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

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ABSTRACT

In order to achieve nearly net zero energy use, both new and energy refurbished existing buildings will in the future need to be still more efficient and optimized. Since such buildings can be expected to be already well insulated, airtight, and have heat recovery systems installed, 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 making it in a new way demand controlled. However, this must be done such that it does not 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. As well, the thermal and moisture conditions of such advanced building shall be considered because of interactions between the hygrothermal parameters, the chemical conditions, ventilation and the wellbeing of occupants.

The project is divided into the five subtasks: 1. Defining the metrics. 2. Pollutant loads in residential buildings. 3. Modeling. 4. Strategies for design and control of buildings. 5. Field measurements and case studies. A flagship outcome of the project will be a guidebook on design and operation of ventilation in residential buildings to achieve high IAQ with least possible energy consumption. The paper illustrates the working program of each of these activities.

INTRODUCTION

The overall objective of the IEA EBC Annex 68 is to provide scientific basis usable for optimal and practically applicable design and control strategies for high Indoor Air Quality (IAQ) in residential buildings. Naturally, those

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strategies should ensure minimal possible energy use. The project aims to gather existing and provide new data on pollution sources in buildings, model the indoor hygrothermal conditions and air quality as well as thermal systems, and will look to ways to optimize the provision of ventilation and air-conditioning.

The work of the Annex is organized into five subtasks: **Subtask 1** will set up the metrics for required performances which combine the aspiration for very high energy performance with good indoor environmental quality. **Subtask 2** is to gather existing knowledge or provide new data about indoor air pollutants as well as combined heat, air and moisture transfer. **Subtask 3** will identify and/or further develop modelling tools that can assist designers and managers of buildings. **Subtask 4** will build up on the fundaments laid by previous subtasks and develop a guidebook on design and control strategies for energy efficient ventilation in residential buildings that will not compromise indoor air quality. **Subtask 5** will identify and investigate relevant case studies and do field measurements where the above mentioned strategies can be examined and optimized. The different subtasks are presented in more detail in the following sections.

Key objectives

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 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 performances can be examined and optimized.
- To disseminate about each of the above findings.

Target audience

The project addresses the following primary stakeholders:

- Building designers (engineers and architects) and facility managers.
- Suppliers of HVAC and control systems.
- Suppliers of materials used for building constructions and indoor furnishing.

The project shall also address the interests of building owners, facility managers and users, as well as standardization bodies and authorities that set standards and rules. The perspective is that the project may indicate ways how future energy classes for buildings can be set in dependency on which pollution targets they can achieve.

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 optimized to the limit in order to become as close as possible to being zero 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.

Annex duration and participation

The project has commenced its three-year working phase (2016-18). Some 19 institutions from 11 countries have committed to be participants in the project (by March 2016). The purpose of the IEA EBC Annex 68 Session at IAQ 2016 is to invite comments and possible project involvement from members of the ASHRAE and AIVC communities with a view to how results from the Annex project can be implemented in policies, standards, and practice.

SUBTASK 1: DEFINING THE METRICS

Subtask 1 aims at summarizing the current knowledge on target pollutants for residential buildings and at evaluating 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 previous studies on the subject available in the literature.

Target pollutants for residential buildings

Due to the high number of pollutants found in indoor environments, it is first necessary to group the most important ones in terms of their health effects. Recent studies have used similar approaches as indicated below: literature review, setting up criteria to select compounds, review of exposure and dose/response data, risk characterization of the selected compounds and prioritization of the selected compounds. In this way, the World Health Organization (WHO, 2010), the European INDEX project (2005) and the French IAQ Observatory (Kirchner et al., 2006a) established the lists with target pollutants in indoor air. Benzene, carbon monoxide, formaldehyde, naphthalene, nitrogen dioxide, particulate matter (PM) and polycyclic aromatic hydrocarbon (PAH) are clearly identified as the high priority target pollutants. These pollutants are frequently found in residential buildings and have multiple sources; many are related with pollutants in ambient air.

Recently, Djouad et al. (2015) established the list of target pollutants for office buildings and hospitals using up-to-date pollutant reference values and concentrations measured in-situ obtained by reviewing literature. Figure 1 presents the list of pollutants for residential buildings established using Djouad et al.'s methodology and the data of the national survey in French dwellings (Kirchner et al., 2006a). PM is clearly the most important pollutant to be considered for acute health effects (75%). Carbon monoxide, acrolein, formaldehyde, and radon should also be considered. The result for chronic exposure is quite different. Ranking of PM reduced to 35% and the ranking of formaldehyde, acrolein, and nitrogen dioxide are about 20% each. Benzene and radon also play a notable role.

Biological pollutants, such as molds, are considered separately and no dedicated guideline values are available. Molds need however to be considered because of their toxic potential and the high prevalence in residential buildings.

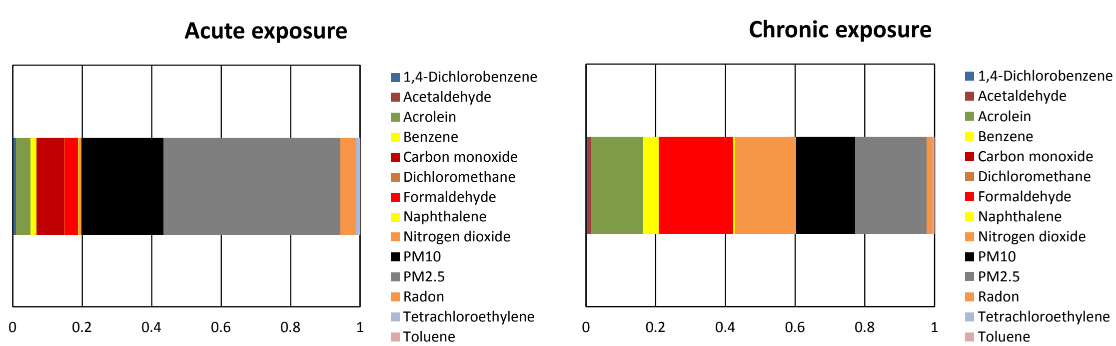

Figure 1. Relative importance of indoor pollutants for residential building sector.

IAQ Metrics

The existing IAQ metrics will be reviewed to propose a scientifically sound index, or set of indices, for evaluation of indoor air pollution. Overall, the IAQ indices considered different pollutants, exposure limits and aggregations of effects (Kirchner et al., 2006b). A dimensionless index is usually calculated by dividing the measured/calculated concentration by a reference value. The reference value usually relates to health (accounting for chronic or acute effects), but other metrics can also be used (e.g. odor threshold). A value higher than one warns about a potential IAQ problem. In this way, an index is calculated per pollutant. Difficulties arise when comparison or aggregation of these indices is required, and investigations into this from literature will be examined in Subtask 1. For example, does a value of 1.2 for formaldehyde represent a lower IAQ than a 1.1 value for PM? Can a single index be defined as a simple sum of individual pollutant indices or by using the maximal value as it has been done by several authors (Cohas, 1996; Gadeau, 1996; Castanet, 1998; Sofuoglu and Moschandreas, 2003)?

Accounting for energy consumption

The last part of this subtask will be dedicated to evaluate the additional energy consumption needed to improve IAQ. The main solutions to reduce the pollution concentrations in indoor spaces can be energy costly: increasing the amount of outdoor air and/or use of air cleaners and pollutant entrapment with hoods or exhausts. Pollution source control will not increase operational costs for energy, or can even reduce this cost, but may be difficult to realize during renovations. In all cases, the main problem here is to define the relative importance between additional energy consumption and IAQ benefit, in other words, how much it costs to improve IAQ in terms of energy.

SUBTASK 2: POLLUTANT LOADS FROM MATERIALS AND ASSEMBLIES 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 from materials and assemblies in residential buildings in the way heating/cooling loads are routinely estimated. Subtask 2 of IEA EBC Annex 68 focuses on the laboratory measurement of fundamental emission/sorption data and the development of mechanistic emission source/sink models for materials and assemblies used in residential buildings. 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.

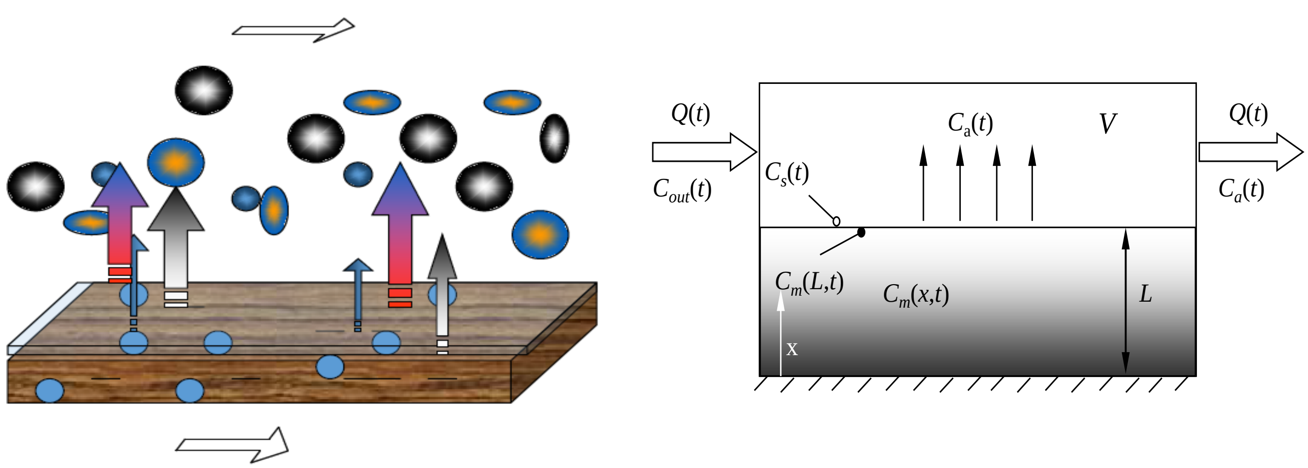

Figure 2. Schematic illustration of pollutant emission from dry materials.

Activities of Subtask 2

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 residential buildings, including models. Next, laboratory testing and model setup to provide examples of new types of data, which shall 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.

Deliverables from Subtask 2

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.

SUBTASK 3: MODELING

Existing knowledge is inadequate for predicting the combined effects of hygrothermal conditions and chemical reactions on the indoor pollution species and concentrations in light of most recent revelation of the importance of secondary emissions such as Ozone-initiated indoor air and surface chemistry in affecting the indoor air quality.

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 (IBPSA-USA, 2016). 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 (ASHRAE 2004, and ISO 2012a and 2012b). 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.

Currently, the certification of simulation tools being made solely by the authors themselfes cannot always be verified by a third party. 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.

Objectives, Scope and Methodology Regarding Modeling

The main objective of ST3 is the development of a modeling quality assurance methodology for building energy performance and indoor air quality simulations. ST3 will start with an appropriate tool registry for all relevant aspects. In the first step, a questionnaire will collect basic information about the available tools from Annex 68 participants.

The questions will be on availability of the tools to the public, commercial strategy, implemented models, available demonstration examples and further development perspectives. In the next steps, the questionnaire will be hierarchically extended for more detailed questions, e.g. on specific modeling aspects, model interoperability, BIM-support, efficiency of numerical solutions and application & validation cases. The aim is to generate knowledge on the existing gaps and to outline the need for further developments.

The questionnaire will be accompanied by the development of new application & validation scenarios. Practical application scenarios are to be broken down into testable individual application & validation cases. Since the application scenarios are mapping at different levels of complexity, a methodology shall be developed in order to separately analyze and quantify the various sources of error. Validation cases shall be designed so that the model complexity builds gradually. A series of “standard” reference scenarios will be developed for common modeling exercises in conjunction with ST5, ranging from laboratory single room/chamber, over single and double chambers in the field, to multizone test houses, and occupied residential buildings. They will cover isothermal, non-isothermal, humidity effects, source-sink interactions, and effects of indoor air and surface chemistry.

Simulation results from the application & validation scenarios will be compared with existing standardized reference solutions. Focus will be on development of new standardized reference solutions whenever the community is lacking them, quantify the uncertainty of simulation models for the reference scenarios, and recommend a set of criteria for reliable modeling and simulations of the effects of IAQ strategies for low-energy residential buildings.

SUBTASK 4: STRATEGIES FOR DESIGN AND CONTROL OF BUILDINGS

The objective of Subtask 4 is to apply knowledge obtained within the Annex 68 project to suggest design and operation strategies for energy efficient ventilation in residential buildings that ensure high IAQ. The strategies should go beyond the state of the art and actively utilize recent research findings regarding indoor air pollutants, ventilation strategies and combined heat, air and moisture transfer as well as benefit from recent advances in sensor technology and controls. The subtask should provide answers to the question: “Do we need to change the way we design and operate ventilation for residences today when we take into account results of the Annex 68 subtasks? If yes, how?”

State of the art and stakeholder survey

The first activity of Subtask 4 will be mapping of the current situation with respect to ventilation and IAQ design in the participating countries. This activity will, besides a review of relevant literature, focus on country-specific “written knowledge” – national building codes, guidelines, standards, guidebooks, thematic web pages, etc. It is believed that the influence of the Annex 68 on selection of design strategies in practice will be strongly dependent on particular country in which the strategy should be applied. The review of national “written knowledge” will provide an overview about current legislative framework as well as and the knowledge-bases, but it will not be able to illustrate the real design processes of ventilation system in practice in various countries. To get an overview about how ventilation is designed and operated in practice, the subtask will conduct a stakeholder survey in the form of structured interviews. It will focus on real design practices, barriers and bottlenecks with respect to high IAQ design.

Suggesting new design strategies

Knowledge gathered by literature survey and stakeholder interviews will be consequently used to identify two most relevant types of dwelling (methodology developed in Levine et al. (2013) will be used) in each participating country together with most prevalent design strategies applied for those dwelling-types. Possible improvements of the design strategy will be studies for such defined cases. The Performance Based Design approach, as introduced by Kalay (1999) will serve as a basic template for a workflow in the simulated design process.. Subtask 4 will exemplify how to support a “Design proposal” stage 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, correlation factors between IAQ and energy consumption developed in Subtask 1 will be exploited in “Performance Prediction”. The 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.

Operational strategies

With respect to operational strategies, Subtask 4 will focus on analysis of data and experiences from case studies included in Subtask 5. Correct operation of ventilation systems has the same weight as their correct design. It is a challenging task especially in residences where skilled operators of building environmental systems are usually not available. At the same time, the modern, low energy dwellings are extremely sensitive to failures and errors in operation of ventilation systems due to their high air tightness. Future ventilation systems that can ensure high IAQ during the whole lifetime of the building have to be easy to commission and operate, they have to enable easy operation monitoring, and they have to be almost maintenance free. However, the first step towards effective operation has to be made on the level of legislation. Appropriate changes in national building codes as well as suitable standards will be needed to transfer part of the focus from design to operation. Subtask 4 will provide a well-structured set of examples that show how recent knowledge concentrated in the Annex 68 can be used during operation of buildings. This should serve also as an incentive towards legislators and standardization bodies.

Annex 68 Guidebook

Final deliverable of Subtask 4 will be an “Annex 68 guidebook”. Its aim is to provide comprehensive overview of information collected and generated within the Annex.

SUBTASK 5: FIELD MEASUREMENTS AND CASE STUDIES

With a tighter building envelope, it can be expected that more secondary interactions can be influential on IAQ, such as how the thermal and hygrothermal properties of the materials may improve the ventilation, or whether the PM distribution is altered with new surface temperatures and flows, and of course how new chemicals, which are introduced to living environments affect IAQ. Data from insitu measurement from field campaigns and case studies form the essential substance of Subtask 5.

One objecetive is to carry out field tests and analysis of buildings for testing and verification of the results from the other subtasks. Another objective is to investigate new ventilation patterns in highly energy efficient residential buildings based on improved airtightness, increased insulation, new use of materials, and possibly also new behaviour.

Work Description for Subtask 5

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 Subtasks 1-4. Several sites and climates shall be investigated, and the field tests will include buildings declared as being energy efficient or recently energy refurbished. The field tests will focus on testing and demonstrating in practice, which low energy operational strategies can be used that will provide amenable indoor environments. Subtask 5 will test buildings with new ventilation strategies.

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 material emissions, i.e. checking for the use of low-emitting materials. Available information on ventilation control and airflow rates, as well as energy consumption data will add to the assessment of IAQ in the case study buildings.

Building operation may be optimized with improvements for energy efficiency, but uphold high IAQ. New sensor technology and model based control will provide data for the proper ventilation. 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.

Summary of Planned Activities of 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 relevant values needed to study and verify IAQ in highly energy efficient residential buildings.

Controlled Measurements: In labs and test houses available at the institutes involved in Annex 68.

In Situ Measurements: Examples of residential buildings from different geographical regions, and which are either new buildings or existing buildings. It shall be possible to interact with operational parameters, e.g. for ventilation control, and to monitor relevant performance parameters for energy consumption and IAQ.

Analysis and Dissemination: The results of ST5 will demonstrate and analyse residential buildings, which achieve optimal energy and good indoor environmental conditions under various climatic situations.

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 danger. Annex 68 shall gather contemporary knowledge regarding indoor pollutants and possibilities for modeling the atmospheric conditions, as well as field test experiences from many countries regarding IAQ in highly energy efficient residential buildings. The outcome shall be guidelines for building operation developed in cooperation with manufacturers, consultants, users and authorities. However, since the project is in its first year in 2016, a first priority will be Subtask 1's formulation of decisive metrics for IAQ with a view to their implementation in policies, standards, and practice.

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