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IEA Project on Indoor Air Quality Design and Control in Low Energy Residential Buildings

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Abstract

Both new and renovated existing buildings will in the future need to be optimized in such a way that can achieve to have nearly no energy use while still providing impeccable indoor climates. Since such buildings can already be assumed to be very well insulated, airtight, and to be equipped with heat recovery systems, one of the next focal points to limiting energy consumption for thermally conditioning the indoor environment will be to possibly reducing the ventilation rate, or to make it in a new way demand controlled. However, this must be done such that it has no have adverse effects on Indoor Air Quality (IAQ).

Annex 68, Indoor Air Quality Design and Control in Low Energy Residential Buildings, is a project under IEA's Energy Conservation in Buildings and Communities Program (EBC), which will endeavor to investigate how future residential buildings are able to have very high energy performance whilst providing comfortable and healthy indoor environments. New paradigms for demand control of ventilation will be investigated, which consider the pollution loads and occupancy in buildings. The thermal and moisture conditions of such will be considered because of interactions between the hygrothermal parameters, the chemical conditions, ventilation and the wellbeing of occupants.

A flagship outcome of the project is anticipated to be a guidebook on design and operation of ventilation in residential buildings to achieve high IAQ with smallest possible energy consumption.

Keywords – IAQ, Energy efficiency, Residential Buildings, Indoor pollutants, Ventilation control

1. Introduction

The Annex has the following specific key objectives:

- To develop design and control strategies for energy efficient buildings that will not compromise the quality of the indoor environment. Operational parameters that will be dealt with will comprise, but not be limited to the means for ventilation and its control, thermal and moisture control and air purification strategies - and their optimal combination.
- To set up the metrics for required performances which combine the aspiration for very high energy performance with good indoor environmental quality.
- To identify or further develop the tools that will be needed to assist designers and managers of buildings in achieving the first key objective.
- To benefit from recent advances in sensor technology and controls, e.g. model based control principles, to identify methods to enhance indoor air quality while ensuring minimal energy consumption for operation.
- To gather existing or provide new data about indoor pollutants and properties pertaining to heat, air and moisture transfer that will be needed for the above analysis.
- To identify and investigate relevant case studies where the above mentioned performances can be examined and optimized.
- To disseminate about each of the above findings.

1.1 Target Audience

The project addresses the following primary stakeholders:

- Building designers (engineers and architects),
- Suppliers of HVAC and control systems
- Suppliers of materials for building structures and indoor furnishing,
- Providers of building management systems
- Facility managers.

The project shall also address the interests of building owners and users, as well as authorities that stipulate the building regulations and who administrate the rules. The perspective is that the project may indicate ways how future energy classes for buildings can be stipulated as being dependent on which pollution targets they can achieve.

1.2 Role of Ventilation in IEA EBC Annex 68

The rationale of carrying out the proposed Annex is that buildings in the future will have to be designer and/or optimized just to the limit in order to become as close as possible to being zero (or even “plus”) energy buildings. This means that the ventilation will also be reduced to just the absolutely necessary, while the quality of the indoor air must not be sacrificed. There is a need to adopt and demonstrate an integral view in the optimization that consider the sources, sink and transport of relevant pollutants that occur in buildings against the effect of ventilation.

The project is one of several past, recent and ongoing IEA EBBC Annex projects where ventilation plays a role. The AIVC (being the perpetual IEA EBC Annex 5) is one of them. Others are IEA EBC Annex 59, 60, 61, 62, 66, 67 and 69, and the EBC Executive Committee has facilitated a platform for coordination between them.

1.3 Annex Duration

The project has commenced its working phase by the end of 2015, and is planned to run until the end of 2018 [1].

2. Subtask 1: Defining the Metrics

Subtask 1 aims at summarizing the current knowledge on target pollutants for residential buildings and at evaluating indoor air quality (IAQ), i.e. how to define indices that provide useful information allowing to achieve low risks for health in indoor spaces, and how to enable the comparison of solutions for achieving high IAQ taking into account energy efficiency. These objectives will be achieved by compiling and analysing previous studies on the subject available in the literature. A first step will consist of determining a list of target pollutants commonly found in residential buildings and by identifying the pollutants that are listed by cognizant authorities as harmful. It will be verified whether they are present in recent low energy residential buildings at the concentrations, which can surpass the recommendations of the different authorities. Additionally, the existing IAQ metrics, e.g. [2], will be reviewed to propose the scientifically sound index (or set of indices) for the evaluation of indoor air pollution. Different endpoints will be considered and the metric scheme(s) defined. The last part of this subtask will be dedicated to examining the energy implications of the proposed metric scheme(s) to ensure that there is no unreasonable increase of energy consumption. Figure 1 gives a schematic overview of Subtask 1.

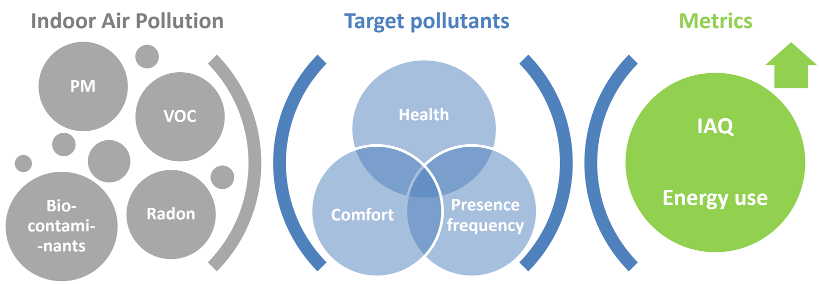


Figure 1: Schematic overview of Subtask 1.

3. Subtask 2, Pollutant Loads in Residential Buildings

One obstacle to integrating energy and IAQ strategies for buildings is the lack of reliable method and data for estimating pollutant loads in buildings in the way heating/cooling loads are routinely estimated. Subtask 2 of IEA EBC Annex 68 is to collect existing data and to a limited extent provide new data about properties for transport, retention and emission of chemical substances in new and recycled materials under the influence of indoor heat and moisture conditions. Formaldehyde, benzene and other harmful volatile organic compounds (VOCs) are of main concern. Collection of results from lab tests on material and room level will be part of this study. Specifically, results will be collected and analysed from tests of emission of harmful compounds under various temperature, humidity and airflow conditions, since such data under combined exposures generally do not exist today.

3.1 Activities

First the Subtask will organize a literature survey and make researcher contacts to gather relevant data and existing knowledge on major pollutant sources and loads in buildings, including models.

Laboratory testing and model setup to provide examples of new types of data which shall be beneficial to improve knowledge on combined effects that must be taken into consideration in order to achieve new paradigms for energy optimal operation of buildings. It is anticipated that the Subtask will gather data about combined effects describing how temperature and moisture conditions influence the emission and sorption of various pollutants in materials.

3.2 Stakeholders Involved

It is anticipated that manufacturers of building materials, furniture, and inventory products shall be involved regarding testing and possible co-development of products that have minimal emission of harmful substances or which may have function to absorb indoor pollutants. In addition, architects, HVAC engineers and developers will also be possibly involved in different stages of “high IAQ, low energy” building projects.

3.3 Deliverables

The Subtask will end with some mechanistic emission source/sink models and IAQ simulation tools for estimating the net loads of pollutions over time under realistic environmental conditions. This will be published in scientific journal articles and in a project report.

Furthermore, the Subtask will produce a database of emission and transport properties of materials for use in the models that will be developed and used in the project’s Subtask 3.

Finally, the Subtask will produce a database of common pollution loads in new and existing buildings.

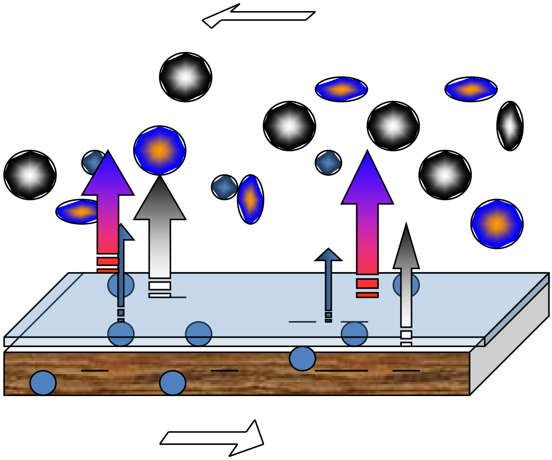


Figure 2: Pollutant emission from materials

4. Subtask 3, Modelling - Review, Gap Analysis and Categorization

4.1 Problem Statement

In the field of building energy performance and indoor air quality, a variety of simulation tools with specific advantages and disadvantages have been already developed or are being developed [3]. Given the number of different simulation programs, it raises the central question of quality assurance. Integral planning tools are used in highly heterogeneous and different areas that have been considerably widened alone in construction engineering in recent decades. However, until now no general quality requirements are available, i.e. requirements on solution accuracy of these tools for well-defined application scenarios covering a wide range of planning tasks in construction engineering.

For the quality assurance of whole building energy simulation tools, just a few standards have been developed [4]. These standards provide reference solutions for very simplified use cases which do not capture the impacts of thermal environment, building materials and envelope, outdoor pollutants, and indoor furnishing and occupant activities on the indoor air quality.

At the current stage, the certification of simulation tools being made solely by the author himself, and cannot always be verified by a third party. So the program codes are often not disclosed and detailed requirements on the quality of results are not formulated. At least one of these points must be met to ensure that calculations are understandable, comparable and reliable.

4.2 Objectives and Scope

The main objective of Subtask 3 “Modeling” (ST3) is the development of a modeling quality assurance methodology for building energy performance and indoor air quality simulation. ST3 thus supports improved comparability and traceability of simulation results and a move towards transparency and standardization. The implementation of the results of research projects in practice will be intensified. In the perspective, a formulation of requirements on permissible simulation tools for public legal evidence can be achieved.

4.3 Methodology

The quality assurance methodology for building energy performance and indoor air quality simulation tools has to be broken down into manageable individual tasks. Result deviations may occur for example due to different calculation equations and inaccuracies in the input parameters. It is therefore necessary to define clear and unambiguous provisions concerning the data models used and implement the widest possible standardization in this field.

With the help of validation cases (validated use cases), practical planning tasks are to be implemented in testable individual problems. Since the application scenarios are mapping at different levels of complexity, a methodology must be developed in order to separately analyze and quantify the various sources of error. The validation cases must be designed so that the model complexity builds gradually.

For development of the validation cases, a modelling framework will be implemented. The modelling framework will include a coupling technology, based on the already standardized Functional Mock-up Interface [5] for simulation coupling that allows the coupling of models that come from different developer domains.

Conceptually, the modelling framework for Coupled Heat, Air, Moisture and Pollutant Simulation (CHAMPS) will include a simulation master that integrates sub-models on a case-by-case basis. In addition, the modelling framework will be supported by shared databases of pollutant properties, sources and sink models, chemical reaction models, material properties and weather conditions.

4.4 Expected Outcomes

The general outcome of ST3 will be a new generation of validated tools, datasets and use cases that can be used to optimize for the minimal energy consumption that satisfies the needs with respect to indoor environmental quality, considering the IAQ metrics and pollution loads to be developed in Subtask 1 and 2, respectively. More specifically, the outcomes for ST3 will include:

- Survey and provision of knowledge about contemporary modeling capabilities in thermal whole building energy and hygrothermal analysis in combination with air flow and emission models.
- Development of a paradigm for work with these models such that they can be used as optimization tool for good building energy performance under high IAQ conditions.
- Development of new procedures that will be needed to model the interaction between energy efficient operation and high IAQ.
- Incorporation of the methods for analysis in modeling paradigms from other ongoing IEA activities, e.g. within IEA EBC Annex 60.

The identification of gaps in current modeling capabilities will initiate improvements and further developments of the simulation tools of IEA EBC Annex 68 participating partners.

5 Subtask 4: Strategies for Design and Control of Buildings

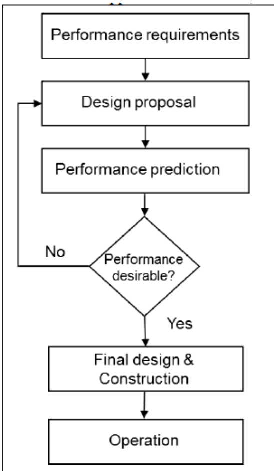
The objective of Subtask 4 is to identify and examine design and control strategies for energy efficient ventilation in residential buildings that ensure high IAQ. The ambition is that the strategies will go beyond the current common practice and actively utilize recent research findings regarding indoor air pollutants and combined heat, air and moisture transfer as well as benefit from recent advances in sensor technology and controls.

5.1 Approach

Subtask 4 will utilize results of previous subtasks of the Annex 68 together with existing knowledge to provide suggestions for optimal and practically applicable design and control strategies. The idea of Performance Based Design, as introduced by Kalay [6] will serve as a basic template for a workflow in the design process. This methodology is currently applied quite widely as a part of so called Integrated Design Process (IDP) or separately in various modifications [7]. Subtask 4 will try to support different stages of Performance Based Design for high IAQ. This approach is illustrated in Table 1. As it can be seen from the table, the subtask will exemplify how to support a “Design proposal” stage (see Table 1) with use of models and databases developed. This should enable addressing new paradigms for “multi-scale” air quality management like for example demand controlled ventilation in residences that considers indoor/outdoor transport of pollutants. With respect to energy performance, the subtask will exploit correlation factors between IAQ and energy consumption developed in Subtask 1. Our ambition is that such key indicators can be used in future standards and by legislators when specifying regulations for IAQ requirements in highly energy efficient buildings.

Because of the complexity of the assignment described above, the Subtask 4 will invite different stakeholders to actively participate in the project, share their practical experiences and provide feedback. Target stakeholders are mainly building designers, companies that provide ventilation systems and controls as well as housing associations, producers of prefabricated houses and facility management companies. Their involvement will start already at the beginning of the project. A stakeholder survey will be conducted in all countries participating in the Annex. It will be focused on current design practices, barriers and bottlenecks with respect to high IAQ design. The survey will serve as a complementary source of information to state of the art review.

Table 1 – Approach of Subtask 4; Performance Based Design workflow adopted from [7] and modified



Requirements for IAQ based on current standards, particular building codes in different countries, as well as newly developed metrics based on health effects.	Input from state of the art review and SUBTASK 1
Type of ventilation system (hybrid, decentralized, active overflow, etc.); air supply mode (intermittent/ vs. continuous) with respect to different building types.	Input from state of the art and SUBTASK 5
Modelling, simulation models/routines usable by practitioners, IAQ benchmarking, labelling schemes.	Input from SUBTASK 2 and SUBTASK 3
Subtask 4 is not intending to address decision making process directly, however it will make suggestions on methodology for data analysis that supports decision making	Input from SUBTASK 1, SUBTASK 3 and SUBTASK 5
Application of recent advances in sensor technology and model based control to optimize the indoor air quality without penalizing on the energy efficiency.	Input from SUBTASK 1 and SUBTASK 5

5.2 Annex 68 Guidebook

Final deliverable of the Subtask 4 will be an “Annex 68 guidebook”. Its aim is to provide comprehensive overview of information collected and generated within the Annex. The target audience are design practitioners, consultants, architects and facility managers who intend to design and operate ventilation in residential buildings to reach impeccable indoor air quality occupancy with minimum possible energy consumption.

6. Subtask 5: Field Measurements and Case Studies

With a tighter building envelope more minimal influences come into consideration. As how the thermal and hygrothermal properties of the materials may improve the ventilation or whether the dust distribution is altered with the new surface temperatures and flows and of course how all other new chemicals which we introduce to living environments affects the IAQ. Preferably the in situ measurement data from the filed campaigns and case studies will be defined as ST5 in Annex 68.

6.1 Objectives of Field Measurements and Case Studies

- To carry out field tests and analysis of buildings for testing and verification of the results from the other subtasks.
- To investigate new ventilation patterns in highly energy efficient residential buildings based on improved airtightness, increase insulation, use of materials, and possibly also new residential behaviour.

6.2 Work Description for Field Measurements and Case Studies

Subtask 5 will investigate and identify relevant case studies through a literature survey and run measurement campaigns to provide data for investigation and validation in Subtask 1-4. Several sites/climates will be proposed, and the field tests will include buildings declared as being energy efficient or recently refurbished to become so. The field tests will focus on testing and demonstrating in practice which low energy operational strategies can be used which will provide amenable indoor environments. Subtask 5 will as far as possible test buildings with the ventilation strategies, both current and novel, as identified in Subtask 4.

The test buildings will be inspected with respect to the building and interior materials, furnishing and occupants' activities. Special attention will be given to documenting the materials' emission status, i.e. checking for the use of low-emitting materials. Availability of information on ventilation system control and flows as well as the necessary energy consumption data will add to the assessment of IAQ in the buildings used in the case studies.

Building operations may be optimized with only small improvements to become more energy efficient but uphold the user comfort given as IAQ. New sensor technology and model based control will provide data for the proper ventilation for the future. By investigating possible adjustments of the building design, material use and ventilation system and control Annex 68 will deliver a feasibility study of the potential energy savings in the highly energy efficient residential buildings.

ST 5 will involve stakeholders. The field tests will be carried out in cooperation with industry partners from the previous subtasks and with building owners. The subtask will involve engineers and building owners/operators from the studied buildings

6.3 Summary of Planned Activities in Subtask 5

STATE OF THE ART AND MEASUREMENT STRATEGY: Summary of the literature review on the necessary parameters, eventually accompanied by guideline values, 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.

CONTROLLED MEASUREMENTS: In labs and test houses available at the universities and institutes involved in Annex 68.

IN SITU MEASUREMENTS: Examples of residential buildings from different geographical regions, and which are either new buildings or existing (possibly retrofitted) buildings will be chosen for investigation. It shall be possible in the chosen buildings to interact with the relevant operational parameters, e.g. for ventilation control, and to monitor the relevant performance parameters for energy consumption and indoor environment.

ANALYSIS AND DISSEMINATION: The results of Subtask 5 will demonstrate and analyse residential buildings which achieve optimal energy and good indoor environmental conditions under various climatic situations.

7. 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 for this reason, it is of paramount interest to ensure that this will not put the atmospheric quality of the indoor environment at danger. IEA EBC Annex 68 seeks to gather contemporary knowledge regarding indoor pollutants,and possibilities for modelling the atmospheric conditions, as well as to gather field test experiences from many countries regarding indoor air quality in highly energy efficient residential buildings. The outcome shall be new guidelines for operation developed in cooperation with manufacturers, consultants, users and authorities.

The project has begun at the turn of the year 2015/16 and will continue for three years. By the beginning of 2016, researchers from some 19 institutions representing 11 countries have signed commitment or are expected to sign commitment to participate in the project.

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