Verification of a simple simulation model of double façades.

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ABSTRACT: In this paper we report measurements with an experimental set-up in order to validate the results of a simple simulation model. Temperatures of surfaces of the double façade and the air in the cavity can be measured, as well as the air flow in the cavity and the energy of the sun on the façade. The measurements are compared with the calculations of the simulation model. There is a good fit between the measurements and the calculations under diffuse sky conditions, in more sunny circumstances the model under-estimates the temperatures in the cavity wall in comparison with the experiments. One of the experimental problems was the measurement of the air flow in the cavity. For a better understanding of the flow measurements, computer simulations of the air flow in the double façade are done with Flovent, a CFD simulation program. These simulations show a mixed pattern of laminar and turbulent flow and visualized the problems of the flow measurements. Another problem, the dynamic effects in the temperature measurements, is a result of heating of the window frame and other absorbing materials in the cavity. The convective heat transport from these materials is not taken into account in the simulation model.

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INTRODUCTION

In to-day’s architecture innovative concepts for the building skin are developed among others to improve the energy performance of a building. Various types of double façades can be distinguished. For instance the glass sheets of a double façade can be completely air-tight or one of both sheets can allow air exchange with the interior of the building or with the outside.

In earlier work we discussed a simple simulation model for the energy performance of double façades of the first mentioned category [1]. The model is developed to provide the architect with a design support tool in an early stage of the design process. In this paper we report an experimental set-up in the façade of our faculty in order to validate the results of the simple simulation model. The data of the experiments are discussed. One of the experimental problems was the measurement of the air flow in the cavity. For a better understanding of the flow, computer simulations of the air flow in the double façade are done with Flovent, a CFD simulation program. After that, final experiments are done.

2. THE SIMULATION MODEL

In earlier work [1] a simple simulation model for the energy performance of double façades was presented. The façade construction was described with a number of transparent parallel sheets. For this model the façade construction with sheets and cavities was subdivided into many segments. In the computational model all sheet segments and all air segments are represented by nodes (fig. 1). In each node all incoming and outgoing energy flows are described. Radiation and convection energy transports are described as functions of the node’s temperatures. The absorption of solar radiation is taken into account, too. The conduction in the glass sheets is not taken into account, there is one node temperature for one glass sheet in a horizontal segment.

![Figure 1: Representation of sheets and the air in the cavity for one horizontal segment of the model of the double façade. The radiation and convection energy flows for each node are visualized together with the solar radiation. A sunshade is optional and can be modelled as a sheet too.](image-url)
3. THE EXPERIMENTS

3.1 The experimental set-up

To validate the simulation model a measurement set-up is built in an east-orientated facade on the fifth floor of the faculty (fig. 2). It is an airflow window with dimensions of 1 x 1 x 0.1 m$^3$, ventilated with interior air. The glass sheets are single panes of 4 mm. The material of the window frame is chipboard coated with a white synthetic layer. The air flow in the cavity is regulated by 4 computer ventilators, at regular distances, at the top of the cavity. In an electric circuit the four identical ventilators are connected parallel and the speed of the ventilators was adjustable by an adaptor. The air velocity can be measured in horizontal and vertical directions by anemometers, suitable for measurements of low flow velocity. There is no sunshade in the cavity. Temperatures of surfaces of the double façade and of the air in the cavity can be measured, as well as the velocity of the air flow in the cavity. The temperature of the window frame can be measured too. The air temperature at four different places in the cavity and at the inlet of the cavity and the temperature in the room behind the cavity are measured with platinum resistances, which are protected by white caps against heating by solar radiation (fig. 3). The places of the four platinum resistances in the cavity are at two different heights (0.3 m and 0.8 m) and at the left and right part of the cavity. By calibration at room temperature all platinum resistances show the same temperature within one degree. The white caps, which are delivered as protection against solar radiation, are checked and compared with aluminium caps. At a solar radiation of for example 400 W/m$^2$ a platinum resistance with white cap shows an air temperature one and a half degree lower than a platinum resistance with an aluminium cap. The surface temperatures of the inner and outer glass sheets of the cavity and of the window frame are measured by contact thermometers at the cavity-side of the façade. These contact thermometers are shielded by aluminium tape to prevent the influence of the solar radiation on the thermometers. The solar radiation on the façade can be measured by a solarimeter. The solarimeter was placed on half height of the cavity in a vertical plane behind the outer glass sheet. During all the measurements represented in this paper, the outer glass sheet was dirty, because the window-cleaner installation had been disapproved.

3.2 The measurements

Measurements were done for different dates and climatic conditions. Figure 4 shows a measurement under sunny circumstances. The temperature of the cavity (Tcavity) is the average temperature of the four platinum resistances in the cavity. Besides this and the inside and outside temperature (Ti and Te), the temperatures of the inner en outer glass sheets are shown (Toi and Toe) and the surface temperatures of the left and the right part of the window frame (Tleft and Tright). The left and the right part are different, because in an east-orientated facade the left part of the frame is heated by the direct sun most of time during the measurements and the right part is not.

The white line in the graph represents the solar energy (Qsun) in a vertical plane behind the outer glass sheet. All the temperatures follow the solar radiation but not all in the same way. Figure 5 shows a measurement with alternately sun and clouds. The temperatures rise and go down with the sun and the clouds, but not in phase.

Figure 2: The measurement set-up.

Figure 3: The platinum resistance with white cap

Figure 4: Measurement of the temperatures in the cavity, on the glass sheets and on the window frame, under clear sky conditions (16 april 2003).
4. DATA ANALYSIS

The experiments were compared with calculations of the simulation model in order to validate the model. Figure 6 and 7 compare the temperatures of the cavity and of the inner glass sheet with the same temperatures calculated with the simulation model. In case of direct sun on the facade the measured temperature of the cavity is about ten degrees higher then predicted by the simulation model. When there is no direct sun on the facade or the sun is behind a cloud the experiments and the simulation show the same temperature. But, after a sunny period, the agreement between measurement and simulation is not immediate, there is a time delay. The measured temperatures of the glass sheets also show a discrepancy with the model, however not as much as the temperature of the cavity. All measured temperatures seem influenced by the direct solar radiation. However, the thermometers are shielded for the direct sun by white caps and by aluminium tape. And the air in the cavity is transparent for short wave solar radiation, so the discrepancy can not be caused by heating the measurement apparatus or by the dynamic effect of energy storage in the air. There is another possibility. The cavity of the set-up is small, in contrary with some others [2] and the surface of the window frame is not taken into account in the simulation model, neither are, for example, the cables of the temperature and flow meters. In fact, the frame surface is not small comparing with the surfaces of the glass sheet. Figure 8 shows the temperature of the cavity together with the temperatures of two contact thermometers on the window frame. One contact thermometer is placed on a shadowed place of the frame, the other on a sunny place of the frame. The temperature of the cavity predicted by the simulation model is within a few degrees in agreement with the shadowed contact thermometer. The measured temperature of the cavity follows much more the temperature of the sunny contact.
thermometer. Besides, the four thermometers in the cavity mutually differ some degrees in temperature under sunny circumstances. The thermometer that is most near the sunny parts of the window frame shows a temperature difference of some degrees with the thermometer near the shadowed part of the frame, for example in the case of the measurement of 16 April at 11:00 hour: 3 °C. So, there is indirect solar gain which is not in the model. The simulation model missed a convective heat exchange term with the window frame. This is very well in agreement with a measurement we did in an extremely winter situation, when the outside temperature was -6 °C, and the window frame was very cold as consequence of air leakage. In that case the measured cavity temperature was ten degrees colder than the calculated temperature. For that case too, the simulation model missed a term of the convective heat transport to the cold window frame.

Another problem was the measurement of the air velocity in the cavity. Figure 9 shows the air flow in horizontal and vertical direction during a measurement. It was expected that the flow was especially vertically, but there was a considerable flow in the horizontal direction too. Only a trend line for the velocities could be given and it was unknown what the best place in the cavity was for a real flow measurement. At different days the flow meters were suspended in different places in the cavity. The overall impression after different measurements was that the nature of the flow is not laminar, the same speed setting of the ventilators not always yields the same measurement of the air velocity. As a consequence, the heat exchange coefficient for convection is difficult to calculate. In our earlier paper [1] it was shown that the simulation model is sensitive for this parameter.

From the theory of fluid dynamics we know a flow is only fully developed in a laminar or a turbulent flow after some distance, the so-called entrance length. If the flow in a cavity may be compared with flow in a square pipe this length is much longer than the height of the cavity. For a better understanding of the air flow in the cavity it was decided to make flow simulations with Flovent, a Computational Fluid Dynamics program [3].

5. SIMULATION OF THE AIR FLOW

CFD-simulations with Flovent have been performed to study the flow pattern in the cavity. Figure 10 shows an impression of the convection simulated in a cavity with the same dimensions as the measurement set-up. The outside temperature was chosen -10 °C and the inside temperature 20 °C. There is no direct sun taken into account. Only the flow pattern as result of the mechanical ventilation is studied. As in the set-up, two air entrances are modelled, each of 150 cm². Four ventilators are modelled, with extract velocity of 1 m/s. The four ventilators had each an outlet of 56,25 cm². The air velocity and the direction is visualised by arrows. The length of the arrows is a measure for the air velocity. Figure 10 shows that the flow is vertically directed, but there are turbulent areas too in the cavity, in the middle and the left and right side of the cavity. In the transverse section of the same simulation (figure 11) the air velocity shows a cold flow downwards along the outer glass sheet and the main stream is not in the middle of the section, above the inlet. Simulations were done for different air velocities. Figure 12 shows the section for a lower velocity, 0.3 m. These simulations show that the place of the flow meters in the measurement set-up is critical. Laminar and turbulent flows are mixed in the same flow.

In all the simulations as in figure 10 the influence of the surface of the air entrance was present too. So, simulations are made for different inlet surfaces. Figure 13 is one of them. One entrance over the whole breadth of the cavity was the best condition for a predominantly vertical air flow. After this observation the measurement set-up was rebuilt with such an inlet.
6. FINAL EXPERIMENTS

Measurements are done with the new measurement set-up. Figure 14 shows a measurement under clear sky conditions. All the temperatures follow the solar radiation on the facade with a time shift. Figure 15 shows clearly that the simulation of the cavity temperature and of the inner glass sheet is much lower then the measured temperatures, the same as in figure 6 and 7. And in this experiment too, the simulated cavity temperature is in conformation with the measured temperature of the shadowed part of the window frame, while the measured temperature of the cavity follows the temperature of the sunny part of the window frame (fig. 16). Figure 17 shows the horizontal and vertical air velocity of this measurement. The speed of the ventilators was adjusted the same as the measurement of figure 9, but, now, with the new air inlet the vertical air velocity is more pronounced than the horizontal one. The fluctuations in the velocity are still present.
7. CONCLUSION

Measurements with an experimental set-up were done in order to validate a simple simulation model. There is a good fit between the measurements and the calculations under diffuse sky conditions, in more sunny circumstances the model under-estimates the temperatures in the cavity in comparison with the experiments. All the temperatures of the cavity and the surrounding surfaces follow the solar radiation on the facade with a time shift. The dynamic effects in the temperature measurements are a result of heating of the window frame and, possibly, other absorbing materials in the cavity. The convective heat transport from these materials is not taken into account in the simulation model. Our experiments were done with a small cavity which increased the influence of the window frame.

An important experimental problem was the measurement of the air flow in the cavity. Computer simulations of the air flow in the double façade showed a mixed pattern of laminar and turbulent flow that explains the flow measurements. After modification of the air inlet the vertical air flow was improved, but fluctuations in the velocities remained.

REFERENCES

