DTU Library

Key findings of IEA EBC Annex 68 - Indoor Air Quality Design and Control in Low Energy Residential Buildings

Rode, C.; Abadie, M.; Qin, M.; Grunewald, J.; Kolarik, J.; Laverge, J.

Published in:
I O P Conference Series: Materials Science and Engineering

Link to article, DOI:
10.1088/1757-899X/609/3/032057

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Key findings of IEA EBC Annex 68 - indoor air quality design and control in low energy residential buildings

To cite this article: C Rode *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **609** 032057

IOP Conf. Series: Materials Science and Engineering **609** (2019) 032057 doi:10.1088/1757-899X/609/3/032057

Key findings of IEA EBC Annex 68 - indoor air quality design and control in low energy residential buildings

C Rode[1], M Abadie[2], M Qin[1], J Grunewald[3], J Kolarik[1] and J Laverge[4]

[1]Technical University of Denmark, Denmark; [2]Université La Rochelle, France; [3]TU Dresden, Germany; [4]Ghent University, Belgium.

[*] car@byg.dtu.dk

Abstract. The overall objective of the "Annex 68" Project, which belongs to the International Energy Agency's "Energy in Buildings and Communities" Implementing Agreement, 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 in a practically applicable guide. The strategies shall facilitate the possibility to design and operate residential buildings with minimal energy use, while ensuring impeccable indoor climates.

The project completes its working phase by the end of spring 2019. 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. The purpose has been to identify and describe amenable ways to optimize the provision of ventilation and air-conditioning. The paper gives an account of the project highlights.

1. Introduction

IEA EBC Annex 68 was approved in Nov. 2014 to commence the preparation phase, and the working phase was commenced in Nov. 2015. By Nov. 2018 the project has been in action for 3 years and has participation from researchers that represent 21 institutions from 14 countries.

The overall objective is to provide a generic guideline for the design and operational strategy of residential buildings which have minimal energy consumption, and at the same time maintain a very high standard regarding Indoor Air Quality based on the control of sources, sinks and flows of heat, air, moisture, and pollutants under in-use conditions.

This is done by gathering the existing scientific knowledge and data on pollution sources in buildings, models on indoor hygrothermal and air quality as well as thermal systems, and looks to ways to optimize the provision of ventilation and air-conditioning. Gaps of knowledge are identified and filled, not least by establishing links between knowledge that exist in the field of indoor air chemistry, modelling, and HVAC technology and controls.

2. Strategy

The project addresses the following challenges within the framework of the Annex:

- To **set up the metrics** for required performances, which combine the aspiration for very high energy performance with good indoor environmental quality.
- To gather existing or, when needed, establish new **data about indoor pollutants** and properties pertaining to heat, air and moisture conditions that will be needed for the above analysis.
- To **identify and configure models and existing tools** that will be needed to assist designers and managers of buildings in achieving the first key objective.

IOP Conf. Series: Materials Science and Engineering **609** (2019) 032057 doi:10.1088/1757-899X/609/3/032057

- To **develop design and control strategies** for energy efficient buildings that will not compromise the quality of the indoor environment. Operational parameters that are dealt with comprise, but are not be limited to the means for ventilation and its control, thermal and moisture control and air purification strategies - and their optimal combination.
- To benefit from recent advances in **sensor and control technology**, which may in part be model-based, to identify methods to enhance indoor air quality while ensuring minimal energy consumption for operation.
- To identify and investigate relevant **case studies** where the above-mentioned performances are examined and optimized.
- A flagship outcome of the project will be a **guidebook** that documents and demonstrate to stakeholders how the knowledge, tools and data brought forward in the project can be used in design and operation of new and refurbished residential buildings, such that they can have impeccable indoor air quality while being nearly zero energy buildings.

3. Structure

3.1 Subtask 1 Defining the metrics

A major obstacle to integrating energy and IAQ strategies in building design and optimization is the lack of a single index (marker) which quantitatively describe the IAQ and allow comparison with the indices describing energy use. Such an index will also quantify the benefits of different methods for achieving high IAQ and can be used in parallel comparison with consequences for energy and greenhouse gas emission.

3.2 Subtask 2 Pollutant loads in residential buildings

An obstacle to integrating energy and IAQ strategies is the lack of reliable methods and data for estimating pollutant loads in residential buildings in the way heating/cooling loads are routinely estimated. This subtask collects existing data and to a limited extent provides new data about: properties for transport, retention and emission of chemical substances in new and recycled materials, and particle transport in residential buildings under the influence of heat, airflow and moisture conditions. Collection of results from lab tests on material and room level are part of this study. Specifically, results are collected and analysed from tests of emission of harmful compounds under various temperature, humidity and airflow conditions, since such data under combined exposures generally have not existed until today.

3.3 Subtask 3 Modelling - review, gap analysis and categorization

In the past, many models have been developed in the field of building performance simulation (e.g. building design, life cycle analysis and energy retrofit). However, existing knowledge has so far still been inadequate for predicting the combined effects of hygrothermal conditions and chemical reactions on the indoor pollution species and concentrations. In light of recent revelations of the importance of secondary emissions such as Ozone-initiated indoor air and surface chemistry, a modelling approach of the effects of combined heat, air, moisture and pollutant (CHAMPS) transport and their impact on energy and IAQ shall be accomplished.

A review, gap analysis and categorization of existing models and standards are carried out within Subtask 3. Validated reference cases are collected and developed by use of contemporary whole building analysis tools and methods to predict the hygrothermal conditions, absorption and transport of humidity and chemical compounds, as well as energy use within buildings. The whole-building perspective is realized by integral consideration of indoor air and building envelope, building users and the building services systems. The feasibility of implementing reduced order models for prediction of IAQ within existing Building Energy Simulation tools is investigated.

3.4 Subtask 4 Strategies for design and control of buildings

This subtask applies the results of previous subtasks (Indoor Air Quality metrics, pollution/emission models and databases developed in the Subtasks 1, 2 & 3 and experiences from the field studies ST5) together with existing knowledge to devise optimal and practically applicable design and control

strategies for high IAQ in residential buildings. The strategies take into account requirements for IAQ based on current standards as well as newly developed metrics based on health effects. Optimal strategy is understood as one that takes into account building energy performance, user comfort and health conditions. A matrix of different strategies is created to evaluate possibilities for win-win solutions (excellent IAQ at low energy consumption) as well as other alternatives that will ensure high IAQ.
Use of models and databases developed under the Annex enable addressing new paradigms for multi-scale and local thermal and air quality management including demand controlled ventilation that consider the transport of chemical compounds to and from the indoor atmosphere. The subtask takes into account recent advances in sensor technology to identify ways to optimize IAQ without compromising on the energy efficiency.

3.5 Subtask 5 Field measurements and case studies
Subtask 5 investigates and identifies relevant case studies through a literature survey and it runs measurement campaigns, in well-known field test buildings, to provide data for investigation and validation in Subtask 1-4. Several sites and climates are included, and the field tests include buildings declared as being energy efficient or recently refurbished to become so. The field tests focus on testing and demonstrating in practice which low energy operational strategies can be used that will provide amenable indoor environments. Subtask 5 tests buildings with the ventilation strategies, both current and novel, that are identified in Subtask 4.
The tests include studies of new ventilation patterns in highly energy efficient residential buildings based on improved airtightness, increase insulation, use of materials, and also new residential behaviour. The field tests are carried out in cooperation with industry partners from the previous subtasks and with building owners. The subtask involves engineers and building owners/operators from the studied buildings. The measurement results are used for common exercises in Subtask 3 and to prove guidelines developed in Subtask 4.

4. Selected key findings
4.1 Subtask 1 Defining the metrics
Subtask 1 has completed in 2017. It was planned to be only a 1 year activity in which the objective was to develop the metrics that would allow assessing the performance of solutions for high indoor air quality in low-energy residential buildings. The Subtask 1 report has been published as an AIVC Contributed Report n°17 [1] in October 2017. Results have been presented during an Annex 68 Workshop of the 7th International Building Physics Conference (Sept. 2018). A column for the ASHRAE Journal summarizing the main findings of Subtask 1 has been published in January 2019 [2]. Hereby, Subtask 1 has completed its mission, but remains as a “dormant” activity, which can be activated again should new information come up pertaining to metrics for IAQ and energy efficient buildings.

4.2 Subtask 2 Pollutant loads in residential buildings
This subtask has organized a literature survey and made researcher contacts to gather relevant data and existing knowledge on major pollutant sources and loads in residential buildings due to building materials and assemblies, including existing source and sink models. A series of datasets have been identified including data from NRC’s MEDB-IAQ project, SU/MIT/Tsinghua’s ASHRAE projects, U. of La Rochelle’s PANDORA, databases from Shenzhen IBR and Tsinghua University.
Three experimental studies have been carried out:

- The first one is to study the combined effects of temperature and humidity on VOC emissions from different building materials. Different VOCs are measured for two different materials. The data will also be used to validate the existing models as well as suggesting new models for correlations between the emission factors and environmental conditions [3] [4] [5]
- The second is a field measurement in the P+ building in Wujin, China to study the relationship between IAQ and different ventilation/ air cleaning strategies and building energy consumption. The tests were started in March 2017, and the plan was to carry out measurements in four seasons. The first round (one year) was completed in March 2018. The test data will also be

used to validate the models developed in Task 3, and provide a case study for Tasks 4 and 5 [6] [7]

- Small-scale environmental chamber tests were conducted at Syracuse University to investigate the adsorption and desorption of VOCs and SVOCs on building materials and furnishing. The data will be combined with previous data to further evaluate and develop sink models.

A theoretical correlation between the emission rate and indoor temperature and relative humidity has been derived.

- A procedure for the definition of reference buildings for estimating the pollution loads, IAQ and energy analysis for different countries/climates has been proposed. An example is provided for a detached house in the Northeastern region of the U.S. including house specification, DesignBuilder/E+ simulation results for energy consumption, and IAQX simulation results for VOCs. The test case has been used for the Common Exercise 1.
- A method and procedure of using a full-scale chamber to evaluate the effects of emission sources and sinks, ventilation and air cleaning on IAQ is developed. Two cases were defined with experimental data, one for a simple source (particle board), and the other with mock up for a room with vinyl floor, ceiling tiles, painted gypsum wallboards, and a desk. The test cases has been used for the Common Exercise 2.
- In order to evaluate the impacts of VOCs emissions from building materials on the indoor pollution load beyond the standard chamber test conditions and test period, mechanistic emission source models have been developed in the past. However, very limited data are available for the required model parameters including the initial concentration (C_{m0}), in-material diffusion coefficient (D_m), partition coefficient (K_{ma}), and convective mass transfer coefficient (k_m). A procedure has been developed for estimating the model parameters by using VOC emission data from standard small chamber tests. The procedure uses the measured data to estimate initial values of the model parameters and refines the estimates by multivariate regression analysis of the data. The measured concentration data are first normalized by the average value of air concentration [8].

Subtask 2 has published three common exercises based on the following descriptions:

- A procedure for definition of reference buildings for estimating the pollution loads, IAQ and energy analysis for different countries/climates.
- A method and procedure of using a full-scale chamber to evaluate the effects of emission sources and sinks, ventilation and air cleaning on IAQ.
- Development of a Procedure for Estimating the Parameters of Mechanistic Emission Source Models from Chamber Testing Data.

4.3 Subtask 3 Modelling - review, gap analysis and categorization

In this subtask, the further consolidation of the so-called "similarity approach" was targeted in ST3 as part of the Common Exercise: "Development of a paradigm for work with models by definition of reference cases with focus on specific physical/chemical processes/effects in the field of building energy performance under high IAQ conditions". The similarity approach implements a methodology to predict VOC transport and storage parameters for arbitrary VOC-material combinations.

The methodology uses existing data on diffusion and absorption measurements of VOCs in porous building materials (dual chamber experiment) to establish similarity relations between water vapour and VOCs. The derived similarity relations should help to provide enough data for continuation of the common exercise with VOC emissions from building materials.

Activities of Subtask 3 mainly include:

- Implementation of a VOC mass balance equation in the DELPHIN6 program
- A VOC mass balance equation has been implemented to DELPHIN6 capturing adsorption, emission and diffusion processes of a single VOC component in porous materials. A documentation of the implemented model has been prepared about this activity.
- Review and definition of similarity variables, and establishment of diffusion similarity relations

- Different diffusion and partition coefficients are discussed and two similarity variables, the diffusion similarity factor and the partition similarity factor are introduced.
- A preliminary hypothesis is established on the basis of the CHAMPS-BES software database. Since the data is unreferenced, average quantities are used to see just a trend rather than a sound relation.
- Annex ST2 delivered reference data on diffusion and partition coefficients for material / VOC combinations. Based on this data, the preliminary hypothesis is substantiated.
- Diffusion similarity relations could be found and the relation between diffusion similarity factors and material properties could be consolidated.

4.4 Subtask 4 Strategies for design and control of buildings

Objective of the Subtask 4 is to gather results and approaches of the other subtasks in Annex 68 and present them in context with existing knowledge. The subtask aims to address optimal and practically applicable design and control strategies for high IAQ in residential buildings. The focus of the subtask is on energy efficient and comfortable mechanical ventilation in tight, low energy residences.
Activities of Subtask 4 mainly include:

- Activity 4.1 comprises of a review of relevant international information sources/activities related to IAQ design and control in residences: information sources include "written knowledge" like international standards, requirements from national building codes as well structured interviews with relevant stakeholders mapping the actual situation in the Annex 68 countries.
- Activities 4.2 and 4.3 focus on case studies that represent development or application of design and operational strategies. The case studies represent current research conducted by the Annex 68 participants as well as application of tools and methods from Subtasks 1, 2 and 3.
- Activity 4.4 represents preparation of an umbrella publication of the Annex 68 – "A guide through current challenges, innovative solutions and inspiring case studies on indoor air quality design and control in residences". The publication targets practitioners involved in design and operation of residences - architects, ventilation designers, facility managers, developers and building owners. Results of the Annex 68 subtasks as well as other relevant up to date research and demonstration will be presented in an easy to read form of "case studies". State of the art evaluation conducted in subtask 4.1 will provide the necessary context with respect to requirements as well as current practice, which still brings many challenges and barriers.

4.5 Subtask 5 Field measurements and case studies

The goal of subtask 5 is to investigate and identify relevant case studies and to run measurement campaigns in well-known field test buildings to provide data for investigation and validation.
Activities of Subtask 5 mainly include:

- 5.1 State of the art and measurement strategy: Summary of the literature review on necessary parameters, possibly accompanied by guideline values, which are necessary to describe the IAQ in the tested buildings. Development of a methodology to obtain the relevant values needed to study, simulate and verify IAQ in highly energy efficient residential buildings.
- 5.2 Controlled measurements: In labs and test houses available at the universities and institutes involved in Annex 68.
- 5.3 In situ measurements: Examples of residential buildings, which are either new or existing (possibly retrofitted) buildings, will be chosen for investigation from different geographical regions. It shall be possible in the chosen buildings to adjust the relevant operational parameters, e.g. for ventilation control, and to monitor the relevant performance parameters for energy consumption and indoor environment.
- 5.4 Analysis and dissemination: The results of ST5 will be a set of demonstrations and analyses of residential buildings that achieve optimal energy and good indoor environmental conditions under various geographical and climatic situations.

5. Conclusion

As both new and refurbished residential buildings are being significantly more energy efficient than in the past, and since new forms of demand controlled ventilation may be introduced, it is of paramount interest to ensure that this will not put the atmospheric quality of the indoor environment at risk. Annex 68 has gathered contemporary knowledge regarding indoor pollutants and possibilities to model the atmospheric conditions, as well as a number of field test experiences from many countries regarding IAQ in highly energy efficient residential buildings. Annex 68 has delivered new results in experimental evidence on the combined effects of thermal and humidity conditions on VOC emissions, in modelling the interacting phenomena, and in situ measurements. A set of common Exercises has been developed and exercised in these fields, and a flagship outcome will be a guide for building operation developed in cooperation with manufacturers, consultants, users and authorities.

References

[1] Abadie M. and Wargocki P. 2017. Indoor air quality design and control in low-energy residential buildings - Annex 68 - Subtask 1: Defining the metrics. *AIVC Contributed Report* **17**. Air Infiltration and Ventilation Centre

[2] Abadie M, Wargocki P, Rode C and Zhang J. JAN 2019. Proposed metrics for IAQ in low-energy residential buildings. *ASHRAE Journal* 62-65

[3] Liang W, Lv M and Yang X, 2016. The combined effects of temperature and humidity on initial emittable formaldehyde concentration of a medium-density fiberboard. *Building and Environment*, **98** 80-88

[4] Liang W, Yang S, and Yang X. 2015. Long-term formaldehyde emissions from medium-density fiberboard in a full-scale experimental room: emission characteristics and the effects of temperature and humidity. *Environ. Sci. Technol.* **49 (17)** 10349-56

[5] Liang W, Lv M and Yang X. 2016. The Effect of Humidity on Formaldehyde Emission Parameters of a Medium-Density Fiberboard: Experimental Observations and Correlations. *Building and Environment* **15** 110-15

[6] Cheng S, Ma Y and Qin M. 2018. The energy saving performance of heat recovery ventilation system in residential buildings in the summer of hot-summer and cold-winter zone in China. *Proceedings of 7th International Building Physics Conference, IBPC2018* 419-24

[7] Liang W and Qin M. 2017. A simulation study of ventilation and indoor gaseous pollutant transport under different window/door opening behaviors. *Building Simulation*, **10(3)** 395-405

[8] Lui Z, Nicolai A, Abadie M, Qin M and Zhang J. 2018. Development of a Procedure for Estimating the Parameters of Mechanistic Emission Source Models from Chamber Testing Data. *Proceedings of 7th International Building Physics Conference, IBPC2018* 1185-90