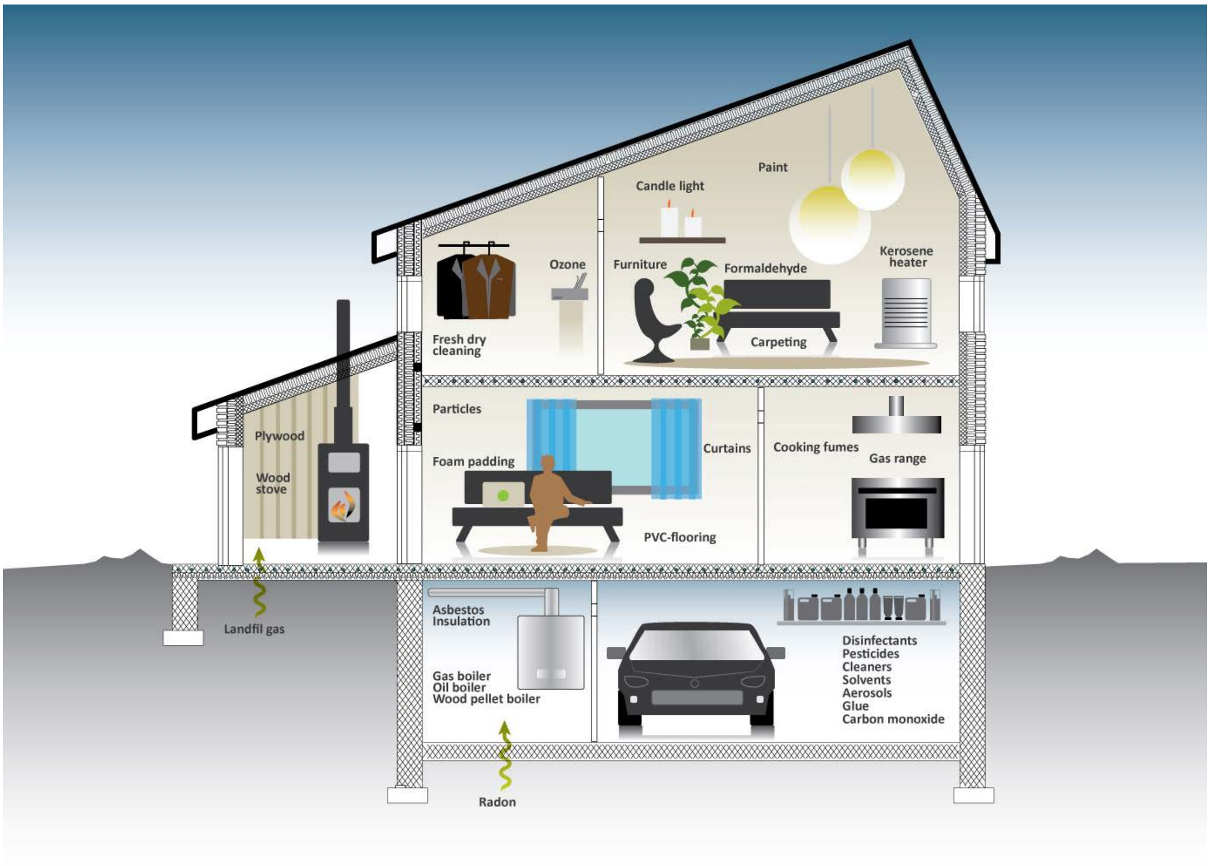
Project Summary Report

IEA EBC Annex 68 Indoor Air Quality Design and Control in Low Energy Residential Buildings



Source: Technical University of Denmark

Editor:

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Technical University of Denmark

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1. Project Summary

New dwellings or deeply renovated existing dwellings are designed to be energy efficient, and have airtight structures. This leads to a risk of high indoor pollutant loads due to activities and emissions from materials in contact with indoor air. Ventilation must be dosed at the right volume of clean air, efficiently distributed in the occupant zone and with proper scheduling in order to keep indoor pollutant concentrations low, while not increasing the energy need. Building designers, contractors, owners and operators, and decision makers need the newest knowledge on how to operate ventilation to achieve this.

The project has focused on new and existing residential buildings, although it should be underlined that many findings may also be relevant to other building types.

At the onset of the project, the existing indicators for indoor air quality (IAQ) were reviewed and indicators were defined that would specifically facilitate the other subtasks in this project. The IAQ indicators to be studied were documented in a report, which collected state of the art information and suggested a principle in the form of a “dashboard” on how to balance the combination of the most significant among many pollutants to be considered. The dashboard also highlighted the energy performance aspect.

A main result of the project is an easy to understand and practically applicable collection of experiences with design and operational strategies to achieve optimal energy performance and high IAQ in residential buildings. The collection is intended for those involved in the construction and maintenance of buildings.

Furthermore, the project presents a modelling framework and design tools, suitable for integrated and coordinated design of buildings with low energy consumption and high IAQ.

With regards to pollutants in buildings, data and models have been applied on sources and sinks of pollutant emissions to estimate the net pollutant loads over time under realistic environmental conditions. This is supported by databases on the properties of materials with respect to pollutant emissions.

Finally, field tests and case studies were documented for different climatic zones as well as methodologies to carry out such testing. Specifically, this activity targeted industry partners, building owners and operators.

The project was carried out with contributions from researchers from some 39 research institutions from 15 countries worldwide, while one participant was a global enterprise that supplies building products and solutions in many areas. Several local stakeholders such as consultants and HVAC manufacturers and associations have been visitors to the project when expert meetings were held semi-annually in different countries. Meetings were usually planned to be held in conjunction with relevant conferences such as by AIVC, ASHRAE but also Indoor Air, IBPC and IAQVEC conferences. The project has also fostered input to meetings in the interest group “CHAMPS” on Combined Heat, Air, Moisture and Pollutant Simulation, which convenes annually in different places of the world.

An important lead from the project to policy makers is to facilitate possibility by legislation that residential buildings may be operated flexibly and intelligently with regards to demand control of building ventilation in a manner that considers realistic hygrothermal and pollutants loads in buildings. Furthermore, the project has highlighted the need for more quality management since traditional and novel mechanical ventilation concepts as presented in this project all have in common that quality assurance during design, construction and operation is crucial for success, i.e. high IAQ and comfort while minimizing energy use. Consequently, a framework for quality assurance and inspection is needed.

2. Project Outcomes

2.1 Background – goals

The rationale for implementing this project stems from the fact that buildings will have to be optimized in the future to come as close as possible to net zero energy consumption. This means that ventilation in particular will also be reduced to what is strictly necessary, while the quality of the indoor air must not be sacrificed. It is therefore necessary to adopt and demonstrate an integral method for optimization in ventilation management that takes into account such elements as the sources, sinks and transport of relevant pollutants present in buildings, including the emissions of volatile organic compounds from building products of construction. Building designers, contractors, owners and operators as well as decision makers need the newest knowledge on how to operate ventilation to achieve this.

New dwellings or deeply renovated existing dwellings are designed to be energy efficient, and have airtight structures. This leads to a risk of high indoor pollutant loads due to activities and emissions from materials in contact with indoor air. Ventilation must be dosed at the right volume of clean air, efficiently distributed in the occupant zone and with proper scheduling in order to keep indoor pollutant concentrations low, while not increasing the energy need. Building designers, contractors, owners and operators, and decision makers need the newest knowledge on how to operate ventilation to achieve this.

Upon starting the project, a technology readiness analysis indicated that there are many pollutants for which we still had only little information; some of the information we have is not updated, so it does not sufficiently pertain to contemporary products and conditions; and there was only very scarce information about combined effects with temperature, humidity and ventilation levels on indoor pollution levels. Furthermore, more global approaches were thought to be needed that consider indoor pollutants mainly by proxies such as CO_2 or humidity, while modelling of pollutants has been hampered by the lack of data about the pollutants, and lack of threshold values. Indoor pollutants were not included directly in building energy simulation models. Appropriate sensors of relevant pollutants were missing, although some are under development. Application, experience and design knowledge in the combined assessment of energy performance and IEQ optimization was expressed as being important but appeared to be too scarce, and generally not consolidated.

2.2 Objectives - the methodology and scope

Thus, the objectives of Annex 68 have been to:

- Develop guidelines for design and control strategies for buildings with low energy consumption that will not compromise the quality of the indoor air. The operational parameters treated are the means and control of heating, ventilation and moisture conditions, and their optimal combination.
- Set up the performance indicators striving to obtain high energy performance and an optimal IAQ.
- Collect, combine and perfect the tools that will be necessary to help designers and managers in achieving the first objective above.
- Benefit from the latest advances in sensor and control technology, in order to identify methods to improve IAQ while ensuring minimum energy consumption for operation.
- Gather existing data and provide new data on indoor pollutants and their properties with respect to temperature, humidity and air transfer that will be required for the above analysis.
- Identify and analyse relevant field and case studies where the high energy performance and optimal IAQ can be examined and optimized.
- Disseminate the knowledge acquired about each of the above results.

Rather than developing the new knowledge from scratch, the project has mainly aimed to collect, process and combine existing knowledge from different scientific communities such as those relating to ventilation, chemical emissions from construction products, hygrothermal phenomena in buildings, materials and thermal and air flow modelling / simulation of buildings.

The project has sought to contribute to the following themes of the IEA EBC strategic plan 2014-19:
Theme #1: Integrated planning and building design, e.g. regarding establishment of knowledge about the design process for zero or low energy buildings with integrated information about the function of building envelopes (e.g. the materials) and the building energy systems (e.g. ventilation systems)
Theme #2: Building energy systems concerning the optimal operation considering building / user / system interactions
Theme #3: Building envelope regarding design and multiple function of the envelope.

The project has had leads back to Annex 18 on Demand controlled ventilation and has complemented other newer IEA EBC Annexes dealing with ventilation. It has throughout been a contributor to the Air Infiltration and Ventilation Centre (AIVC).

2.3 Activities and deliverables - the work done in the project

2.3.1 Definition of indicators

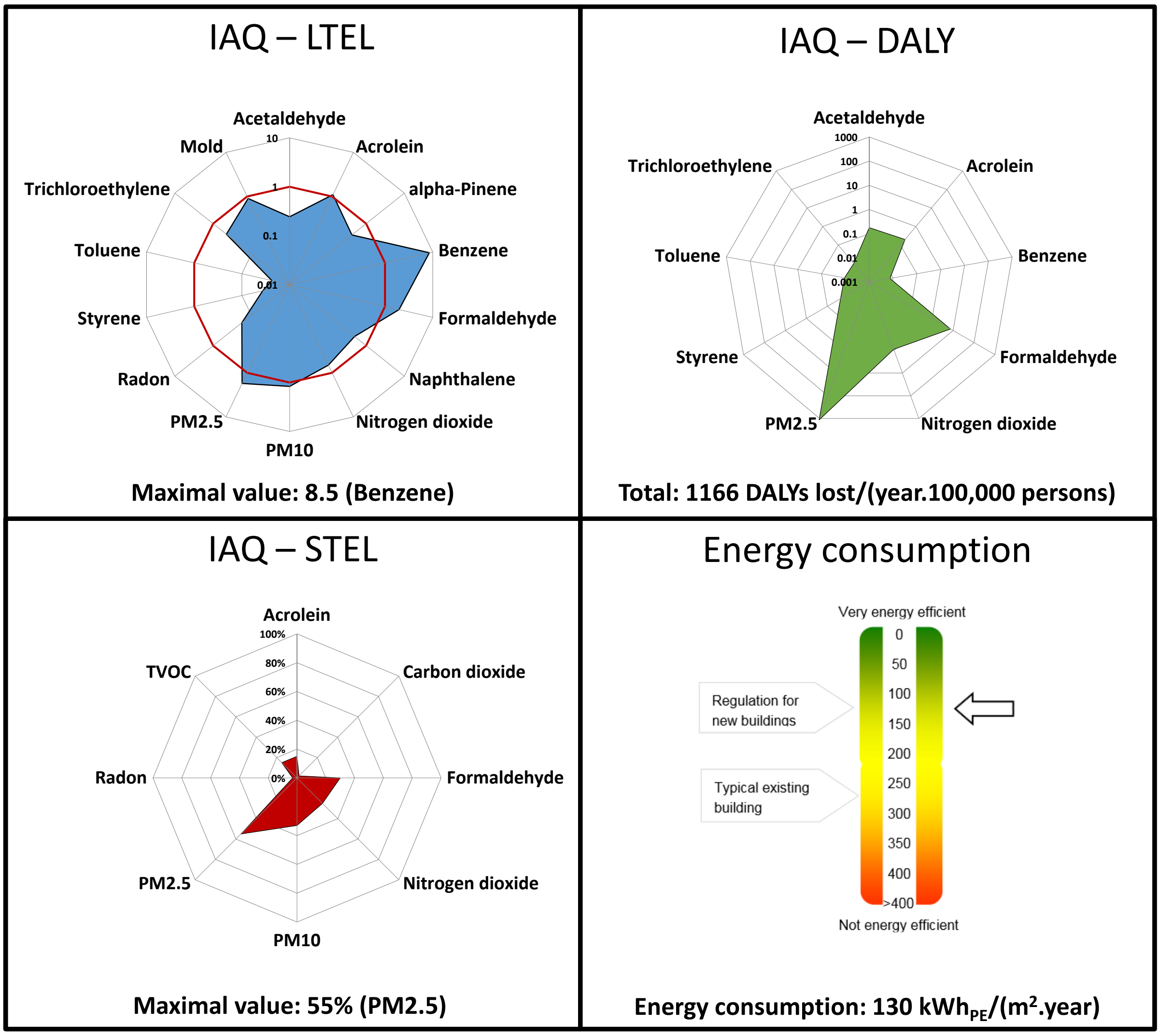
A important obstacle to integrating energy and IAQ strategies into building design and optimization is the lack of a single index that would quantitatively describe IAQ and allow comparison with the indices describing the energy consumption. Such an index would also make it possible to quantify the advantages of different methods for achieving high IAQ and compare them in parallel with the consequences for energy and greenhouse gas emissions. With this activity, the existing correlations between IAQ and health care costs will be examined as the index will be considered useful if it properly accounts for the benefits of IAQ and energy in the design and the operation of buildings. In particular, the index should include the additional energy consumption necessary to improve IAQ compared to current practice, such as the increase in fan consumption induced by air change rates or the use of filters, particulate / gas or air purifiers.

Figure 1 is a graphical summary presenting the main points discussed in this first activity of the project, namely:

- Do residential buildings with low energy consumption have a poorer IAQ?
- What are the target pollutants to monitor to assess IAQ in low-energy residential buildings?
- How to quantify the level of IAQ?
- Can we combine the IAQ and energy indicators into a single indicator?

Figure 1 also presents the IAQ / Energy dashboard proposed by the working group. Three IAQ indices were proposed in the project based on Exposure Limit Values (ELVs) or DALY (Disability-Adjusted Life Years). 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 ELVs for short-term exposure and gives the frequency that the pollutant concentration exceeds those ELVs over a period of time (hours or days) depending on the pollutant ELV definition. Regarding the risks associated with long-term (over weeks or years) 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 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 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 an estimate of burden for the society that can be economically quantified that are relevant for policy and decision makers, and 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.

All these points are presented in the AIVC report CR17 (Abadie and Wargocki, 2017) available for download at www.aivc.org.



IAQ – LTEL

Maximal value: 8.5 (Benzene)

IAQ – DALY

Total: 1166 DALYs lost/(year.100,000 persons)

IAQ – STEL

Maximal value: 55% (PM2.5)

Energy consumption

Energy consumption: 130 $kWh_{PE}/(m^2.year)$

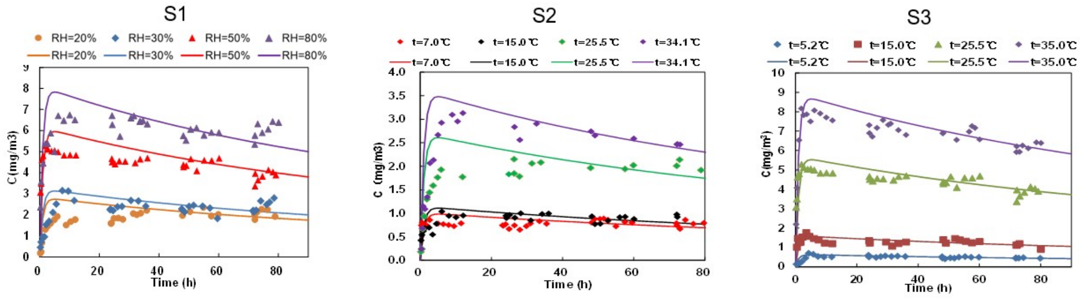
Figure 1. Graphic summary of indicators (Source: Université La Rochelle)

2.3.2 Pollution load in residential buildings

One of the obstacles to integrating energy and IAQ strategies is 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 activity has involved collecting existing data and to some extent providing new data on the transport, retention and emission properties of chemicals in new and recycled materials under the influence of heat, airflow and humidity conditions. The collection of laboratory test results at the material and building scale has been part of this study. Specifically, the results were collected and analyzed from tests for emission of volatile organic compounds under various conditions of temperature, humidity and airflow, since such data in the context of combined exposures currently were not generally existing.

The specific main developments of the activity on pollution loads in residential buildings have been:

- Analysis of the coupled or uncoupled effects of temperature and humidity on the emission of various pollutants (formaldehyde, benzene, etc.) for various materials (MDF, plaster, etc.) such as Illustrated in Figure 2.
- A procedure for defining reference buildings for the evaluation of pollutant loads, IAQ and energy analysis for different countries / climates.
- A method and procedure for using a scale 1 test chamber to assess the effects of pollutant sources and sinks, ventilation and air cleaning on IAQ have been developed. Two cases were defined with experimental data, one for one single source (particle board) and the other for a room with vinyl flooring, ceiling tiles, painted plaster panels and an office cabinet.
- In order to assess the impact of VOC emissions from construction materials on the indoor pollution load beyond chamber test conditions and test period standard, emission source models have been developed in the past. However, very little data is available for the required parameters of the model, including the initial concentration, the diffusion coefficient in the material, the partition coefficient and the coefficient of mass transfer by convection. A procedure has been developed to estimate model parameters using VOC emission data from standard tests in small chambers.



C_0 (mg/m³)	D_m (m²/s)	K (—)
1.75×10^6	3.40×10^{-14}	6340
2.00×10^6	3.36×10^{-14}	5514
3.80×10^6	3.50×10^{-14}	5340
5.20×10^6	3.14×10^{-14}	3128

C_0 (mg/m³)	D_m (m²/s)	K (—)
7.90×10^5	3.00×10^{-14}	9467
8.50×10^5	3.15×10^{-14}	7844
1.75×10^6	3.40×10^{-14}	6340
4.30×10^6	3.57×10^{-14}	4570

C_0 (mg/m³)	D_m (m²/s)	K (—)
4.93×10^5	2.90×10^{-14}	9752
1.14×10^6	3.15×10^{-14}	7280
3.80×10^6	3.50×10^{-14}	5340
1.10×10^7	3.60×10^{-14}	3450

Figure 2. Effects of temperature and relative humidity on formaldehyde emission from an MDF panel (Source: Technical University of Denmark).

2.3.3 Modelling - analysis and classification

In the past, many models were developed in the field of dynamic thermal simulation of buildings (e.g. building design, life cycle analysis and energy efficiency improvement). However, current knowledge is still insufficient to predict the combined effects of hygrothermal conditions and chemical reactions on species and indoor pollution concentrations. In light of the most recent developments on the importance of secondary emissions such as indoor and surface air chemistry initiated by ozone, an approach for modelling the effects of combined heat, air, humidity and pollutant transport (CHAMPS - Combined Heat, Air, Moisture and Pollutant Simulation) and their impact on energy and IAQ is necessary. The objective of the modelling activity has been to review, make gap analysis and classify existing models and standards. This has involved collecting and developing validated reference cases using modern tools and methods of analysis of the whole building to predict hygrothermal conditions, absorption and transport of humidity and chemicals and energy consumption in buildings. The overall modelling of the building was carried out by considering the indoor air and the building envelope, the users of the building and the technical management systems of the building.

The main contributions of the project's modelling activity have been:

- A global analysis of the practical integration of building performance simulation tools.
- A reference case with description of the problem, input parameters and solution, which was the subject of a common exercise between the participants (Figure 4).
- Classification of the tools available according to their strengths and weaknesses.
- Testing of selected tools and their possible combinations (co-simulation)
- Features and implementations required following the analysis of the lack of available tools.
- Proposals for improving quality assurance standards in the development of simulation tools.

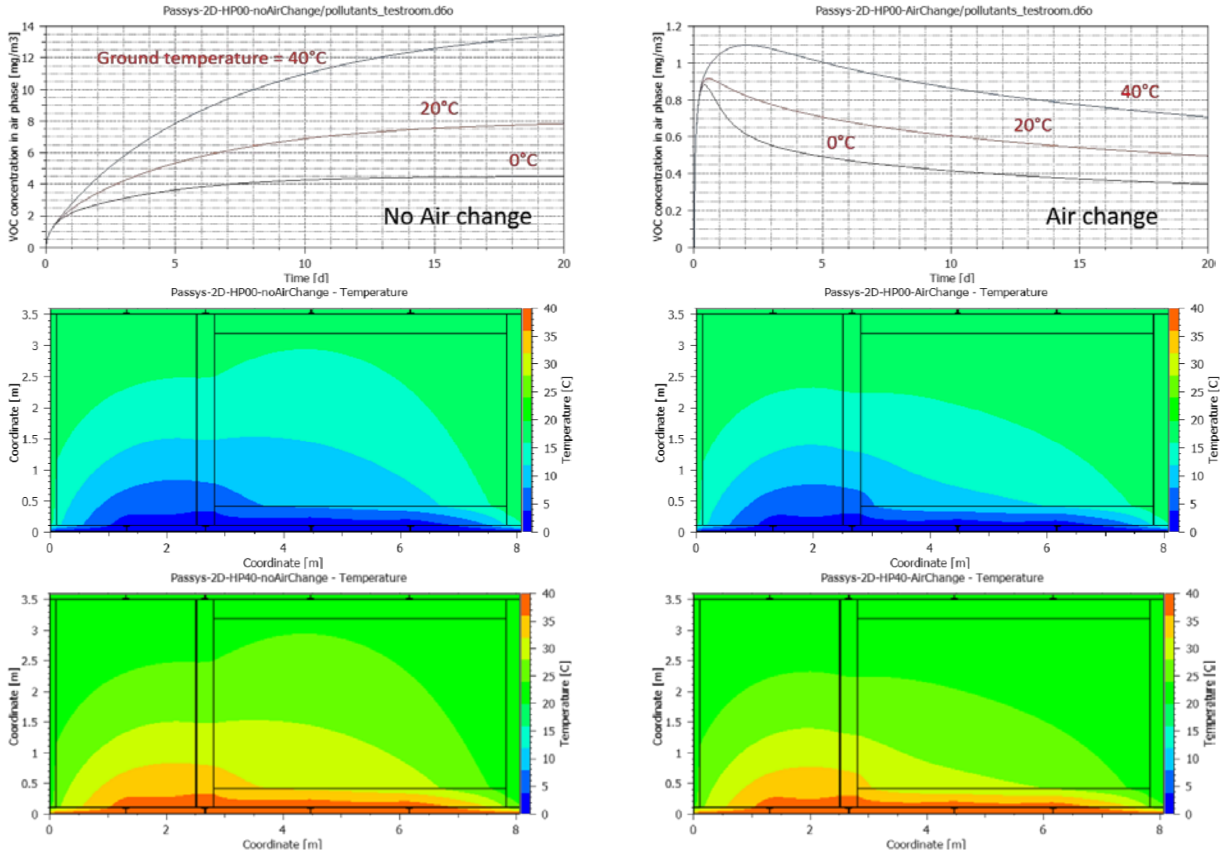


Figure 4. Test case - Modelling of the evolution of the VOC concentration coming from the floor at different temperatures and with and without air exchange (Source: TU Dresden).

Particular attention has been paid to the integration of the transport and diffusion equations of VOCs in materials. In particular, a so-called *similarity approach* has been pursued with respect to the sorption of water vapour in order to be able to generate data on the diffusion and partition coefficient for the VOC - material pairs (which are few in number) from the databases of data on the hygroscopic properties of existing materials. This analysis showed correlations between these parameters (Figure 5).

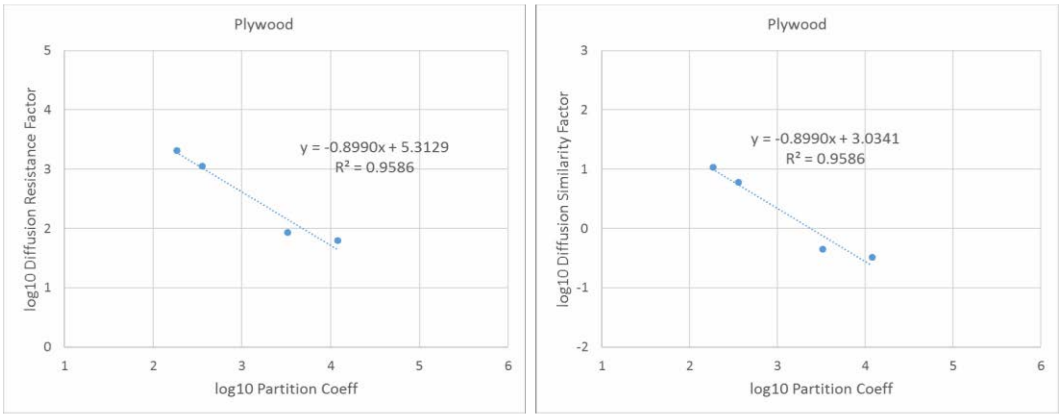


Figure 5. Similarity analysis for a plywood (Source: TU Dresden).

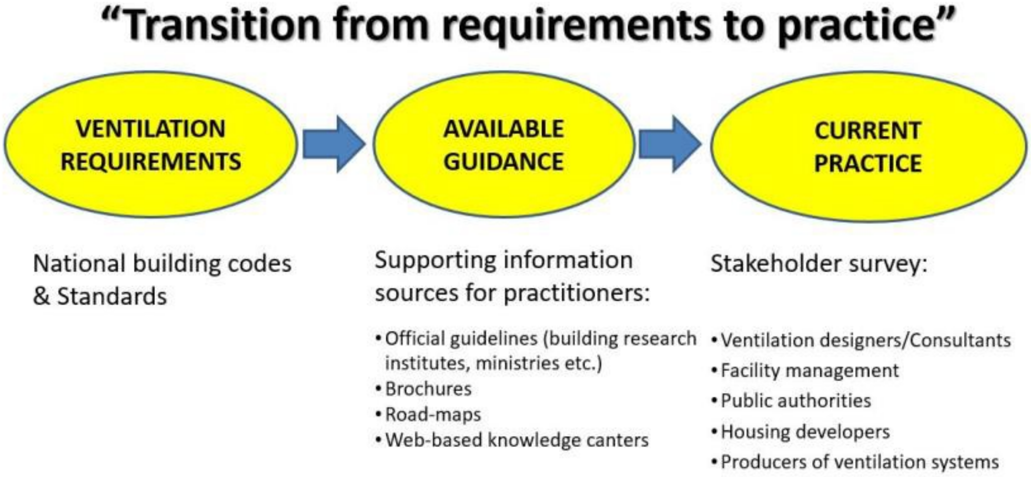
2.3.4 Building design and control strategies

This activity has been based in particular on the results of the activities from other parts of the project on indoor air quality indicators and measurements, models and databases on pollution and emissions, and the results of in-situ measurements, as well as existing knowledge to develop optimal and practically applicable strategies for design and control to promote high IAQ in residential buildings. The strategies consider IAQ requirements based on current standards as well as new measures developed based on health effects. Optimal strategy can be understood here as strategies, which take into account the energy performance of the building, comfort and healthy conditions. Matrixes of different strategies should be created to assess the possibilities of win-win solutions (excellent IAQ with low energy consumption) as well as other alternatives that will ensure high IAQ. The use of models and databases developed in the framework of the annex will allow to address new paradigms for the local and multi-scale management of air quality and energy, including ventilation modulated (by humidity, CO_2 or other pollutants) taking into account the transport of chemical compounds to and from the interior atmosphere. The activity has considered recent advances in sensor technology to find ways to optimize IAQ without compromising energy efficiency. On the energy side, the activity has sought to establish correlation factors between, on the one hand, pollution loads in buildings and the methods to mitigate such loads and, and on the other hand, energy consumption.

The objective of the project's activity on building design and control strategies has been to bring together the results and approaches of the other sub-tasks and present them against the existing technical knowledge. The original purpose of the activity was to devise optimal and practically applicable design and control strategies. As the project progressed, it became evident that it was not feasible to develop a precise set of "recommended strategies". Rather the activity focused on collecting and presenting the variety of approaches that exist in the practice of all Annex 68 members who were involved. We can distinguish two main parts:

- 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 (Figure 6).

- Inspiration for design and operation: case studies presented in the form of sheets structured according to "Objectives, description and methods", "Main results and findings", "Conclusions and lessons" and "Further reading".



“Transition from requirements to practice”

VENTILATION REQUIREMENTS

AVAILABLE GUIDANCE

CURRENT PRACTICE

National building codes & Standards

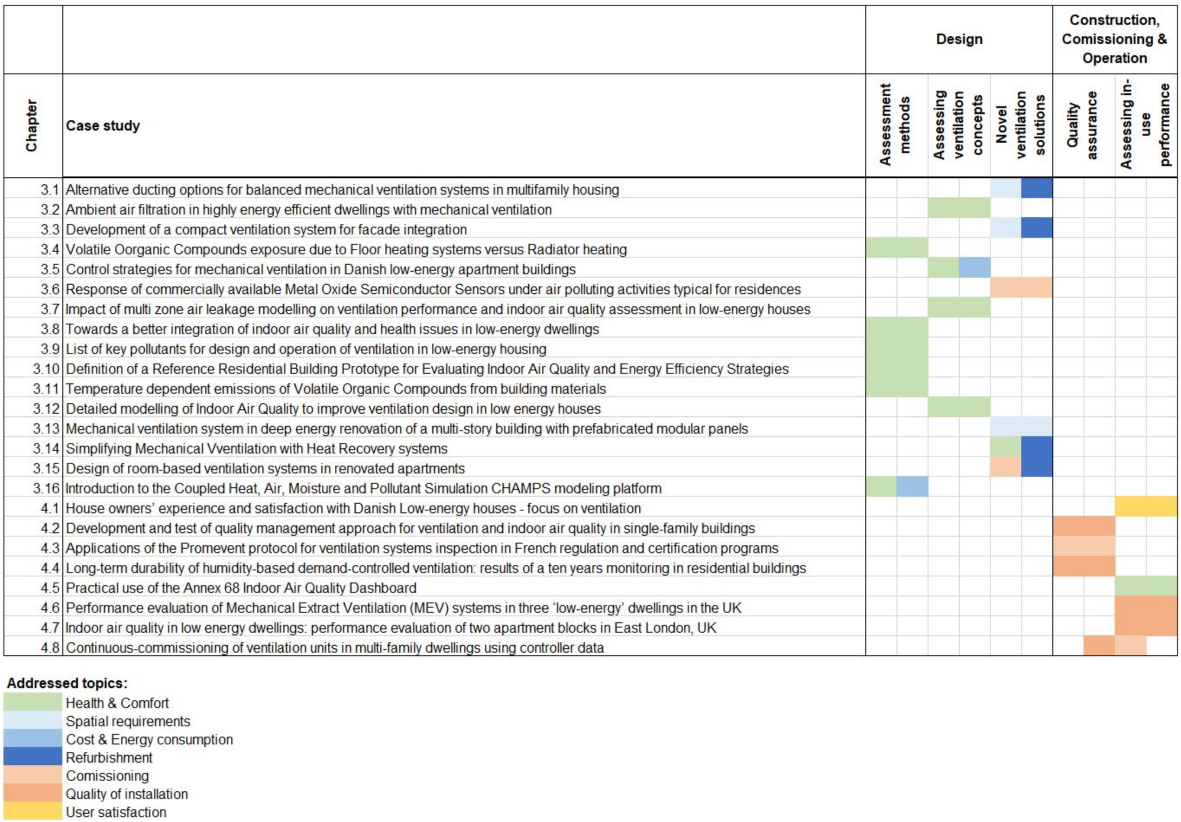
Supporting information sources for practitioners:

- Official guidelines (building research institutes, ministries etc.)
- Brochures
- Road-maps
- Web-based knowledge canters

Stakeholder survey:

- Ventilation designers/Consultants
- Facility management
- Public authorities
- Housing developers
- Producers of ventilation systems

Figure 6. Sources of information used when studying the transition from requirements to practice (Source: Technical University of Denmark).



		Design						Construction, Comissioning & Operation			
Chapter	Case study	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	Volatile Oorganic Compounds 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 Indoor Air Quality and Energy Efficiency Strategies	🟩	🟩								
3.11	Temperature dependent emissions of Volatile Organic Compounds from building materials	🟩	🟩								
3.12	Detailed modelling of Indoor Air Quality 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 Mechanical Vventilation with Heat Recovery systems					🟩	🟦				
3.15	Design of room-based ventilation systems in renovated apartments					▨	🟦				
3.16	Introduction to the Coupled Heat, Air, Moisture and Pollutant Simulation CHAMPS modeling platform	🟩	▒								
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 Annex 68 Indoor Air Quality 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									🟧	🟧
4.8	Continuous-commissioning of ventilation units in multi-family dwellings using controller data								🟧	▨	

Addressed topics:

🟩	Health & Comfort
░	Spatial requirements
▒	Cost & Energy consumption
🟦	Refurbishment
▨	Comissioning
🟧	Quality of installation
🟨	User satisfaction

Figure 7. Overview of case studies (Source: Technical University of Denmark).

2.3.5 In-situ measurements and case studies

The activity on *In-situ measurements and case studies* has investigated and identified relevant case studies through literature review and conduction of measurement campaigns in field test buildings, to provide data for validation of other activities in the Annex project. Several sites / climates have been studied, and in-situ tests have included buildings declared to be energy efficient new buildings or recently renovated ones. Field test have focused on testing and demonstrating in practice how low energy operational strategies can be used alongside with creating healthy indoor environments. Test buildings with existing and new ventilation strategies that were identified in the activity on *Building design and control strategies* were incorporated to the maximum possible extent. Testing included investigation of new ventilation principles in energy-efficient residential buildings with strong airtightness, increased thermal insulation, use of materials and also new residential behaviours. Field trials were carried out in collaboration with industrial partners from other project activities and with building owners. This involved engineers and owners / operators of the buildings studied. The results of the measurements were used for the common exercise of the project's modelling activity and to provide input to the guidelines developed in the activity on *Building design and control strategies*.

Specifically, the activity on *In-situ measurements and case studies* comprised the following elements:

- Analysis of the metrology resources necessary for the assessment of IAQ in residential buildings.
- Carrying out experiments to provide validation data for digital models. Three levels of increasing complexity have been defined: an outdoor test cell, a small student studio, and an occupied house (Figure 8 and Figure 9).
- Compilation of results of IAQ measurements in residential buildings with low energy consumption in the form of a summary sheet including overall building data (location, geometry, structure of the envelope, thermal and ventilation systems) as well as information concerning the measurement and levels of pollutant concentrations in these buildings.

Figure 8. Spaces of the house (living room and dining room) during the experiment (Source: Ghent University).

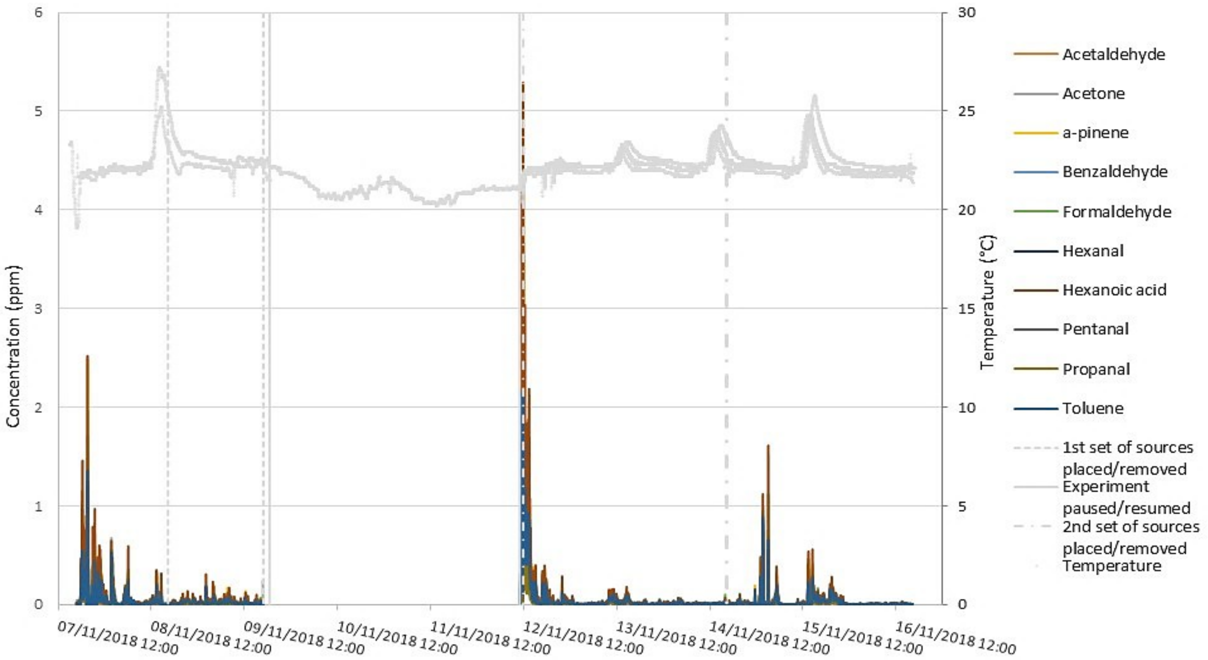


Figure 9. Evolution of the VOC concentration monitored in the house with Sift-MS (mass spectrometry) after placement of VOC sources in the form of OSB boards and an air freshener (Source: Ghent University).

2.4 Outcomes - significant results found.

The project produced the following results:

- A clear definition and presentation in a “Dashboard” of indoor pollution sources to be considered when assessing the impacts of chemical emissions and other pollutants in dwellings. The dashboard balances these considerations with a presentation of the energy of performance of a building under study.
- A tool was developed to guide collecting of the most relevant indoor pollutant sources according to the selections elected in the activity on definition of indicators and presenting them graphically on the “Dashboard” for overview and prioritization.
- New data on chemical emissions from building products as they are influenced by temperature and humidity. A paradigm has been developed according to a so-called “similarity approach” whereby data from for instance moisture transfer performances of building products can be used also in estimation of their properties for storage and emissions and chemical compounds.
- Three common exercises were described and documented with relation to chemical emissions from building product and modelling thereof. Data from these exercises have value in their own right, but can also be used in training of future experts in estimating and assessing the coupled transport phenomena involved with pollution processes in indoor environments.
- A platform has been set up for modelling/simulation of whole building performance of the complex and interacting processes of energy/thermal assessment of buildings with their moisture, airflow and chemical/atmospheric conditions. The platform was tested and documented by its use in a common exercise whereby conditions in a so-called PASSYS reference test cell were computed.
- A survey has been carried out comprising a varying set of stakeholders (architects and ventilation designers, facility managers, property developers and representatives of public authorities) who have expressed their opinions on challenges and desirable possibilities for designing and implementing advanced ventilation systems and their control for optimal

operation with respect to energy use and provision of good indoor environments. A total set of 24 themes have been discussed in this respect - many of which represented solutions that were exemplified as realized cases studies from which learnings could be collected.
- An overview was given of test methodologies to use in measurements campaigns/experiments to assess indoor climate and ventilation performance.
- A collection of field test of indoor climate performance of test chamber, and controlled field tests where emissions of pollutants and hygrothermal conditions were studied under varying exposures and operational conditions with regards to materials and ventilation.
- A collection of studies from high performance buildings in seven places spread in different geographies of the world. Apart from energy use and standard indoor climate parameters, the buildings were also characterised for their chemical indoor environment. The cases are indexed as an archive from which valuable data can be retrieved for research.

While Annex 68 has concentrated on collecting fundamental inputs in its field of research, it has led to the formulation of a new Annex 86 project, which will take the Annex 68 results further with a focus on practical and intelligent implementation of ventilation systems in residential buildings by use of smart components and materials.

3. Project Participants

Country	**Organization**
Austria	Universität Innsbruck
Belgium	Ghent University
Canada	Health Canada British Columbia Institute of Technology
China	Nanjing University
Czech Republic	Czech Technical University of Prague
Denmark	Technical University of Denmark
Estonia (observing country)	Tallinn University of Technology
France	LaSIE, Université La Rochelle LOCIE, Université de Savoie Saint-Gobain Recherche
Germany	TU Dresden
Korea	Korea Institute of Civil Engineering & Building Technology
The Netherlands	TU Eindhoven
New Zealand	Building Research Association of New Zealand
Norway	Norwegian University of Science and Technology Norwegian Institute for Wood Technology Norwegian University of Life Sciences
United Kingdom	University College London
USA	Syracuse University

A total of 39 institutions from the above countries have contributed to the project. The table lists only organizations with whom an official Letter of National Participation has been signed.

4. Project Publications

The project has delivered five reports and a database as listed below:

- Report on Metrics for high IAQ and energy efficiency in residential buildings
- Report on Pollutant loads in energy efficient residential buildings under in-use conditions
- Report on Modelling of IAQ and energy efficiency - review, gap analysis & categorization
- Guidebook on design and operation for high IAQ in energy efficient residential buildings
- 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.
- A database of VOC emissions for IAQ simulations