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IEA EBC Annex 68—Ambitions and Achievements in Hindsight

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ABSTRACT

The overall objective of the IEA EBC Annex 68" Project, "Indoor Air Quality Design and Control in Low Energy Residential Buildings", has been to develop the fundamental basis for optimal design and control strategies for good Indoor Air Quality (IAQ) in highly energy efficient residential buildings, and to disseminate this information for use in practoce. The project was defined in 2015, the working phase lasted for the years 2016-19, and the project was concluded with publications on 2020. The project has engaged researchers from 21 companies and institutions from 15 countries.

The work has gathered laboratory and field data and developed new knowledge on pollution sources in buildings and how the transport mechanisms for the pollutants interact with heat, air and moisture conditions in materials and indoor zones. Furthermore, the project has assembled a set of contemporary models to simulate the combined heat, air, moisture and pollution conditions of buildings and their assemblies. In addition, a set of so-called "common exercises" about the various subjects have been developed and tested. The purpose has been to identify and describe amenable ways to optimize the provision of ventilation and air-conditioning and to assess possibilities to bring this knowledge into practice.

The paper will review the original intentions of the project against the final achievements with the purpose to focus on which elements have been successfully achieved, and to identify areas where the project has only opened research and applications that should be followed up.

INTRODUCTION - CONTEXT OF THE PROJECT

IEA EBC Annex 68 "Indoor Air Quality Design and Control in Low Energy Residential Buildings" has been an international research project that was established under the International Energy Agency's (IEA) Building and Communites programme (EBC).

The reason for the implementation of this Annex project stems from the fact that in the future buildings will have to be optimized to get as close as possible to zero net energy consumption. This means that ventilation in particular will also be reduced to the bare minimum, while indoor air quality should not be sacrificed. It is therefore necessary to adopt and demonstrate an integral vision of optimization in ventilation management that takes into account elements such as sources, sinks and transport of relevant pollutants present in buildings, including the emissions of volatile organic compounds from construction.

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The objectives of Annex 68 have been to:

- Develop guidelines for design and control strategies of low-energy buildings with high IAQ by optimizing operational parameters with regards to ventilation, heating and humidity, and their optimal combination.
- Set performance indicators, that combine the aspiration of high energy performance with optimal IAQ.
- Determine or perfect tools to help designers and managers in achieving the first objective.
- Benefit from advances in sensor and control technology to improve IAQ at minimum energy use for operation.
- Provide data on indoor pollutants and their properties with respect to temperature, humidity and air flow.
- Identify and analyze relevant case studies where the performances mentioned above can be examined.

METHODOLOGY

Structure of Annex 68

Figure 1 presents the 5 subtasks of Annex 68 whose objectives are briefly described in the following paragraphs.



Figure 1 Schematic overview of the subtasks and their interrelations.

Subtask 1: Defining the metrics. A major obstacle to the integration of energy and IAQ strategies in the design and optimization of buildings has been the absence of an index that would quantitatively describe IAQ and allow comparison with an indicator for energy consumption. This subtask has had the pupose to develop such an index that could be considered in design and operation of buildings.

Subtask 2: Pollutant loads in residential buildings. One of the barriers to integrating energy and IAQ strategies has been the lack of reliable methods and data to estimate the pollution load in residential buildings in the same way as heating and cooling loads are regularly estimated. This subtask has collected existing data and developed new data and correlations on the transport, retention and emission properties of volatiiel organic compunds in new and recycled materials under the influence of heat, air flow and humidity conditions. Material and envelope scale laboratory tests have been carried out and results were collected and analyzed from emission tests of volatile organic compounds under various conditions of temperature, humidity and airflow, since such data have generally been non-existing in the context of combined exposures. So-called common exercises were set up for a a procedure to defining local reference buildings for IAQ analysis and for developing a database of VOC model parameters to be used in IAQ simulations.

Subtask 3: Modelling – review, gap analysis and categorization. Many models have been developed in the past in the area of dynamic thermal simulation of buildings for designing thermal indoor environment and energy use. However, knowledge has been insufficient to predict the combined effects of hygrothermal conditions and chemical reactions on species and indoor pollution concentrations. This subtask developed an approach for combined heat, air, moisture and pollutant simulation (CHAMPS) and its impact on energy use and IAQ. Subtask 3 has made review, gap analysis and classification of existing models and standards to build upon. This has involved collection and development of validated reference cases for entire buildings to predict their hygrothermal conditions, absorption and transport of moisture and chemicals, and energy use taking into account the indoor air, building envelope, occupants and building

services systems. A common exercise of Subtask 3 was to systematically verify and validate the models from simplified to more realistic cases, and to identify the limitations of existing models and specific areas for further development.

Subtask 4: Strategies for design and control of buildings. This subtask built upon findings from the previous subtasks and field studies of Subtask 5 combined with state-of-the-art knowledge from literature and from stakeholders such as building designers, faculit managers, manufacturers, housing developers and authorities. The purpose was to give guidance and disseminate on strategies and experiences regarding novel design and control strategies that can be applied in practice to advance high IAQ in residential buildings. The use of models and databases developed in the project allowed new paradigms for local and multi-scale management of air and energy quality, including ventilation, to be described. The subtask has also recent advances in sensor technology into asccount to find ways to optimize IAQ without compromising energy efficiency.

Subtask 5: Field measurements and case studies. Subtask 5 was to collect relevant case studies among the participating institutions. Several sites and climates have been dealt with, and in-situ tests have included buildings declared to be low energy consuming or recently renovated. The field trials focused on testing in practice and demonstrating low-energy operational strategies that can be used to create healthy indoor environments. Furthermore, a review of measuring technology for use in the filed was carried out.

MAIN RESULTS

Subtask 1: Defining the Metrics

Figure 2 is a graphical summary presenting the main points addressed during this first subtask, namely: Do residential buildings with low energy consumption have a poorer IAQ? What are the target pollutants to follow to assess IAQ in low energy consuming residential buildings? How to quantify the level of IAQ? Can we combine the IAQ and energy indicators into a single indicator?

Figure 2 also presents the IAQ / Energy dashboard proposed by the working group. Three IAQ indices were proposed in the project. The first index is the IAQ-STEL index (Short-Term Exposure Limit) and represents the risks associated with short-term exposure to pollutants. Its calculation is based on the Exposure Limit Values (ELVs) for short-term exposure and gives the frequency that the pollutant concentration is exceeded over a longer calculation period (days, weeks, or a year). Regarding the risks associated with long-term exposure to pollutants, two indices are considered: the IAQ-LTEL index (Long-Term Exposure Limit) is calculated as the ratio of the pollutant concentration over the ELV for long-term exposure, and the IAQ-DALY index (Disability Adjusted Life Years) is calculated using DALYs. The highest values separately for IAQ-STEL and IAQ-LTEL indices are selected to form multipollutant indices. IAQ-DALY is derived by calculating DALYs for all pollutants and summing them up. The IAQ-STEL and IAQ-LTEL



Figure 2 Graphical summary of the Subtask 1 metrics.

indices indicate whether the concentration of a pollutant is above or below its exposure limit. IAQ-DALY provides information on the burden of disease that is associated with the exposure. Thus, it provides information on the associated risks that are relevant for policy and decision makers. Thus, the two approaches and three indices are complementary. Along with this IAQ signature, the building energy consumption is provided to illustrate the energy consequences of IAQ remediation. These points are presented in the AIVC CR17 report (Abadie and Wargocki, 2017).

Subtask 2: Pollution Loads in Residential Buildings

A model-based testing and evaluation approach has been used to characterize the short and long-term emissions of VOCs from building materials and furnishings, how the emission rates (and hence indoor pollution loads) are affaceted by the environmental conditions including the temperature, relative humidity, local air velocity, and concentrations. In this approach, the VOC emission behaviour is represented by a coupled heat, air, moisture and pollutant simulation model (CHAMPS), and the emphasis in this subtask was to determine the required model parameters related to emission sources for IAQ analysis. We developed a method and procedure to generate the required emission source model parameters (i.e., initial VOC concentration in the material, in-material diffusion coefficient, and material to air partition coefficient) from emission data obtained from widely used standard small chamber tests. A database of model parameters for material emissions has been developed by using the procedure as well as based on a comprehensive review of the published literature data. In addition, experiments were conducted to investigate how the temperature and relative humidity affect the emission characteriscs and the source model parameters (Figure 3).

In order to simulate realistic residential conditions, a procedure was also developed to define a local reference house including the climate conditions, typical type and amount of materials used, occupancy and required indoor conditions, and ventilation rate. The refrerence house also provides a local baseline for evaluating the effectiveness of a proposed IAQ or energy efficiency strategy as well as the specifications of materials for which emission data are required.



Figure 3 Effects of temperature and relative humidity on formaldehyde emission from an MDF panel. C0 is the initial emittable concentration, Dm the diffusion coefficient, and K the partition coefficient.

Subtask 3: Modelling - review, gap analysis and categorization

Subtask 3 included a review, gap analysis and categorization of existing simulation tools according to their usability in the planning practice of buildings. The modeling activities of other IEA-EBC annexes - in particular, the achievements of the Modelica Annex 60 library are also taken into consideration. Two common exercises revealed further implementation demand and the necessity of quality assurance management.

In the planning process of buildings, optimization potentials are often not exploited, because the tools do not sufficiently support interdisciplinary work. The dynamic behavior of buildings and facilities using simulation programs is only investigated in exceptional cases. Variant analyzes have not yet been established as standard method for cost reasons. The lack of reliable data also represents a major obstacle. Input and model parameters are not known in the early planning stages or, due to their complexity, only available in expert or research programs.

Criteria for evaluating the quality of the simulation results should be established in order to improve the predictive accuracy between calculated and real building behavior. In summary, it can be stated that improved, higher-level coordination in simulation software development is required in order to respond appropriately to current challenges and to avoid costly duplication of work.

As part of the work under Subtask 3, a collaborative development towards a fully Coupled Heat, Air, Moisture and Pollutant Simulation (CHAMPS) platform was accomplished. The CHAMPS platform (Figure 4) is a collection of open-source numerical solvers and data to simulate the most important physical processes involved in the Annex 68. The focus of the platform was on development of interdisciplinary modeling capabilities related to air, light, energy, HVAC operation, moisture and pollutants. The basic idea was to integrate free solvers developed in the scientific community that all can handle relevant transient physical problems under one graphical user interface (GUI).

The simulations can be setup using the BIM HVAC Tool, which allows import of building models in many formats as well as manual input from scratch. While all solvers are free programs, is the BIM HVAC Tool the only commercially distributed software on the CHAMPS modeling platform. During the course of the Annex 68 project, the developmental work focused the development of coupling technologies to support co-simulation and on implementation of a pollutant mass balance in DELPHIN6. Several application examples demonstrated the broad range of topics and scenarios that can already be addressed by using single or coupled tools from the CHAMPS modeling platform.

A clear division of tasks between science and

practice is seen as a prerequisite for achieving the goals and maximum synergy effects. For the further development, it is important to shift the focus away from traditional single tool development to network-coordinated collaboration. The implementation of high-quality physical-mathematical models and the development of user-friendly program interfaces for their own use are priority tasks of the scientific development teams. Sales, support and marketing, should be provided by commercial software companies.

Subtask 4: Strategies for Design and Control of Buildings

The objective of Subtask 4 was to collect the results and approaches of the other subtasks and present them in relation to existing technical knowledge. The subtask was originally intended to develop optimal and practicable design and control strategies. However, as the project progressed, it became apparent that it was impossible and impractical to develop a specific set of "recommended strategies". It seemed more appropriate to present the variety of approaches that exist in the practice of all Annex 68 members involved in the subtask. Two main parts were pursued:

Transition from theory to practice: bibliographic study and series of interviews with key stakeholders in the building sector in relation to the implementation of international standards, national standards and building codes, as well as numerous brochures, guides and existing web pages. Inspiration for design and operation: case studies presented (see Figure 5) in the form of files structured according to "Objectives, description and methods", "Main results and discoveries", "Conclusions and lessons learned" and "Further reading".



Figure 4: Multi-scale and multi-disciplinary CHAMPS modeling platform.

Chapter	Case studie	Design			Construction, Comissioning & Use	
		Assessment methods	Assessing ventilation concepts	Novel ventilation solutions	Quality assurance	Assessing in- use performance
3.1	Alternative ducting options for balanced mechanical ventilation systems in multifamily housing					
3.2	Ambient air filtration in highly energy efficient dwellings with mechanical ventilation					
3.3	Development of a compact ventilation system for facade integration					
3.4	VOC exposure due to Floor heating systems versus Radiator heating					
3.5	Control strategies for mechanical ventilation in Danish low-energy apartment buildings					
3.6	Response of commercially available Metal Oxide Semiconductor Sensors under air polluting activities typical for residences					
3.7	Impact of multi zone air leakage modelling on ventilation performance and indoor air quality assessment in low-energy houses					
3.8	Towards a better integration of indoor air quality and health issues in low-energy dwellings					
3.9	List of key pollutants for design and operation of ventilation in low-energy housing					
3.10	Definition of a Reference Residential Building Prototype for Evaluating IAQ and Energy Efficiency Strategies					
3.11	Temperature dependent emissions of Volatile Organic Compounds from building materials					
3.12	Detailed modelling of IAQ to improve ventilation design in low energy houses					
3.13	Mechanical ventilation system in deep energy renovation of a multi-story building with prefabricated modular panels					
3.14	Simplifying MVHR systems: Assessing the extended cascade ventilation and active overflow concept					
4.1	House owners' experience and satisfaction with Danish Low-energy houses - focus on ventilation					
4.2	Development and test of quality management approach for ventilation and indoor air quality in single-family buildings					
4.3	Applications of the Promevent protocol for ventilation systems inspection in French regulation and certification programs					
4.4	Long-term durability of humidity-based demand-controlled ventilation: results of a ten years monitoring in residential buildings					
4.5	Practical use of the Annex68 IAQ Dashboard					
4.6	Performance evaluation of Mechanical Extract Ventilation (MEV) systems in three 'low-energy' dwellings in the UK					· · · · · · · · · · · · · · · · · · ·
4.7	Indoor air quality in low energy dwellings: performance evaluation of two apartment blocks in East London, UK					



Figure 5 Overview of case studies explained in Subtask 4.

Subtask 5: Field Measurements and Case Studies

Subtask 5 included three activities. The first activity was an analysis of the metrology resources necessary for the assessment of IAQ in residential buildings. This resulted in an overview report with the available measurement techniques for both IAQ and airflow measurements as well as guidelines on selecting the appropriate techniques for a field study.

The second activity consisted of carrying out experiments to provide validation data for digital models. Three levels of increasing complexity have been defined: a single stainless steel test room with a source for a single pollutant, a small student studio with 3 selected materials for emissions and an occupied house (Figure 7 and Figure 8).

The last activity consisted of the compilation of IAQ measurement results in low energy consumption residential buildings in the form of a summary sheet including global building data (location, geometry, envelope structure, thermal and ventilation systems) as well as information concerning measurement equipment and levels of pollutant concentrations in these buildings. This summary sheet is indended to provide at-a-glance information on the case study to other researchers interested in the data and it is recommended to include this as a supplementary material in publications and reports. Annex participants have provided 7 examples of such summary sheets included in the report.

Deliverables

The project has now been completed, and specific results can be found on the project homepage http://www.iea-ebc-annex68.org/. The project has resulted in five reports and a database as listed below.

- D1: Subtask 1 Report on Metrics for high IAQ and energy efficiency in residential buildings.
- D2: Subtask 2 Report on Pollutant loads in energy efficient residential buildings under in-use conditions.

D3: Subtask 3 Report on Modelling of IAQ and energy efficiency - review, gap analysis & categorization.

- D4: Subtask 4 Report on Current challenges, selected case studies and innovative solutions covering indoor air quality, ventilation design and control in residences.
- D5: Subtask 5 Report on Field tests and case studies documentation of residential buildings, with regards to performance on achieving optimal combination of good IAQ and low energy use.
- D6: A database of VOC emissions for IAQ simulations.

D1 and D4 were co-published in partnership with the Air Infiltration and Ventilation Centre (AIVC) in the form of Contributed Reports (Abadie and Wargocki, 2017; Kolarik and Rojas-Kopeinig, 2020).

SUMMARIZING CONCLUSION AND REFLECTIONS

The IEA EBC Annex 68 project has highlighted the core metrics to be dealt with in the balance between operating new or renovated residential buildings in an energy efficient way and ensuring healthy indoor environments free from potentially harmful compunds. This relies on specifying the proper ventilation rates of indoor environments to ensure good IAQ without excessive energy use. Lists were generated as part of the project's Subtask 1 of essential indoor pollutants to consider along with their limit values for short and long-term exposure (STEL and LTEL) as well as the effect of the so-called Disability Adjusted Life Years (DALY).

Proper indoor ventilation rates have traditionally been governed by humidity and CO₂ levels, but this project has extended the focus by studying emissions of volatile organic compunds (VOCs) from building products. Studies of VOC emissions are not new, but this project's Subtsk 2 has had two areas of focus to extend the current knowledge:

- (1) to initiate studies of moisture and temperature interactions on emission rates, since these interactions can be quite influential, not least for situations occurring in practice,
- (2) to develop and describe the so-called "similarity approach", whereby VOC emissions can be described and modelled in a similar way as how moisture diffusion is traditionally modelled, which will facilitate the incorporation of such modelling in state-of-the-art building simulations tools.

Since advanced simulation tools for building analysis and design are far beyond being used only for research but are commonplace among practitioners in the building industry, it was considered important to integrate models from the theme of Annex 68 into a platform that combines the simulation of heat, air, moisture and pollutants. CHAMPS (Combined Heat, Air, Moisture and Pollutant Simulation) is such a platform, which has been matured during the course of this project and its Subatsk 3 with the knowledge gained on interacting effects and which has been subjected to a thorough quality assurance check. CHAMPS is compliant with a suite of commercial tools used in building design and with paradigms for functional mockup interfaces which were the focus of research in IEA EBC Annex 60.

Several institutions who were active in Annex 68 have had relevant field case studies where the operation of ventilation systems was studied in conjunction with indoor air quality and energy use. The collection of such cases from the field and from controlled site experiments was supplemented with an overview of the measuring technologies which are available for field measurements. Thus, while the case studies are presented as such in Subtask 5 during the annex, this subtask should also be seen as an invitation for future research projects to follow up using the presented paradigms.

All this research has value especially when it relates to its application and use under practical circumstances in design and operation. Therefore, as a flagship outcome of the project, Subtask 4 gathered a suite of examples. A stakeholder survey was carried out including 44 interviews with practitioners from seven European countries, which provided insights into current practices with respect to design and operation of residential ventilation. More importantly, it also highlighted which barriers and challenges practitioners meet. The initial costs of mechanical ventilation systems were one of the most frequently mentioned barriers, followed by increased spatial requirements for ventilation unit and ducting, which is not necessarily related to renovation projects only. Furthermore, Subtask 4 gathered and presented a set of 22 contributions by researchers from several European countries, USA and China describing research as well as practical projects focused on high air quality and energy efficient ventilation in modern residences.

Apart from such tangible deliverables of the project as outlined above, three of its Subtasks (2, 3, and 5) have developed so-called Common Exercises, which during the project were seen as vehicles for conducting and inspiring

the research within the project. The Common Exercises are documented so they are now available for future and young researchers to pick up and further use either for training and development of data to enrich the research field.

Some hindsight reflections comprise:

For metrics definition in this project, we have chosen the minimal value among Exposure Limit Values (ELVs) suggested by health agencies from around the world because the levels may be significantly different for the same pollutant and the same exposure time depending on the criteria used by the committees setting the guideline values. However, another approach could have sought for consensus values. It should also be noted that those values are frequently updated according to the scientific knowledge on the health risks.

Furthermore, it was decided to consider energy consumption separately from the IAQ indices. A prerequisite to aggregate energy and IAQ indices is that both are measured on the same absolute scale, which they are not. Monetizing the effects of IAQ and energy could be a way to bring both indices to the same scale (e.g. such as by Turner et al. (2013) and ANSES (2014)), but many questions remain before it can become standard practice.

Annex 68 has provided a general framework for integrated simulation and assessment of energy efficiency and chemical indoor air pollution. This framework can now be expanded to develop and assess a series of intelligent IAQ management strategies. In order to propose intelligent and energy efficient IAQ management strategies, a number of points must be developed:

- Analyze implementation of IAQ management strategies to resolve problems specific to the residential sector.
- Determine the means of measuring the effects of the strategies applied (indicators of efficiency).
- Adapt strategies to different climates, construction styles and practices in different countries (flexibility).
- Implement strategies for typical residential construction projectss not limited to developmet projects.
- Check and test the strategies proposed by research studies or solid case studies.

A follow-up project, IEA EBC Annex 86 "Energy Efficient Indoor Air Quality Management in Residential Buildings" will optimize the energy efficiency of IAQ management by addressing the previous points. For IAQ management, the focus will be on the use of materials that actively influence IAQ in spaces and smart ventilation, since these are the strategies that potentially can give highest energy efficiency.

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