Air Transport in and through the Building Envelope

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ABSTRACT

A national R&D program dealing with air transport in and through the building envelope is presented, including some overviews of results. The program develops predictive models for evaluating air movements in and through the building envelope. These models are coupled to the outside climate and pressure situation and to the inside climate through the interaction with models defining the building services system. A major aim of the program is to analyze problems of relevance to the building process. This includes site inventory, modeling of typical situations, and laboratory testing for input data and to validate the models. The objective is to develop tools to help design and evaluate building elements and to give the necessary foundation for estimating the convective transport of heat and moisture in the envelope, which is decisive for the indoor climate, the consumption of energy, and the durability of the construction. The research program is ongoing and this presentation is to invite communication with others.

INTRODUCTION

The R&D Program

Air movements within structures and materials have an impact on the flow of moisture and heat in a building and, thereby, on the balance of moisture and dryness in the building envelope. Air movements may also carry emissions from building materials, a factor that is of significance to indoor air quality. Consequently, this is an important part of a professional building physics design, by which is meant actions in the building process that contribute to buildings with good indoor climate, low energy consumption, and durability and that the building is not damaged due to the moisture, air, or temperature.

Air movement and airtightness have been studied in different contexts, often as part of a given problem. The need for wind protection has been studied in the Nordic countries. Air movement and its impact on thermal insulation has been studied in Europe and North America. Airtightness of layers, materials, and joints between building elements has been measured in some designs. Models of air movements in a building envelope and in a building as a system are limited. The need for tight layers as part of the protection against moist air has been observed, as well as the significance of workmanship. In general, available knowledge is not used in practice. This is the current situation in the Nordic and a number of other countries.

A building is a complex system. Varying pressure and temperature distribution in and around the envelope generate air movements through the building envelope and in permeable building materials and cavities and cracks that are included in the envelope. The pressure situation throughout the building envelope is influenced by weather conditions, how the building is ventilated, by the distribution of air leakages, and geometry, etc. To predict the distribution of air movements requires an analysis of components and an analysis of the building as a system, which account for the interaction of components, both in terms of air leakage and heat and mass transfer.

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A national R&D program is underway in Sweden dealing with air transport in and through the building envelope. This program has three parts:

I. Modeling of convective processes in building components

II. System modeling and analysis of air transport in and through the building envelope as part of a whole building

III. Airtightness for the building process and transformation and demonstration of results for practical use

The two first parts include analysis of problems of relevance, the validation of models, and the demonstration of their application. The third part includes an inventory of the current situation in the building process, laboratory measurements, and implementation through information and education.

The predictive models for evaluating air movements are coupled to the outside climate and pressure situation and to the inside climate through interaction with models defining the building services system. The theoretic modeling is validated in laboratory investigations and through field measurements.

Literature

A survey of the available literature has been done to collect knowledge concerning questions that relate to air infiltration and airtightness in building components and whole buildings. The result has been divided under subheadings that also indicate in what areas previous results of interest are available (Mattsson 2004). These are:

- theoretical descriptions, modeling, and simulation of air leaks and air flow
- leakage details
- airtightness in whole buildings
- wind pressure at buildings
- natural and forced convection in permeable materials
- dynamic insulation
- other, such as life-cycle performance, prefabricated housing, HVAC systems, moisture transport, certification, etc.

In general more than a hundred references have been found of some interest, mostly from the Nordic countries, USA, and Canada. A number of references relate to energy conservation, more recently also dealing with moisture problems. Systems approach, building design, building process, and workmanship are mostly missing. No similar R&D programs have been found.

MODELING OF CONVECTIVE PROCESSES, PART I

Models

In part I of the program, models and instruments are developed to analyze air movements and model different types of air leakages through the building envelope and its components. The models are used to estimate the influence of air transport on heat transfer, temperature field, moisture situation, and ventilation.

For the computer modeling, a CFD program, Fluent (www.fluent.com), is used. This type of program has traditionally been used to model aerodynamic problems, but today it is possible to model a number of other flow problems. The advantages of the program are that it presents more modeling possibilities than are available in simpler programs. Of special interest is the possibility to include different types of boundary conditions, models for radiation, airflow through porous materials, and natural convection. Condensation of moisture and the possibility of computing moisture transport in materials, however, has to be done by modifications or by other models.

The work so far has shown, as in many other cases, that a lot of the input data that has to be given in the models are missing (Mattsson 2004). Many of the measurements done in previous research cannot be directly used in the structures and situations of interest in this case. Measurements are therefore made in the laboratory to give relevant information and input data for the analysis. Measurements are also used to validate the model. A major part of the experimental work is done in part III of the program, which deals with the building process, and is where information and data relevant for later implementation and application purposes are found.

Application

Figures 1 and 2 are examples from the ongoing work.

Figure 1 shows additional heat loss due to convective processes in a wall with dimensions of 2.5 m × 0.3 m, with sill and top plate and design heat loss of 0.138 W/(m^2 K). The wall is insulated with mineral wool (10 kg/m^3, 0.034 W/(m K), 6e-9/10e-9 m^2, permeability in two directions). Airflow is induced in the insulation due to a pressure drop at the surface of the insulation, e.g., due to a wind with a higher velocity at the top of the wall. Wind protection of gypsum board, mounted tightly (Sikander and Olsson-Jonsson 1997) or loosely at sill and top plate (illustrating varying workmanship), is compared to no wind protection.

Figure 2 shows temperature fields in the wall (2.5 m × 0.3 m, with design heat loss of 0.138 W/(m^{2}K)). In the figure, from left to right: (1) only natural convection at ΔT 50°C adds 0.002, at 30°C 0.001 W/(m^{2}K); (2) without wind protection and pressure drop 10 Pa/m from top to bottom; (3) with loose wind protection and pressure drop 10 Pa/m from top to bottom; (4) with tight wind protection and pressure drop 10 Pa/m from top to bottom; and (5) only natural convection (with wind protection) and with imperfections in the insulation installation (2 cm air crack at one edge of the insulation and 2 cm air space at the warm side). This adds 0.091 W/(m^{2}K) to the design heat loss at ΔT 30°C and 0.097 at ΔT 50°C.

SYSTEM MODELING OF WHOLE BUILDING, PART II

Part II of the program deals with modeling of the whole building. This is done by combining information on the building envelope with models for ventilation systems and infor-

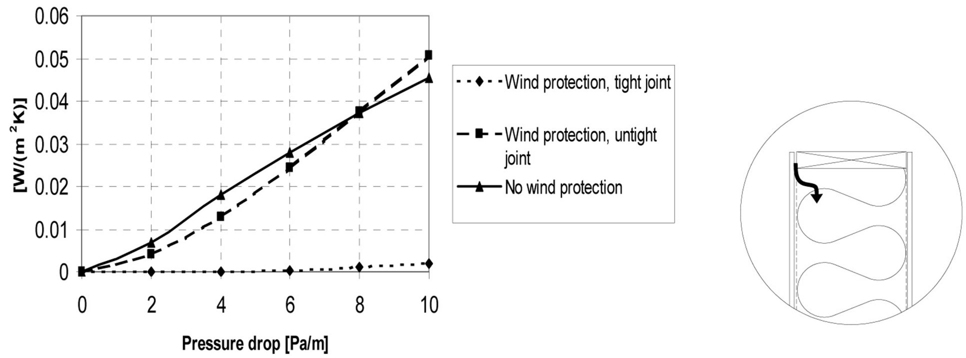

Figure 1 *Additional heat loss due to convective processes in a wall, insulated with mineral wool, with and without wind protection.*

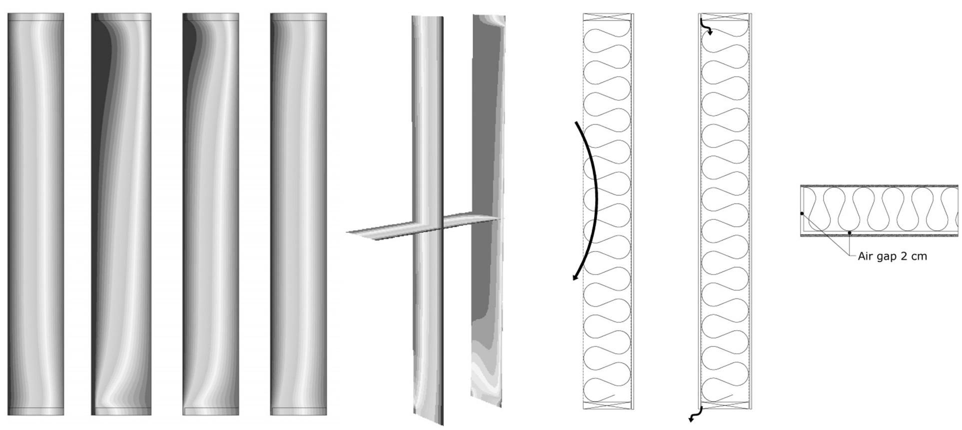

Figure 2 *Temperature fields in the wall, with natural and forced convection, with and without wind protection, and with and without imperfections in the insulation installation.*

mation on the pressure/wind situation. The model used in this case is designed in the graphical program language Simulink, which is a part of the calculation tool Matlab. A special calculation tool "HAM-Tools" is used. This stands for heat, air, and moisture transport processes in a building and a building envelope, which are simulated in a modular structure (Sasic Kalagaidis 2004). The following capabilities are available:

- one-dimensional transient heat, air, and moisture (HAM) transfer through the building components, which can be combined into a three-dimensional building enclosure
- transient HAM balance of an enclosed (fully mixed) air
- multi-zone HAM calculations
- modeling of external and internal HAM loads, radiant heat exchange, wind- and temperature-induced air flows through intentional and unintentional openings, rain, HVAC equipment, people, and appliances, with variable intensities and control strategies

HAM-Tools is a publicly available research and educational tool for integrated building simulations. It is available for free download from www.ibpt.org.

The main purpose of this tool is simulation of transfer processes related to building physics, e.g., heat and mass transport in buildings and building components in operating conditions. This is a research and educational tool, with modeling based on the present knowledge in this area. It is used for the investigation of the mechanism of the transport processes and the degree of correlation when they are coupled. By providing coupled HAM simulations for the whole building and by having the modular structure, this program differs from other existing codes in this area.

Application

The HAM-Tools wall module has been validated through the intermodel comparison performed within the HAMSTAD

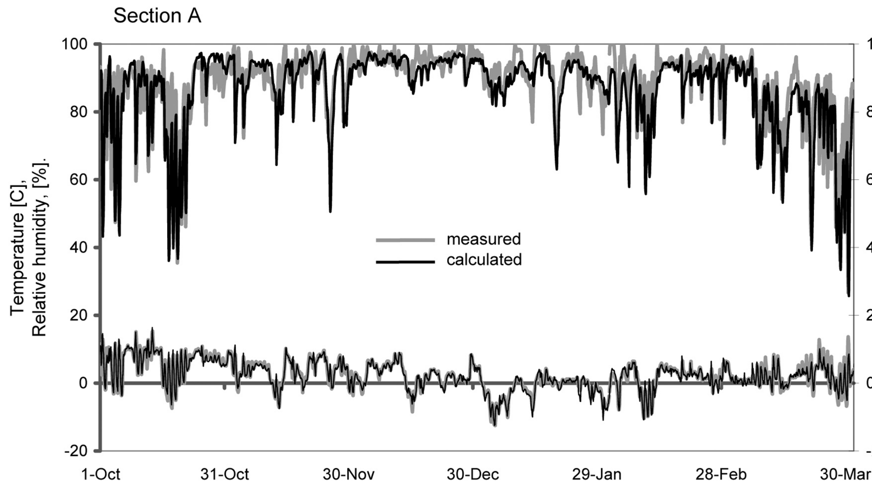

Figure 3 *Climate conditions in the mechanically ventilated attic section A with mineral wool insulation. Comparison between calculated and measured data.*

project (heat, air, and moisture standardization) initiated by the European Union in 2000-2002 (Hagentoft 2002).

The HAM-Tools whole model validation (e.g., simulations of the building or the building section as a whole) has been done against measurements taken on experimentally investigated cold attics with six different ventilated and insulated compartments. The program has shown good predictive accuracy of internal climate conditions (indoor temperature and relative humidity) for all six compartments compared with field results. This is shown in Figure 3 and details can be found in the report, “The Whole Model Validation for HAM-Tools. Case Study: Hygrothermal Conditions in the Attic Under Different Ventilation Regimes and Different Insulation Materials” (Sasic Kalagasidis 2003).

Modeling has also been done of a single-family house with dynamic insulation in the ceiling (Figure 4). Air leakages were detected along the floor-wall connections. The investigation focused on the airflow distribution through the unintended openings in the presence of wind and, thus, on the functionality of the dynamic insulation. Energy consumption was calculated for two cases: “poor” ceiling design (due to the high airflow resistance of the air supply terminals in the ceiling, only up to 60% of designed airflow comes through the insulation) and with “improved” ceiling design (low airflow resistance in the ceiling where airflow goes up to 80% of the designed one). These findings are illustrated in Figure 5, indicating calculated results.

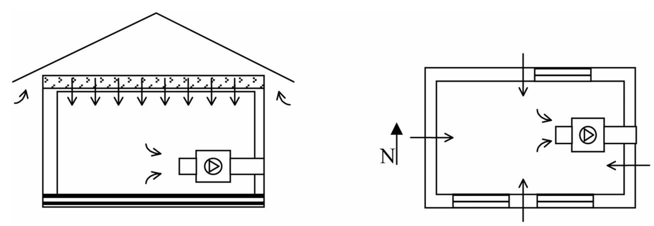

Figure 4 *Section and plan of the modeled house. Airflow paths are indicated with arrows.*

BUILDING PROCESS AND AIRTIGHTNESS IN PRACTICE, PART III

Building Process

A major aim of the program is to find and analyze problems of relevance to application and the building process. Therefore, part III of the program deals with design and practical work situations that are critical, i.e., where competence and technical solutions have to be developed to achieve sufficient airtightness. This part of the work includes the inventory and the modeling of typical situations. Part III also includes the majority of the laboratory testing for input data and to validate the models.

In the inventory, knowledge and experience are recorded through interviews with a number of persons in the building process (such as architects, consulting engineers, site engineers, foremen, carpenters, and damage investigators) to find their opinion of airtightness and its perceived causes and consequences. A number of specific questions are used and the answers are analyzed. A number of buildings sites have been visited. Details critical in relation to airtightness have been collected (Johansson 2004).

In a parallel analysis of air flows due to normal deficiencies in airtightness, the consequences of these airflows are noted. This gives overall information on the “airtightness problem” and is the foundation for recommendations concerning designs, methods, education, and special quality considerations at the building site (Sandberg and Sikander 2004).

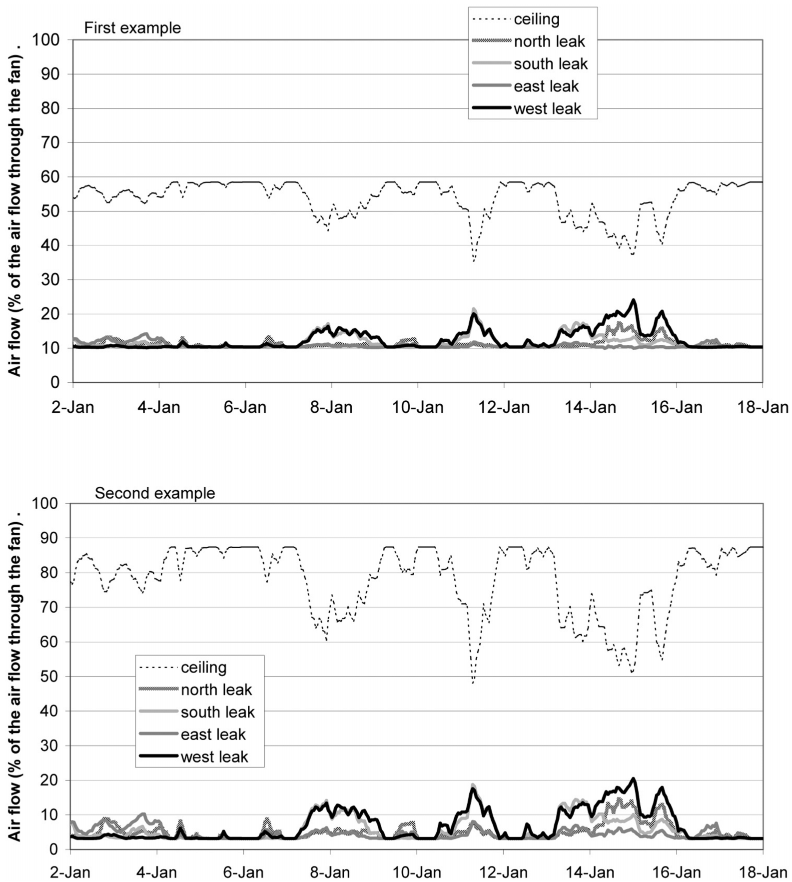

Figure 5 *Dynamic ceiling insulation. Air flows through openings indicated in Figure 4. First example—poor ceiling design. Second example—improved ceiling design. Whenever the wind acts, there is a non-zero airflow through unintended openings, indicated here as north-south leaks.*

Interviews

The following summarizes some comments from persons in the building process.

Attitude: Most persons think airtightness is important. They also indicate that their workmates have the same attitude. The closest boss, however, seldom has a viewpoint or requirements; "It's not his job."

At the building site: Drawings and descriptions are not good enough. Fifty percent of the details have to be solved at the building site. Airtightness is seldom discussed or commented on at site meetings and is seldom mentioned in checklists or quality plans.

Information/education: Nearly everyone sees a need for information/education. "Gladly spend half a day with information and demonstration." Comment: Those not motivated need education to understand the importance of airtightness. Those motivated need information about how to accomplish airtightness. A lot of knowledge is missing. In many cases it is difficult to distinguish between airtightness, resistance to moisture diffusion, or thermal resistance. "It is so well insulated with mineral wool that it should be airtight."

New materials and methods: Some point to the need to develop better materials and methods. Others say that the special solutions that are available are not used because they are too expensive or there is no time to order them.

Reasons for deficiencies in airtightness: Most common: Deficiencies in design, drawings, and descriptions. "How can they think it is possible to obtain an airtight layer, right through a lattice beam?" Sometimes: Shortage of time, carelessness, and/or insufficient knowledge (the latter most often relates to installations). Seldom: materials and intentional negligence.

Critical details: There have been many different suggestions, but dominating are penetrations (for example, electricity and HVAC), joints against steel and concrete, windows, floor structures.

Consequences: Most often mentioned at the building site is energy loss and draft. Others, for example, damage evaluators, are of course more detailed and in addition primarily mention moisture problems but also diffusion of odors, poorly functioning ventilation systems, freezing pipes, and noise problems.

Measurements and control methods: Most feel that airtightness is seldom tested. Those with experience from the blower-door method think it works well. A few see the need to be able to measure local air leakages.

New and old buildings: Those who were active in the seventies state that airtightness questions were given priority then, but this priority has since been lost. The questions that are given priority today are moisture problems and how to lower costs.

Elementary Leaks—Airtightness in Practice

The literature study, the field investigations, and interviews have clearly shown that to be able to use the modeling activities for their intended practical use, it is necessary to have relevant measured data of leaks of interest in the building envelope. In the literature some leakage data have been found. Many are, however, missing, and the data are normally from idealized and perfect workmanship. This often gives incorrect information about the airtightness. It is, consequently, necessary to perform a number of measurements of "elementary leaks" in the building envelope. For the validation of the modeling it is also of interest to do a number of full-scale measurements on the building envelope and parts of the building envelope in the laboratory and in the field. Airflow, temperatures, and moisture situations are recorded and compared to the results from the calculations of air movements and their consequences. Measurements have been done on a number of leaks and also of some complete wall designs, including connections between window and wall, installations in the building envelope, etc.

A catalog of airtightness information is being built, covering construction details and their leakages characteristics.

SUMMARY

The research program is ongoing. The modeling work is added to and validated. Critical details related to the air leakages are tested and modeled. This gives information about the air transport in the building components and the building envelope and forms the basis for information on temperature field, heat flow, moisture transport, etc., in the building. These results are analyzed to give answers to questions concerning the influence of specific factors such as moisture, thermal performance, and ventilation problems and questions such as:

- What details are the most critical ones to avoid comfort and moisture problems?
- What details are, constructively, the most difficult ones to perform to achieve sufficient airtightness?
- Why do a number of designs turn out not tight, even if they are carried out according to guides and good experience?

The results of the inventory and the simulations are being collected in recommendations for

- need for improved designs,
- designs that need special care at the work site,
- need for further information/education and training.

The information developed in part III is used in all parts of the program to focus on relevant problems and types of design and the need for information. The interviews indicate that unless the implementation and transformation of the research results are considered from the beginning, their impact on the building process will be minor.

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HAM-Tools, www.ibpt.org.