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IEA EBC Annex 68 – Consequences on ventilation and hygrothermal operation of buildings

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Abstract. The 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. Focus has been on emission of chemical pollutants from building products and use of ventilation to alleviate IAQ effects. The question has been whether new paradigms for demand control should be developed based on knowledge from this project.
The paper gives an overview of the project's activities with regards to:
- Gathering of laboratory and field data on pollution sources in buildings.
- Formulation of a so-called "similarity approach" to predict emissions of volatile organic compounds based on knowledge from moisture transfer properties.
- Gathering of a set of contemporary models to simulate the combined heat, air, moisture and pollution conditions of buildings and their assemblies.

Based on this background, the project has identified and described an extended set of amenable ways to optimize the provision of ventilation and air-conditioning and to assess possibilities to bring this knowledge into practice. The paper gives an overview of the suggested solutions and their conditions.

1. Introduction

The background for the IEA EBC Annex 68 project has been the fact that new dwellings or deeply renovated existing dwellings must be designed to be energy efficient, and have airtight structures. This could potentially lead 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, operators, and decision makers need the newest knowledge on how to operate ventilation to achieve this.

Thus, the objectives of Annex 68 were to:

- Set up the performance indicators required that combine the aspiration of a very high energy performance with an optimal IAQ.
- Gather existing data or provide new data on indoor pollutants and their properties.
- Determine or perfect the tools to help designers and managers in achieving the first objective.
- Develop guidelines for design and control strategies for buildings with low energy consumption that will not compromise the quality of the indoor environment.

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- Benefit from the latest advances in sensor and control technology, in order to identify methods to improve IAQ while ensuring minimum energy consumption for operations.
- Identify and analyse relevant case studies to examine and optimize performance.

The project prioritized to collect, process and combine knowledge from different scientific communities such as those relating to ventilation, chemical emissions from construction products, hygrothermal phenomena in buildings and their materials, and thermal simulation of buildings.

2. Definition of IAQ indicators

An 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 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 have been examined as the index will be considered useful if it properly accounts for the benefits of IAQ and energy in the design and operation of buildings.

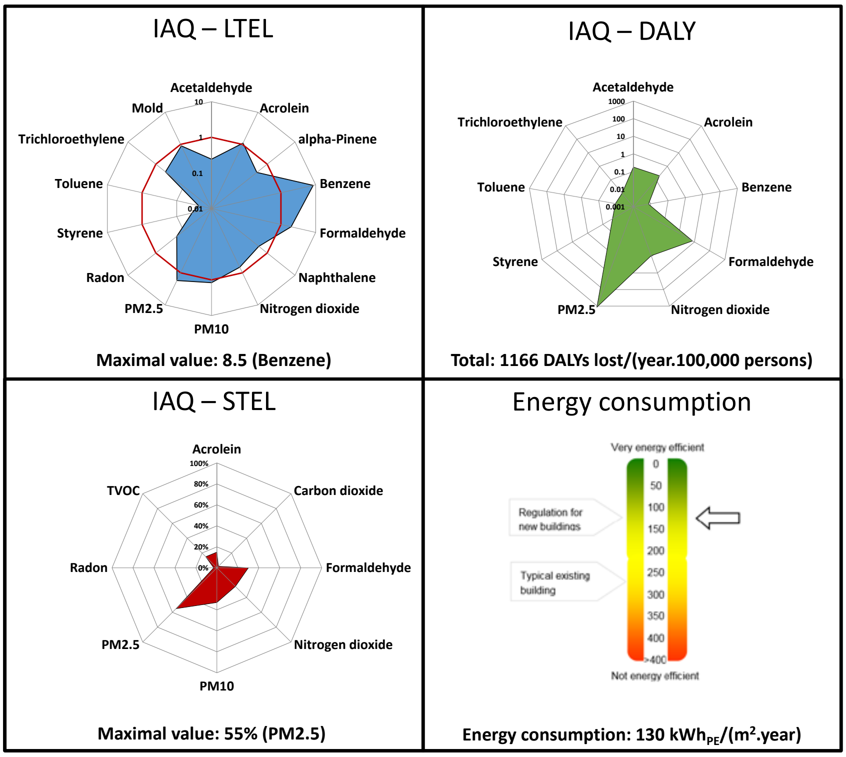


Figure 1. Graphical summary of indicators.

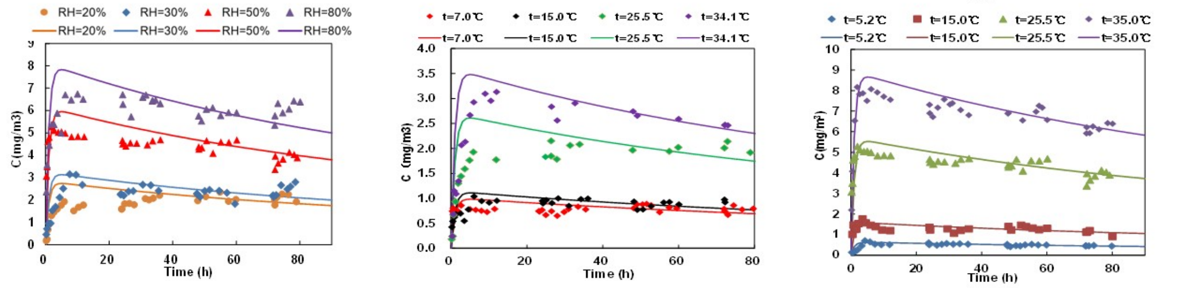
Three IAQ indices were proposed in the project based on Exposure Limit Values (ELVs) or DALY (Disability-Adjusted Life Years) as illustrated in Figure 1. The first index is the IAQ-STEL index (Short-Term Exposure Limit) and represents the risks associated with short-term exposure to pollutants. Its calculation 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) calculated as the ratio of the pollutant concentration over the ELV for long-term exposure, and the IAQ-DALY index 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 and be of relevance 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. These points are presented in [1].

3. Laboratory and field data on pollution sources 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. Collection of laboratory test results at the material and building scale has been part of this study. Specifically, the results were collected and analysed from tests for emission of volatile organic compounds (VOC) under various conditions of temperature, humidity and airflow, since such data in the context of combined exposures did not exist.

The specific main developments of the activity on pollution loads have been [2]:

- Analysis of the coupled 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.



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. C_0 is the initial emittable concentration, D_m the diffusion coefficient, and K the partition coefficient.

- 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 full-scale test chamber to assess the effects of pollutant sources and sinks, ventilation and air cleaning on IAQ. 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.
- A procedure to estimate model parameters using VOC emission data from standard tests in small chambers. Emission source models to assess the impact of VOC emissions from construction materials on the indoor pollution load beyond chamber test conditions and test period standard 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.

4. Similarity approach to predict emissions of volatile organic compounds

Particular attention has been paid to the integration of the transport and diffusion equations of VOCs in materials. 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 3) [2].

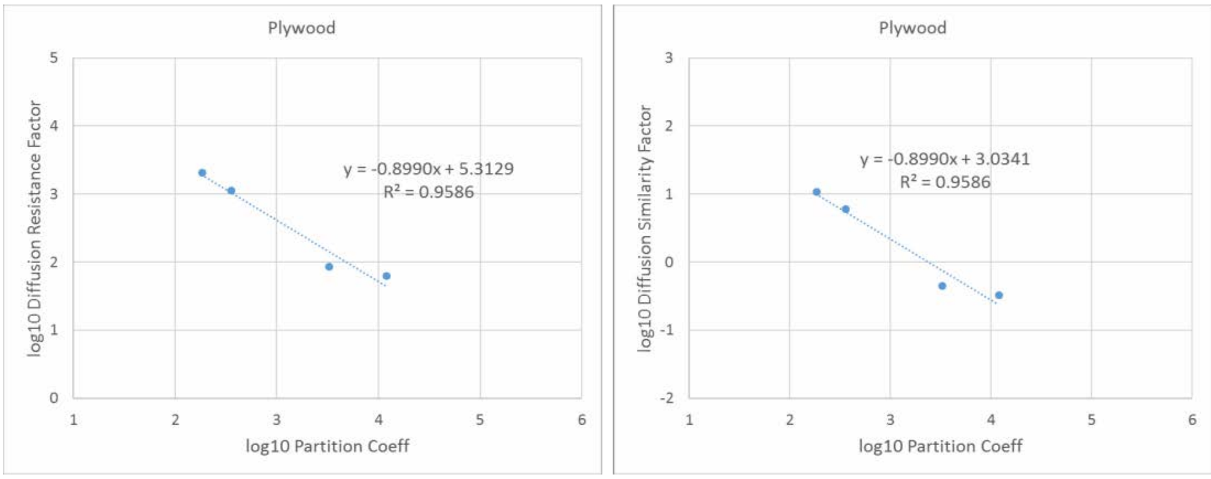


Figure 3. Similarity analysis for plywood.

5. Models to simulate combined heat, air, moisture and pollution conditions

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 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 [3]:

- 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.
- 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.

6. Building design and control strategies

The theory for how to obtain a high IAQ is in principle clear and straightforward. There exist international standards, national standards and building codes as well as many brochures, guidebooks and thematic web pages. However, how is the transition of all this knowledge into practice? How do the theoretical deliberations project into the daily life of architects and engineers? This transition, illustrated in Figure 4, was addressed by performing a literature review and a series of interviews among key stakeholders. The stakeholder survey helped to identify implementation barriers and operational challenges related to mechanical ventilation. Despite the fact that the survey included 44 interviews from six European countries, it cannot be considered representative for the whole of Europe. The results indicate that there exists a knowledge gap between "written knowledge" and how things actually work in practice. This can be related to the design, installation, commissioning and operation of ventilation systems.

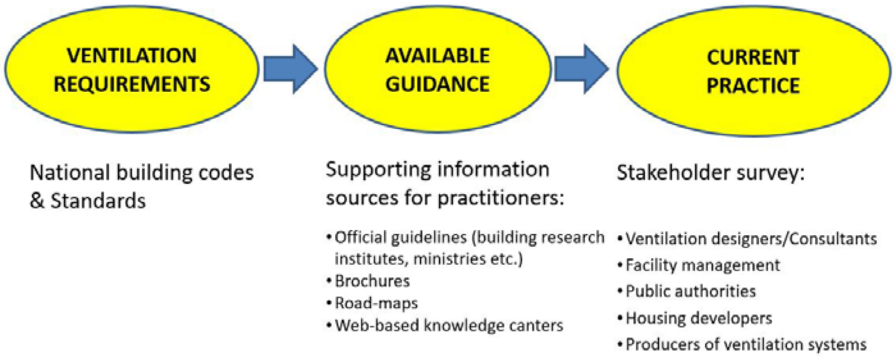


Figure 4. Intended transition from requirements to practice.

Overcoming knowledge gaps can be difficult. There exist certain work routines in the daily life of ventilation designers. National standards and requirements are interpreted in a certain way; the future building owner usually does not have special requirements regarding ventilation systems. Commissioning and maintenance in residential applications are often influenced by tight budgets. In the case of commercial buildings, voluntary certification schemes help to involve the building owner. It is the building owner who usually comes with wishes to fulfil a particular certification level. It adds prestige and helps to acquire future tenants. The same model is rarely applicable in residential projects. Here, a good example in the form of a case study, which clearly describes obtained benefits, can help to escape from established routines.

The target audience for the results of this activity are stakeholders involved in enabling better IAQ in new and renovated residential buildings. This especially includes architects, ventilation designers, facility managers, property developers and employees of public authorities.

6.1. Review of national requirements and guidelines

A review of the national building regulations and standards in Austria, Belgium, Denmark, Estonia, France, Norway and the United Kingdom (UK) was conducted with special attention being paid to key aspects, such as recommended ventilation systems (if any), background and nominal ventilation rates, supply and extract airflows from habitable rooms, bathrooms, toilets and kitchens, state-of-the-art system typology, requirements for heat recovery, specific power input (SPI) and demand controlled ventilation (DCV), see [4].

Additionally, the Annex 68 participants reviewed 33 guidelines for practitioners from the seven countries. Target groups of the guides were mostly heating, ventilation and air-conditioning (HVAC) engineers, consultants and architects followed by housing developers, the construction industry and private owners. The review of the guidelines is also included in [4].

6.2. Stakeholder survey

Gathering information about current practices in design, operation and commissioning of residential ventilation systems was based on semi-structured interviews (44 in total) performed in 2017 in the countries participating in Annex 68: Austria (6), Belgium (10), Denmark (5), Estonia (4), France (5), Norway (7) and the UK (7). Five different interview templates were used dependent on the target group of stakeholders to be interviewed: Ventilation designers/consultants, Facility management companies / Building administration, Public authorities, Housing developers and Producers of ventilation systems. The first part of each interview was focused on the stakeholders' opinion regarding state-of-the-art ventilation systems installed in low-energy dwellings. The second part focused on barriers and problems during design, commissioning, operation and maintenance as well as on key changes in legislation, technical measures, financial incentives, market requirements and outreach programs that stakeholders found needed to provide high IAQ in energy efficient homes. The results of the survey are reported in detail in [4]. The survey provides a valuable snapshot of current practices and insights into potential barriers, however, due to the relatively low number of responses from each country, the results can only be treated as trends seen in the countries.

6.2.1. Mechanical ventilation in low energy dwellings – current practice

With respect to types of ventilation systems, the interviews revealed that mechanical ventilation (MV) systems are dominant in low energy dwellings, and with heat recovery (MVHR) in most countries. In Austria, natural ventilation (NV) and mechanical (MEV) systems are receiving comparable attention. In Belgium, NV is barely applied due to problems with achieving the required airflows. Mechanical supply ventilation (MSV) is not popular for practical reasons and concerns with moisture management of the façade in pressurized dwellings. MEV is being pushed out of the market by MVHR in low energy dwellings, however, it is still installed in many new apartments and dwellings and it is commonly used in renovated constructions. Demand control ventilation (DCV) MEV was mentioned by most of the Belgian stakeholders as the dominant type of MEV. In France, exhaust-only humidity-based DCV systems including humidity-sensitive trickle ventilators and extract devices seem to be the state of the art in new low-energy residential buildings. The dominance of MVHR systems is obvious in Scandinavian countries and for dwellings with air permeability lower than 5 $m^3/m^2/h$ (50 Pa) in the UK. Centralized air handling systems are often used in social housing, because inhabitants are not interested in maintaining a decentralized system and it is more expensive to service several individual units.

In the interviews from Estonia, the separated exhaust system for a kitchen hood was mentioned. Most of the respondents from Austria referred to the use of recirculating hoods. In contrast to that, the Norwegian stakeholders noted that it is common to connect the kitchen hood to the ventilation system. The Norwegian, Danish, Belgian, France and the UK designers stated that in their systems fresh air is supplied into bedrooms and living rooms and extracted from bathrooms, toilets and kitchens (i.e. a cascade system). When designing/implementing balanced systems in Austria, the so-called extended cascade systems seem to be preferred, where fresh air is supplied into bedrooms and extracted from wet rooms and the kitchen. The living room is purely treated as an overflow zone, and in this way the total number of supply air terminals and supply air rate are reduced. Application of DCV appears to be rare in the countries participating in the survey, except in France and Belgium. Answers to the question regarding minimum required ventilation rates and IAQ in dwellings indicated that the stakeholders were mostly aware of the lower limits for ventilation airflows imposed by particular building codes. More country specific details on current practices can be read in the final report of Subtask 4 of Annex 68 [5].

6.2.2. Barriers and problems

Barriers and problems identified in the survey were categorized based on the building's procurement stage: design (incl. decision making, concept design and detail design), construction (incl. installation and commissioning) and post-handover (incl. operation and maintenance). The main problems along with the number of times each item was raised in the interviews are shown in Table 1. All collected responses regarding the barriers and problems are published in [4].

6.3. Inspiration for design and operation

The report from this activity has been built up as a series of research studies, building projects or methodological approaches that can provide an innovative insight for the reader [5]. The studies are presented in a fixed structure comprising: ***Objectives, description and methods*** – presenting the background, aim and main methodology used in the cases. ***Main results and findings*** – documenting how the objectives were fulfilled. ***Conclusions and lessons learned*** – representing a direct connection between the case studies and practice, while addressing issues that practitioners can directly transfer into their daily practices.

Table 1. Barriers and problems associated with mechanical ventilation of low-energy dwellings identified in the survey. The numbers indicate the frequency each item was raised in the interview.

Stage	Barrier or problem	Total (of 44)
Design	Spatial requirements & duct routing	24
	High capital cost of MVHR systems	10
	Coordination within all design stakeholders (and customers)	6
	Complexity of MVHR (incl. auxiliary systems)	3
	Difficult to find an appropriate location for exterior in-/outlets	3
	Difficult to position the units to minimize noise	2
Construction	Poor quality in system installation & commissioning	9
	Lack of qualified/experienced installers and lack of quality	4
	Balancing and adjustment of flow rates	3
	Designers are often not involved in commissioning	2
Post-handover	Maintenance issues	16
	Noise	11
	No proper support for tenants / Lack of occupant knowledge	5
	Draughts / covering grids	4
	Odours	2

Table 2 gives an overview of topics and challenges addressed in the report and their relation to the different phases in the design, construction or operation process of a ventilation system. The addressed topics are marked with different colours while the different phases are classified in columns.

7. Conclusion - significant results found in Annex 68

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 performance.
- A tool was developed to guide collection of the most relevant indoor pollutant sources according to the selections 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.
- 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.
- 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.

As a follow up of IEA EBC Annex 68 a new project, IEA EBC Annex 86 on “Energy Efficient Indoor Air Quality Management in Residential Buildings”, will focus on IAQ system management. The new project may tackle some of the issues mentioned in this paper’s Section 6.2.2.

Table 2. Overview of case studies.

		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			Spatial requirements; Refurbishment		
3.2	Ambient air filtration in highly energy efficient dwellings with mechanical ventilation		Health & Comfort			
3.3	Development of a compact ventilation system for facade integration			Spatial requirements; Refurbishment		
3.4	Volatile Oorganic Compounds exposure due to Floor heating systems versus Radiator heating	Health & Comfort				
3.5	Control strategies for mechanical ventilation in Danish low-energy apartment buildings		Health & Comfort; Cost & Energy consumption			
3.6	Response of commercially available Metal Oxide Semiconductor Sensors under air polluting activities typical for residences			Comissioning		
3.7	Impact of multi zone air leakage modelling on ventilation performance and indoor air quality assessment in low-energy houses		Health & Comfort			
3.8	Towards a better integration of indoor air quality and health issues in low-energy dwellings	Health & Comfort				
3.9	List of key pollutants for design and operation of ventilation in low-energy housing	Health & Comfort				
3.10	Definition of a Reference Residential Building Prototype for Evaluating Indoor Air Quality and Energy Efficiency Strategies	Health & Comfort				
3.11	Temperature dependent emissions of Volatile Organic Compounds from building materials	Health & Comfort				
3.12	Detailed modelling of Indoor Air Quality to improve ventilation design in low energy houses		Health & Comfort			
3.13	Mechanical ventilation system in deep energy renovation of a multi-story building with prefabricated modular panels			Spatial requirements		
3.14	Simplifying Mechanical Vventilation with Heat Recovery systems			Health & Comfort; Refurbishment		
3.15	Design of room-based ventilation systems in renovated apartments			Comissioning; Refurbishment		
3.16	Introduction to the Coupled Heat, Air, Moisture and Pollutant Simulation CHAMPS modeling platform	Health & Comfort; Cost & Energy consumption				
4.1	House owners’ experience and satisfaction with Danish Low-energy houses - focus on ventilation					User satisfaction
4.2	Development and test of quality management approach for ventilation and indoor air quality in single-family buildings				Quality of installation	
4.3	Applications of the Promevent protocol for ventilation systems inspection in French regulation and certification programs				Comissioning	
4.4	Long-term durability of humidity-based demand-controlled ventilation: results of a ten years monitoring in residential buildings				Quality of installation	
4.5	Practical use of the Annex 68 Indoor Air Quality Dashboard					Health & Comfort
4.6	Performance evaluation of Mechanical Extract Ventilation (MEV) systems in three ‘low-energy’ dwellings in the UK					Quality of installation
4.7	Indoor air quality in low energy dwellings: performance evaluation of two apartment blocks in East London, UK					Quality of installation
4.8	Continuous-commissioning of ventilation units in multi-family dwellings using controller data				Quality of installation	Comissioning

Addressed topics:
- Health & Comfort
- Spatial requirements
- Cost & Energy consumption
- Refurbishment
- Comissioning
- Quality of installation
- User satisfaction

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