Heat Flow in Building Components, Experiment and Analysis

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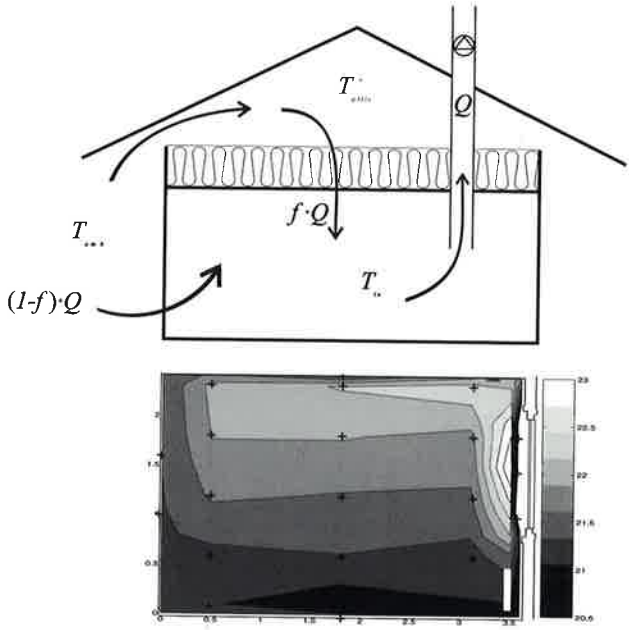
Heat Flow in Building Components



Experiment and Analysis

Petter Wallentén

Building Science

Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 97 600 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 5 850 employees and 38 200 students attending 50 degree programmes and 850 subject courses offered by 170 departments.

Department of Building Science

The Department of Building Science is part of the School of Architecture within the Faculty of Technology. The Department has two professorial chairs, Building Science and Building Services. Research at the Department is concentrated on energy management, climatic control and moisture problems. The main areas of research are:

- design and preformance of new low-energy buildings
- energy conservation in existing buildings
- utilization of solar heat
- climatic control
- climatic control in foreign climates
- moisture research

Heat Flow in Building Components

Experiment and Analysis

Petter Wallentén

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Keywords

heat transfer, dynamic insulation, counter flow insulation, measurements, in situ, natural climate, full scale, convective, heat transfer coefficient, window, wall, measurements, finite difference , frequency analysis, transient, shortwave, longwave, radiation exchange, temperature, building, solar radiation, window model

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Petter Wallentén
1998-05-06, Lund , Sweden.

Background

The study of the thermal performance of buildings has always taken advantage of the mathematical tools up to date. When dealing with experimental data, the tradition has mostly been to make energy demand calculations and try to manually fit thermal building models with the data. In a way the experimental data have been viewed as varying and the models of the building or building components as constant. In many industrial disciplines parameter identification and other techniques are becoming more common. With those techniques one treat the models as dynamic and the data as the static input.

When I started to study building physics with special focus on thermal processes I had much of this view that the models were static and the data a dynamic resource for studying these models. When I was introduced to the project to study the Optima house, which used a dynamic insulation in the attic insulation, I immediately understood the difficulty of measuring the air flow through the insulation directly. A more roundabout method had to be used; first measuring the temperatures in the insulation and then match this with temperature calculations for a given airflow. This was nothing new, the new idea was that this could be done continuously thus giving continuous airflow estimations, hour by hour or whatever time interval that was measured. The results from such a method are always more susceptible to errors than static method or laboratory methods. The advantage is that the measurements can be done under realistic conditions.

After finishing the Optima project I became more involved in the study of windows and the especially superinsulated windows. The focus was on comfort and energy. I soon realised that in order to make comfort and energy calculations the convective heat transfer coefficient was much more important than in "normal" energy calculations of buildings. With this in mind I designed an experimental setup that would be a compromise between laboratory and in situ experiments. The setup was a room equipped with thermocouples and other instruments. The room could be furnished or empty but would constantly be exposed to the natural climate. I performed intermittent measurements in this room from 1994-98. To deal with the large amount of measured data I had

to write a computer program specifically designed for this data. In this program I successively implemented increasingly more complex thermal models of the window and wall. The method was much the same as in the Optima project. The experimental data was the static input and the convective heat transfer, radiation heat transfer and especially the heat transfer coefficient were the dynamic output of the model.

I now present these two investigations as my thesis to become doctor of technology. The specific problems are different but, in my view, the methodology has been much the same.

A brief summary of the projects and results are presented below.

Dynamic insulation

The term dynamic insulation implies that part of the inlet or exhaust air passes through the insulation of a house. The main reasons for using dynamic insulation with inlet air are: the dynamic insulation is similar to a heat exchanger for the ventilation air, the insulation filters the air to a theoretically very high degree and the inlet air is preheated, thus providing a high degree of comfort in the house. Dynamic insulation can be used in any insulation in contact with ambient air. The energy efficiency of a dynamic insulation is measured by the 'dynamic U value' or an equivalent heat exchanger efficiency. The efficiency of a dynamic insulation depends on the amount of air that passes through the insulation. Typically, the air flow through the insulation is produced by keeping the inside of the house at a pressure lower than that of the ambient air.

A house with dynamic insulation in the ceiling was continuously measured for approximately a year and a half. The house was a single storey one family house built at Dalby in the south of Sweden. The house was constructed in conformity with the Swedish Building Code. The performance of the dynamic insulation was estimated by using hourly values of the temperature distribution inside the insulation. The air flow through the insulation was calculated as the air flow that best fitted the measured temperature distribution. In order that the temperature distribution for a given air flow may be calculated, the transient and steady state heat transfer equations were solved both analytically and numerically. The numerical solutions were used to make hourly calculations of the air flow. The analytical solutions were used to better understand the importance of the physical parameters and to verify the numerical solution. The method described above is here called the *gradient method.* The main objective of the study was to investigate the performance of a dynamic insulation placed in a realistic environment. The only major exception to this was that the house was unoccupied during the measurement period.

The analytical calculations showed that for periods shorter than 6h it was necessary to use a true transient calculation. The most important parameter was the first term in the series solution of the transient heat transfer equation. The analytical solution clearly verified the numerical solution.

The air flow through the dynamic insulation as measured by the gradient method was 40% of the total inlet air. Results from a few tracer gas and direct measurements indicated a higher flow, but this could be expected since the gradient method was the only method that measured the flow in the insulation itself.

The dynamic U value for the insulation was about 0.05 $W/m^2°C$ for the ceiling. This corresponds to a dynamic energy efficiency for the insulation of 35%. This factor should be multiplied by the proportion of the total inlet air that passed through the insulation, i.e. 40%, to obtain the total energy efficiency for the ventilation system. The total energy efficiency calculated this way is 14%. A theoretical calculation shows that if 100% of the inlet air were to pass through the insulation, this would correspond to an energy recovery of the ventilation energy by 22% which for the OPTIMA house corresponds to a power saving of 15 W/°C or an energy saving of 1600 kWh/year.

The calculated 24h average air flow increased slightly with increasing difference between inside and outside temperature. Both the 24h and 2h average air flow decreased with increasing wind speed. The reduction was of the same order as reported in the literature. No obvious effect of wind direction was found.

The transient calculation showed a daily variation of the air flow that increased with increasing sunshine. This variation was typically +/- 30% of the average flow with the maximum at midnight and the minimum at noon. This air flow variation could not be detected in the inlet terminals.

When the ventilation system was turned off and the inlet terminals completely closed, the air flow through the insulation changed from 0.2 mm/s downwards to 0.1 mm/s upwards. This could be a dangerous situation if the air moving upwards came from the living space. The air moving upwards could then create condensation in the insulation. If the air came from outside, this would only lead to a higher energy loss.

The measurements in the OPTIMA house showed that the use of dynamic insulation could not be justified by the energy savings alone. However, the inlet air was preheated and filtered and there were fewer ventilation ducts for transporting the inlet air than would be needed in a house with a heat exchanger system. Taken together, this makes the dynamic insulation an attractive choice,

at least in theory. In practice the leakage in the rest of the house reduced the energy saving of the dynamic insulation to about 70% of the maximum value and only 40% of the inlet air was filtered by the dynamic insulation. The general conclusion from the measurements was that the dynamic insulation requires a house constructed to much more exacting standards in order to work properly.

Heat flows in a full scale room exposed to natural climate

It is, with the thermal models used in today's building simulation programs, possible to calculate the major part of the heat transfer in a room with an ambient outer wall. However, there are some parameters these models calculate with less or unknown accuracy: heat flows in poorly insulated walls or windows, heat flows in a room exposed to strong solar radiation, temperatures on the inside of ambient outer walls and windows.

The reason for these difficulties is mainly that there is a lack of experimental data for the detailed energy transfer in a window exposed to ambient climate and the convective energy transport in a room exposed to ambient climate.

The aim of this study was to investigate the detailed energy transfer at an ambient wall including window. The investigation included both theoretic analysis and measurements performed under conditions close to the real situation with, for example, ambient climate.

The method used in this study was to estimate the heat flow through wall and window from measured solar radiation on the façade and temperatures. The temperatures were measured inside the wall, on the window panes, in the air, at inner surfaces etc. The longwave radiation was calculated from surface temperatures. The convective heat transfer was calculated as the difference between the heat flow through the building element and the longwave radiation. This indirect way of measuring the convective heat transfer was not as accurate as other more direct techniques but it was however a method which permitted measurement under realistic conditions.

The most important conclusions regarding the calculation models and measurement technique used in this study were:

- It is possible to measure the continuous heat flow through a window from temperature sensors and solar radiation measurements. The accuracy at

least for low angles of incidence of the solar radiation was estimated to +/- 10%

- The absorption of solar radiation on the thin thermocouples (0.08 mm) glued to the window pane beneath a microscope cover glass was not a problem.

- To measure air temperatures in sunlit places thin (0.08 mm in this case) stripped thermocouples are the only alternative. With the thin thermocouples the measurement error was estimated to less than 0.5°C when exposed to 400 W/m^2 of solar radiation.

- The one-dimensional finite difference model for the heat transfer through the wall was acceptable. It was possible to calculate the heat flow through a wall from temperature sensors but some problems were noticed when the room was heated by a radiator making the surface temperature slowly increase 6°C.

- The one-dimensional dynamic heat transfer model for the window which included shortwave radiation was fairly good except for small temperature differences and high angles of incidence for solar radiation.

Conclusions for the convective heat transfer coefficient were:

- It is possible to continuously measure the convective heat transfer coefficient on the inner surface of a wall or a window. The accuracy is not very good: at best +/-15% for the window and +/- 20% for the wall. Even with this low accuracy the effect of different heating and ventilation strategies on the inside could clearly be detected.

- The presented results show that the importance of the ventilation design and the position of the radiator is crucial. Local convective heat transfer coefficients can be more than 10 times the expected, due to ventilation or position of the radiator.

- It is not obvious how the results of this study should be generalized. But as a rough estimate, we suggest that the following formulae can be used:

$$h_c = f \cdot \begin{cases} 1.34(\Delta T / H)^{1/4} & \Delta T H^3 < 9.5\,\mathrm{m^3K} \\ 1.33\Delta T^{1/3} - 0.474 / H & \Delta T H^3 > 9.5\,\mathrm{m^3K} \end{cases}$$

h_c = the convective heat transfer coefficient (W/m^2°C)
ΔT = temperature difference between surface and air
H = height of the wall or window in meters.

Radiator at back wall: f=0.7 for the window and f=1 for the wall.

Radiator below window: f=2.5 for the window with the radiator power on and f=0.7 with the radiator off and f=0.7 for the wall.

Future studies

With the already measured data comfort calculations will be performed. The importance of low U-value windows and comfort will be studied. The experimental setup also allows total heat transfer coefficients to be estimated with a furnished and occupied room.

The presented method was not entirely satisfying due to the low accuracy. Future studies will be focused on investigating the Mayer ladder technique, or more precisely to measure the temperature difference very close to a surface with thermocouple pairs in series. This study suggests that the measurement error of that type of technique could be less than 10% in the convective heat flow.

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