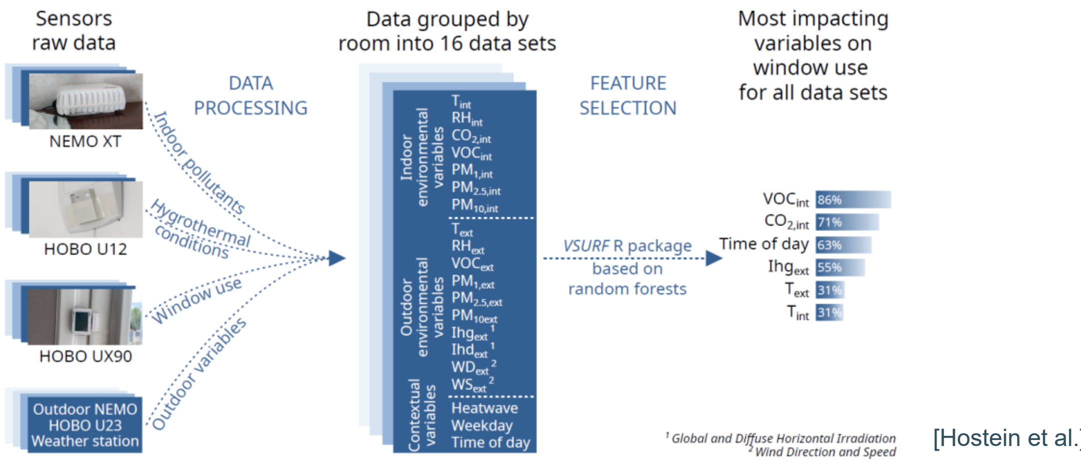
Hilde Breesch
(KU Leuven, venticool)

Overview resilient ventilative cooling track

October 4th	October 5th
1C: Topical Session: Summer comfort and energy efficiency in hot periods: interest of mixed mode cooling and need of occupant feedback	5C: Topical Session: Importance of good resilient building design and standards to ensure good ventilative cooling performance to reduce overheating and environmental impact
2C: Climate change & Resilient cooling	6C: Ventilative cooling & Natural Ventilation
3C: Topical Session: Resilient Cooling of Buildings meets Resilient Cooling in Cities	7C: Topical session: Personalized Environmental Control Systems (PECS) operation and evaluation
4B: Ventilation strategies & thermal comfort	

Window opening behaviour

- Window use drivers
  - [Hostein et al.], [Tookey et al.], [Berger et al.]

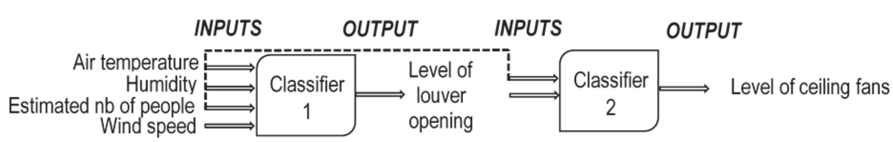


[Hostein et al.]

3

Window opening behaviour

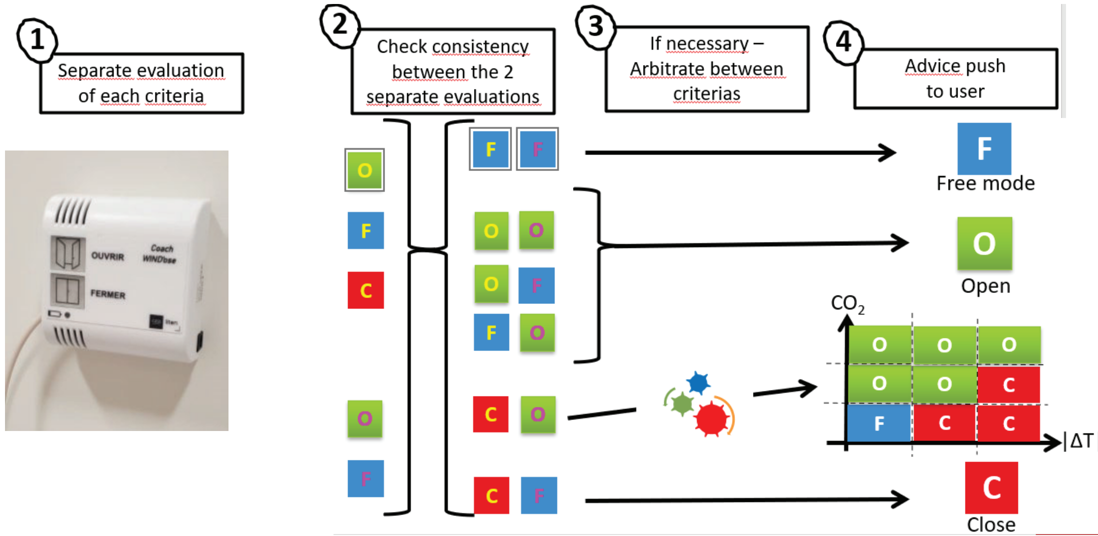
- [Payet et al.] Decission tree & Random forest model: windows and ceiling fans occupant behaviour



4

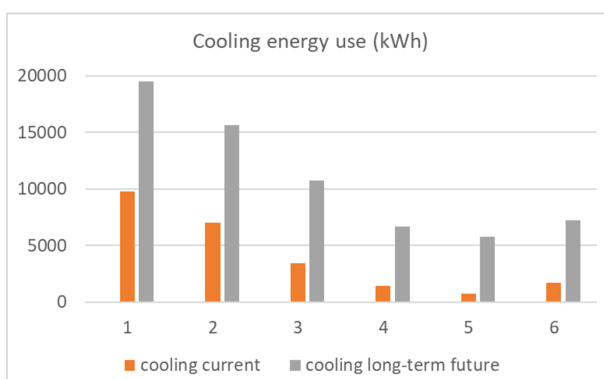
Window opening behaviour

- [Jay et al.] Prototype coach to help occupants opening/closing windows



Assessment: use of future weather data

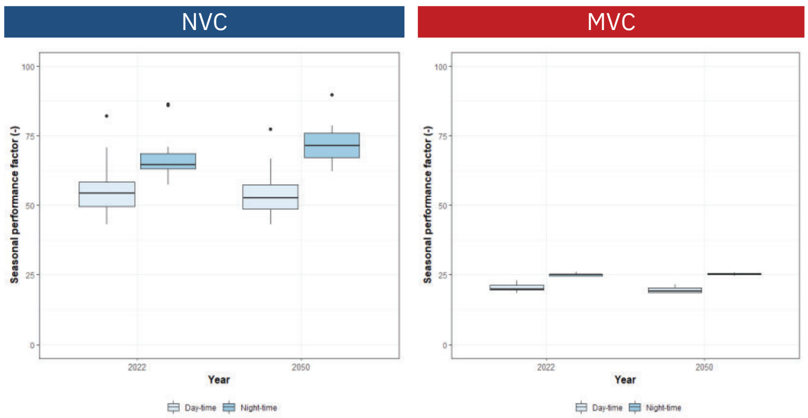
- Resilience [Sengupta et al.], [Khosravi et al.]
- Thermal comfort [Sengupta et al.], [Kolokotroni et al.], [Khosravi et al.]
- Energy use/demand [Kolokotroni et al.], [Khosravi et al.], [Romero-Lara et al.] [O'Donovan et al.]



[Khosravi et al.]

Assessment: use of future weather data

- SPF natural & mechanical ventilative cooling [O'Donovan et al.]

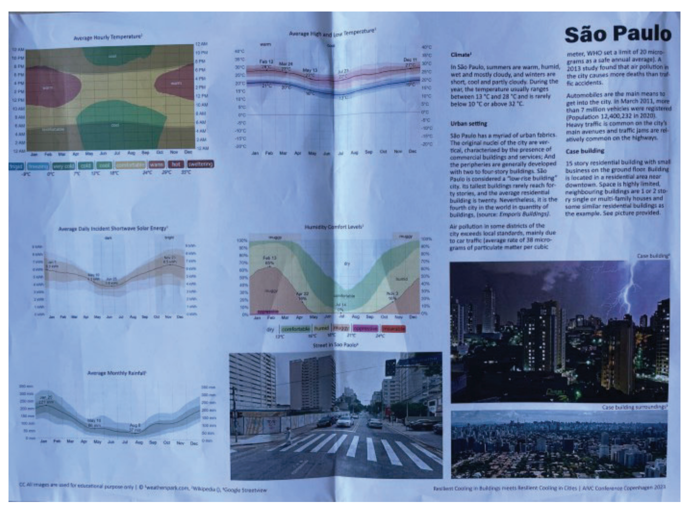


7

7

Design resilient cooling/ventilative cooling

- Resilient cooling design exercise
  - Climates
    - Sao Paulo
    - Los Angeles
    - Abu Dhabi
  - Measures
    - Building envelope
    - Interior & operation
    - Surroundings
    - Other: technical political, societal



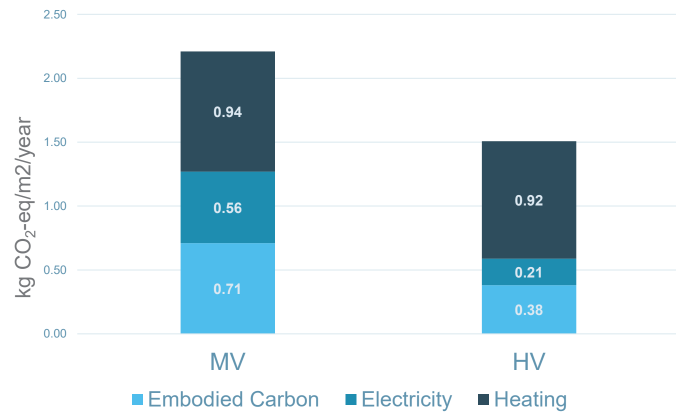
[Czarnecki et al.]

8

8

Design resilient cooling/ventilative cooling

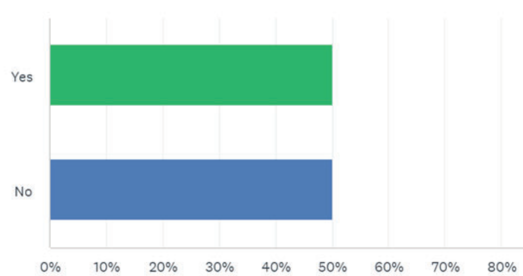
- LCA
  - [Roth] example office building comparing CO_2-eq mechanical <> hybrid ventilative cooling



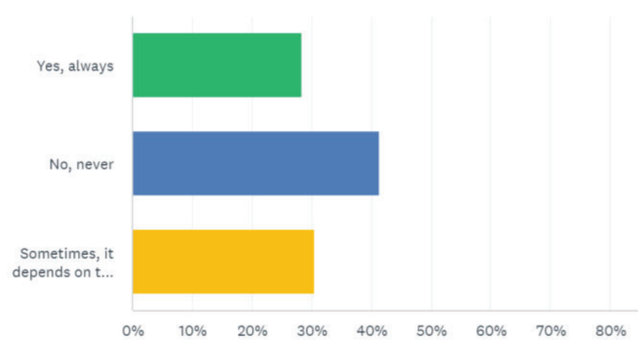
9

Design resilient cooling/ventilative cooling

- Design practice: survey design practitioners UK&IE [Sohail et al.]
  - Are you familiar with term "ventilative cooling"?



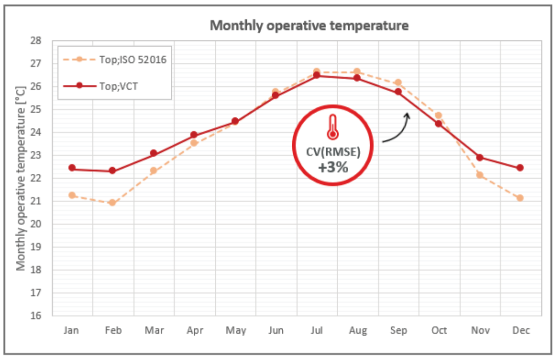
  - Do you use tools ventilative cooling design?

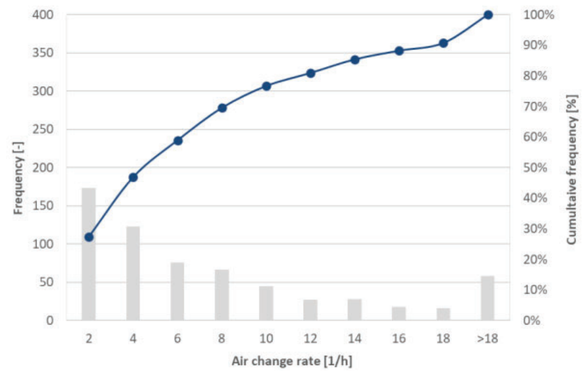


10

Design resilient cooling/ventilative cooling

- Update early-stage design tool ventilative cooling [Radice Fossati, et al.]
  - Validated BESTEST heavyweight — output: required ACH (Denver)

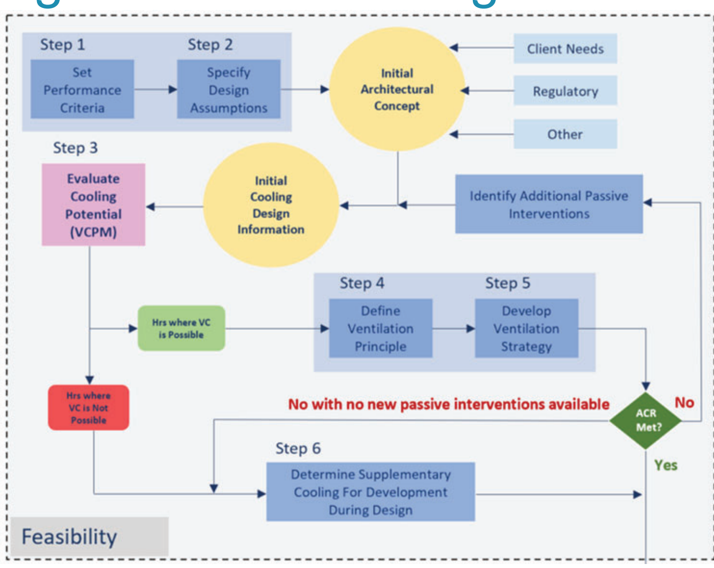




11

Design resilient cooling/ventilative cooling

- new CEN VC technical specifation: framework (reasonably) easy assessment feasibility VC designs [Plessner], [O'Sullivan]



12

[O'Sullivan]

Best paper/poster award &
Student Competition awards

1

Best paper award nominations

JURY
Hilde Breesch – KU Leuven
Benjamin Jones – University of Nottingham
Valérie Leprince – Cerema
Iain Walker – LBNL

1. **Impact and benefits of the air cleaning measures implemented in two schools**
   - Authors: *Liang Grace Zhou, Chang Shu, Justin Berquist, Janet Gaskin, and Greg Nilsson – NRC, Canada*
2. **Can naturally ventilated office buildings cope with dusty outdoor air?**
   - Authors: *Evangelos Belias – EPFL, Switzerland, Flourentzos Flourentzou – ESTIA SA, Switzerland, Dusan Licina – EPFL, Switzerland*
3. **Airtightness predictive model from measured data of residential buildings in Spain**
   - Authors: *Irene Poza-Casado, Pilar Rodríguez-del-Tío, Miguel Fernández-Temprano, Miguel Ángel Padilla-Marcos & Alberto Meiss – Universidad de Valladolid*

2

Best paper award

Can naturally ventilated office buildings cope with dusty outdoor air?

Authors: *Evangelos Belias – EPFL, Switzerland, Flourentzos Flourentzou – ESTIA SA, Switzerland, Dusan Licina – EPFL, Switzerland*

Can naturally ventilated office buildings cope with dusty outdoor air?

Evangelos Belias*[1], Flourentzos Flourentzou[2], Dusan Licina[1]

1 Human-Oriented Built Environment Lab, School of Architecture, Civil and Environmental Engineering, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

2 ESTIA SA, EPFL innovation Park, 1015 Lausanne, Switzerland

**Corresponding author: evangelos.belias@epfl.ch*

ABSTRACT

Naturally ventilated (NV) buildings, when well designed and operated, can provide adequate indoor environmental quality (IEQ) while reducing the building energy demand. However, in dusty outdoor air, this ventilation technique may increase the penetration of outdoor particulate matter (PM) indoors, leading to adverse health effects. Given the increasing frequency of outdoor dust episodes in Mediterranean climates, an important research question is whether NV buildings can provide adequate indoor air quality (IAQ) during increased outdoor air dust episodes. We monitored indoor and outdoor concentrations of size-resolved PM for six months in an occupant-operated NV low-energy office building in Cyprus, an island with frequent episodes of airborne dust. In parallel, the building was monitored for its energy consumption, indoor air temperatures, relative humidity, and CO_2 concentrations. We also interviewed the building occupants regarding their perceived IEQ conditions. The results revealed that the NV provided adequate IAQ conditions in 4 out of 5 investigated indoor spaces for $PM_{2.5}$ and in 2 out of 5 investigated spaces for PM_{10}. The average indoor concentrations were in the range of 4.4-5.1 $\mu g/m^3$ for $PM_{2.5}$ and 13.8-19.9 $\mu g/m^3$ for PM_{10}, while the average outdoor concentrations for the same period were 7.4 $\mu g/m^3$ for $PM_{2.5}$ and 38.1 $\mu g/m^3$ for PM_{10}. Additionally, unlike the outdoor air, the indoor PM concentrations respected the WHO short-term 24-hour limits, indicating that the building addressed well the dusty days. In terms of other IEQ parameters, the CO_2 levels remained below 1000 ppm for more than 90% of the time, while more than 90% of the occupants were satisfied with the thermal comfort conditions. The final actual energy consumption was ~164 kWh/m^2/yr, drifting only by 7% from the predicted energy use. The results of this case study indicated that well-designed low-energy NV office buildings can provide adequate IEQ conditions, even in outdoor environments with dusty air.

KEYWORDS

passive technologies, office buildings, pollution penetration, I/O ratio, climate change

1 INTRODUCTION

Energy-efficient buildings are necessary to limit the energy demand and reduce greenhouse gas emissions globally. Natural ventilation (NV), when adequately designed and operated, can contribute to reducing the operational and grey energy demand in buildings while, in parallel, improving thermal comfort and indoor air quality (IAQ) (Flourentzou et al., 2017). Nevertheless, several studies criticize naturally ventilated buildings for not providing adequate protection to their occupants concerning outdoor air pollution, as the higher ventilation rates

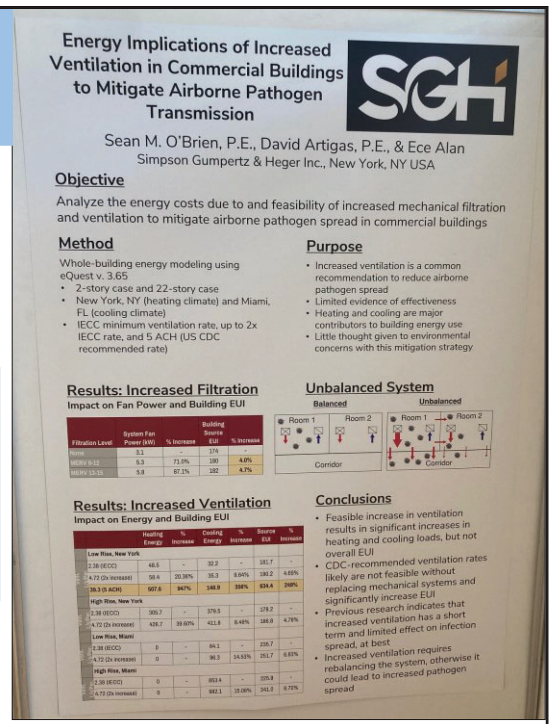
3

Best poster award

JURY

Jaap Hogeling – REHVA

Max Sherman– Nottingham University



Energy implications of increased ventilation in commercial buildings to mitigate airborne pathogen transmission

Authors: *Sean M. O'Brien, David Artigas, Ece Alan – Simpson Gumpertz & Heger Inc., New York, USA*

4

Student Competition award

JURY

Alireza Afshari – Aalborg University

Maria Kolokotroni – Brunel University

Method for Evaluating an Air-Conditioning System with Na tural Ventilation by Coupled Analysis of a Building Energy Simulation Tool and Computational Fluid Dynamics

Authors: *Ryuichi Yasunaga & Yasuyuki Shiraishi – The University of Kitakyushu, Japan*

Long-term energy performance of dew-point indirect evaporative cooler under the climate change world scenario

Authors: *María Jesús Romero-Lara, Francisco Comino & Manuel Ruiz de Adana – University of Cordoba, Spain*

Method for Evaluating an Air-Conditioning System with Natural Ventilation by Coupled Analysis of a Building Energy Simulation Tool and Computational Fluid Dynamics

Ryuichi Yasunaga[1], Yasuyuki Shiraishi[1]

ABSTRACT

KEYWORDS

1 INTRODUCTION

Long-term energy performance of dew-point indirect evaporative cooler under the climate change world scenario

ABSTRACT

KEYWORDS

1 INTRODUCTION

TightVent Europe – BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM | AIVC | venticool – the platform for resilient ventilative cooling | INIVE

1

'One hundred thousand welcomes'

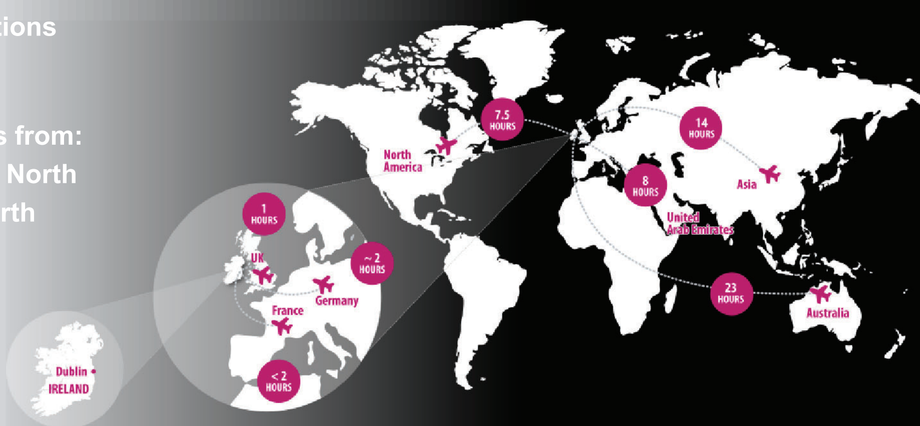
2

Welcome to Dublin and Ireland

- Considered one of the Friendliest Countries to visit
- 1000-year old city
- City of culture and history
- Dublin Airport only 12km / 20 mins from city centre

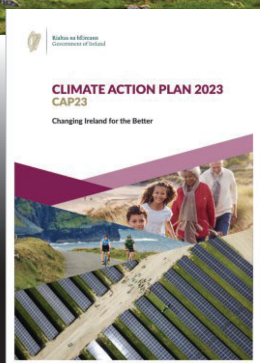
Access

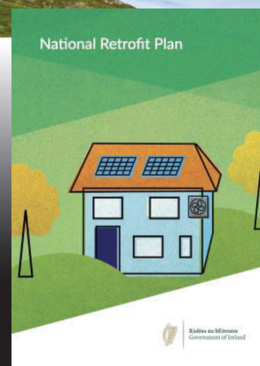
- 170 Destinations
- 55 airlines
- Direct flights from: GB, Europe, North America, North Africa, UAE



Sectoral Strengths

Maynooth University
National University of Ireland Maynooth





Ollscoil na Gaillimhe
University of Galway

MTU
Ollscoil Teicneolaíochta na Mumhan
Munster Technological University

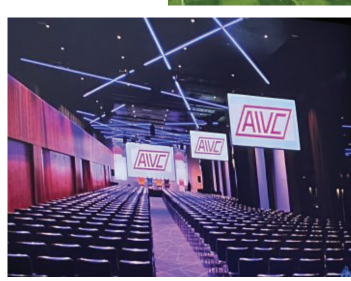
UCD
DUBLIN

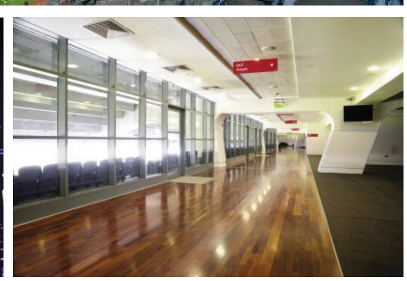
Construct Innovate
Built Environment Research Ireland

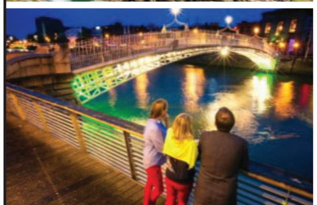
Croke Park Stadium

- A long history and tradition
- Third-largest stadium in Europe
- First stadium certified to the new ISO14001
- 50 Mile Menu
- 15-minute walk to city centre

GAA
WHERE WE ALL BELONG





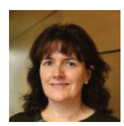


Europe's Largest City Park

AIVC 2024

- Scientific Programme

James McGrath
Maynooth
University



Marie Coggins
University of
Galway

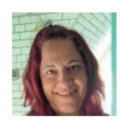
Simon Jones
Air Quality
Matters

Brain McIntyre
SEAI

Arnold Janssens
Ghent University
/ INIVE

Maria Kapsalaki
INIVE

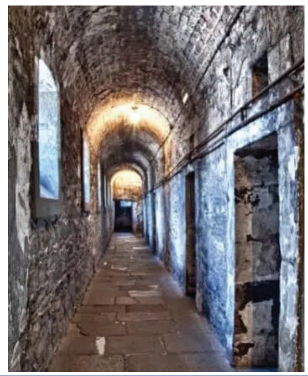
Peter Wouters
BBRI / INIVE



Georgia
Kateriniou
CONVIN

AIVC 2024

- Scientific Programme
- Culture Experience



AIVC 2024

- Scientific Programme
- Culture Experience
- A REAL pint of Guinness

AIVC 2024

- Scientific Programme
- Culture Experience
- A REAL pint of Guinness
- The 'Craic'

11

Feicfidh mé thú i mBaile Átha Cliath

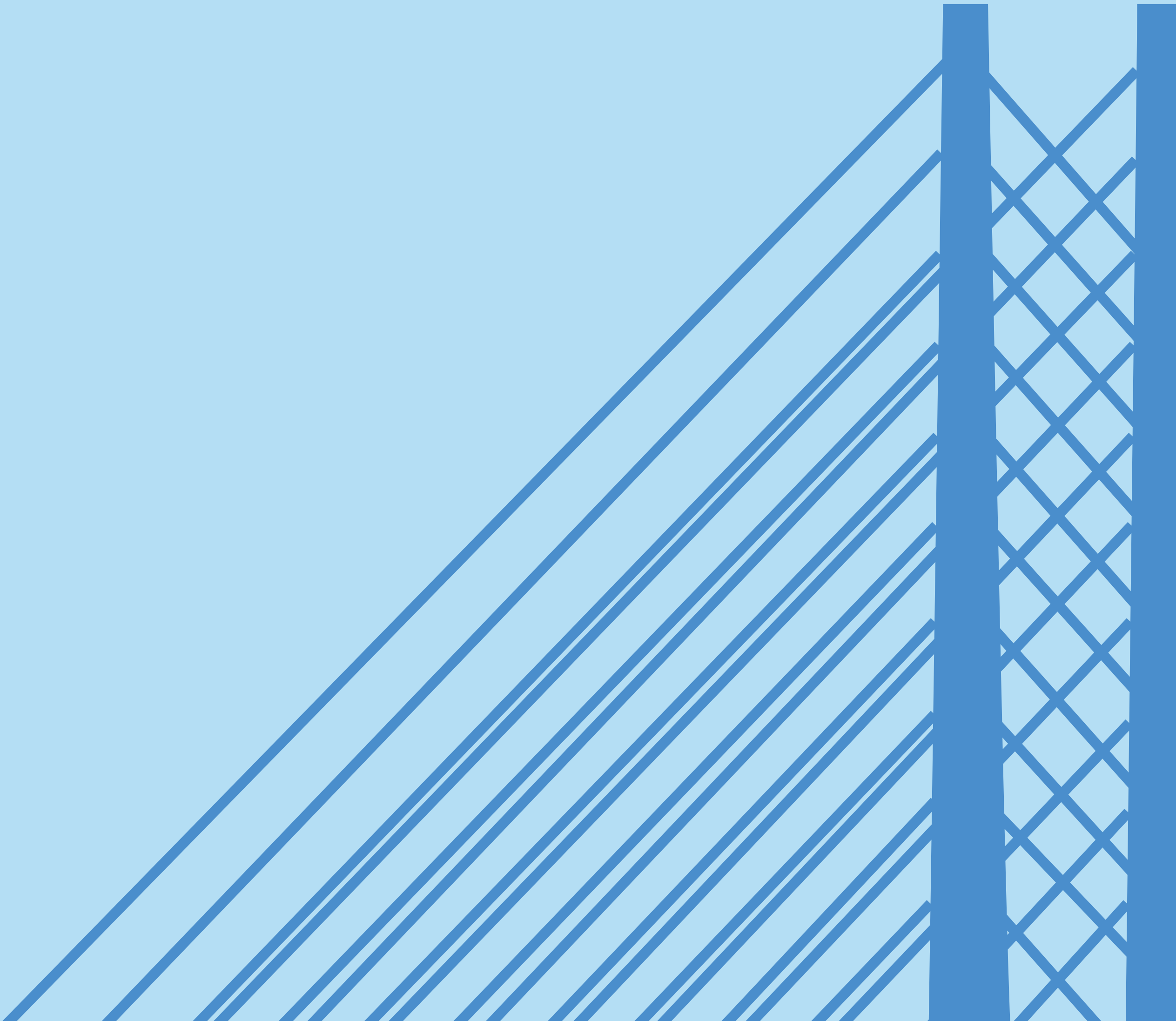
(See you in Dublin!)

12

43rd AIVC
11th TightVent & 9th venticool Conference

Ventilation, IEQ and health in sustainable buildings

October 4-5, 2023
Copenhagen
Denmark



Professional Congress Organizer

convin

CONVIN S.A.

Website: www.convin.gr
T: +30 210 6833600

Mrs Georgia Kateriniou
Email: secretariat@aivc2022conference.org