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DESIGN SUPPORT SIMULATIONS FOR A DOUBLE-SKIN FAÇADE

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Abstract

The paper presents the methodology, results and recommendations of a design support study for a double-skin façade. The underlying modelling and simulation work is elaborated. A discussion on how the simulation results were transformed in relevant design information is included.

Introduction

For predicting the future reality in combined building and system configurations (such as a ventilated double-skin façade; Figure 1), computer modelling and simulation is currently one of the most powerful techniques available to engineers and designers (see eg Drkal et al. 2001); although there are still several challenges to overcome both in practice (see e.g. Dunovska and Hensen 2001) and in general (Hensen 2001).

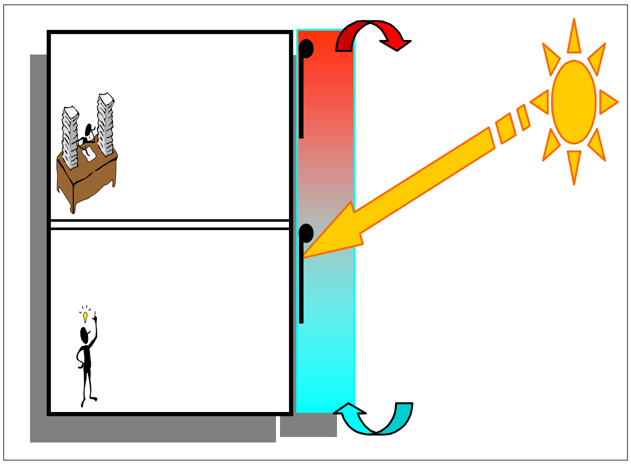

Figure 1 Double-skin facade principle

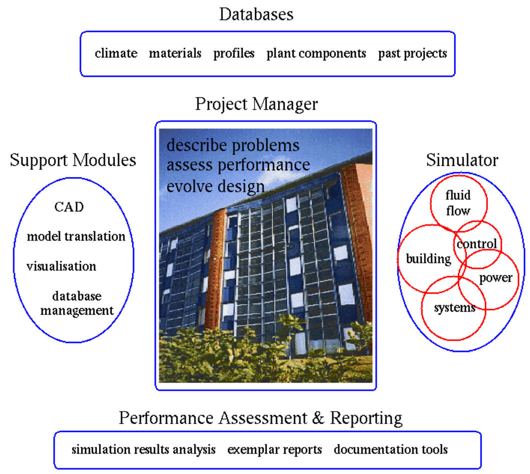

Figure 2 Main architecture of ESP-r

The current double-skin façade study (Hensen and Bartak 2001) made use of the advanced building simulation environment ESP-r depicted in Figure 2 (Clarke 1985, http://www.esru.strath.ac.uk). The main aim of this system is to permit an emulation of building performance in a manner that a) corresponds to reality, b) supports early-through-detailed design stage application and c) enables integrated performance assessments in which no single issue is unduly prominent.One of the very powerful features of this simulation environment is that it alllows modeling of building air flow on different levels of resolution (from user defined air change rates, via mass balance network approach to computational fluid dynamics) and on different levels of integration (e.g. air flow on its own, or coupled with energy balance, and/or coupled with CFD) (Hensen 1991).

The methodology of using computer modelling and simulation in building design is basically an iterative process comprising the following main steps.

1) Analysis of the problem and re-expressing the building design in a manner suitable for simulation; i.e. at suitable levels of detail and complexity.
2) Calibration of the model, against measured data or relying on the experience, intuition and professional judgment of the simulator.
3) Performing simulations against relevant hourly in- and outside boundary conditions.
4) Analysing and reporting of results, perhaps followed by changing the model and further simulations.

Modelling the double-skin façade

Inside a double-skin façade (Figure 1 and Figure 3), the air temperature will mainly depend on heat gains and on the amount of air flow. However, in a naturally ventilated double-skin façade the air flow itself is mainly governed by the temperature difference with outside, and, possibly, also by wind induced pressure differences; the air flow is typically highly erratic as demonstrated in Figure 4. In our experience, such a system is best modelled by a nodal air flow network (Figure 3) fully integrated in a building thermal energy model. As explained elsewhere (Hensen 1999) special attention needs to be paid to the thermodynamic coupling of the air flow network with the thermal energy model.

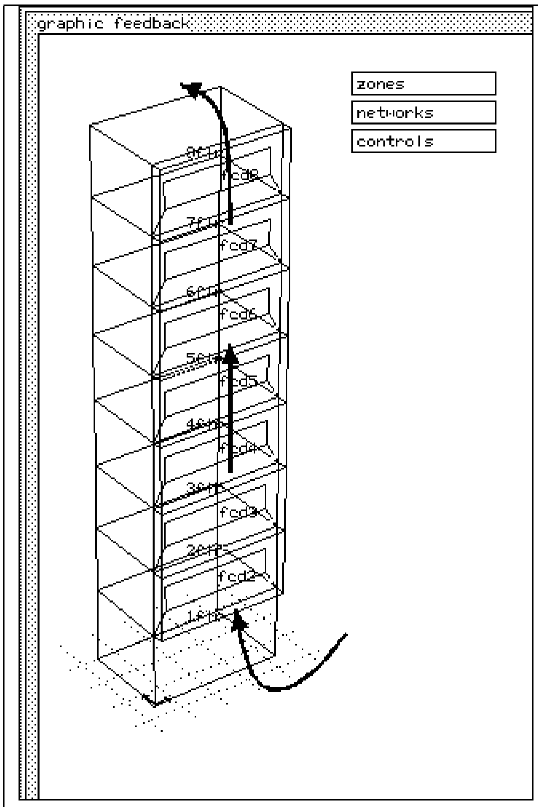

Figure 3 Double-skin façade model

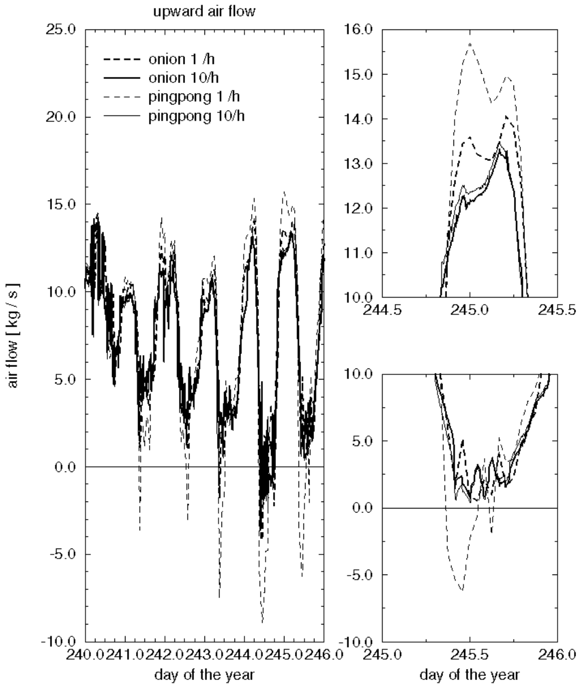

Figure 4 Predicted typical air flow variations in a natural ventilated glazed vertical building structure, such as a double-skin façade (Hensen 1999)

As shown in Figure 3, the current model comprised a typical 7.5 m wide section of the building, consisting of a “stack” of 8 zones representing the offices up to a dept of 5 m behind the façade, and another 7 “stacked” zones representing the double-skin façade itself. These 7 zones are coupled by an air flow network which also includes the inlet opening (modelled by a connection between the bottom cavity zone and outside, i.e. the air temperature and

wind pressure in front of the façade) and the outlet opening (a connection between the upper cavity zone and outside, i.e. the air temperature and wind pressure on the roof).
It was assumed that the windows and the shading devices are closed and that effectively there will be no air exchange between the offices and the cavity of the double-skin façade. All entering direct solar radiation was received by the office surface adjacent to the double-skin module. While the outer surface of the double-skin façade was made from single clear glass 6 mm thick, the office windows had an advanced double glazing with external blinds.

Simulations

In order to generate relevant design information, the following cases have been considered:

A – Building without the double-skin façade during an extreme summer day in Prague.
B – As A but with the double-skin façade.
C – As B but assuming that there would be no wind.
D – As B but assuming that the damper in the double-skin façade outlet would be closed.

Comparison of the results for case B with those for case A show the influence of the double-skin façade as designed. The results for case C represent the case without the influence of wind, e.g. because of sheltering by neighbouring buildings. The results for case D represent the unlikely event that the outlet damper would be closed, perhaps due to malfunctioning.

Results and Discussion

Due to space constraints, only the air temperature results for cases B and D are shown in Figures 3 and 4. It was found that for this building there was not much influence of the wind; i.e. the buoyancy forces are the dominant driving force for the air flow.

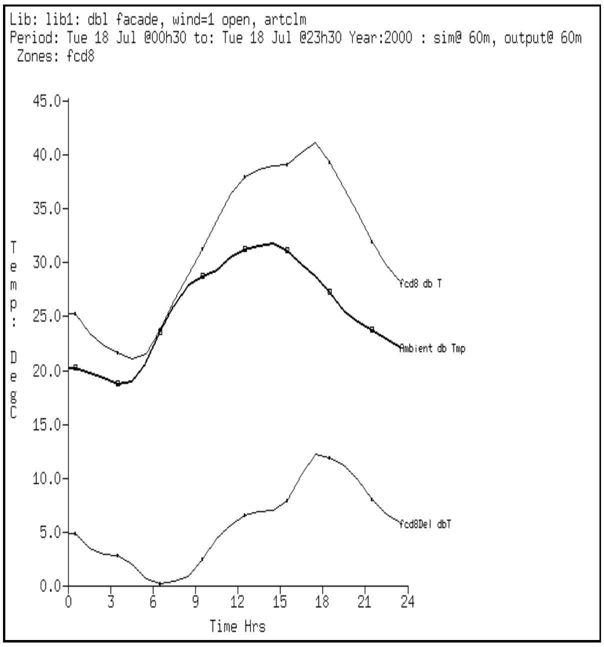

Figure 5 Case B (as designed) inlet and outlet air temperatures of the double-skin façade during an extreme summer day. The lower graph shows the inside-outside temperature difference.

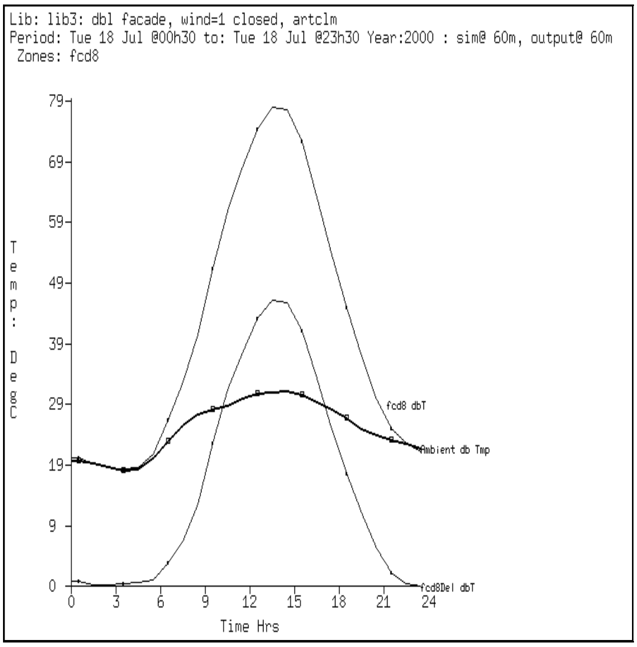

Figure 6 Case D (as designed, with closed outlet damper) inlet and outlet air temperatures of the double-skin façade during an extreme summer day. The lower graph shows the inside-outside temperature difference.

As can be seen in Figure 6, the air temperature rise would be considerably higher in case the outlet damper would not be open. In that case the air temperature could rise up to almost 50^{o}C above the ambient temperature, and this would happen in the middle of the afternoon.

Figure 7 shows some results in terms of air flow rate through the double-skin façade for the case B conditions. During most of the day the flow is upward, basically because the average air temperature in the double-skin façade is above the ambient temperature; i.e. the cavity works as a “chimney”. During part of the early morning, the average air temperature in the double-skin façade is lower than ambient, and this results in downward air flow through the cavity. The reason is that the thermal capacity of the façade “holds back” the temperature rise of the air relative to rapid rise of the ambient air temperature. During this part of the day, the south facing double-skin façade is actually shaded.

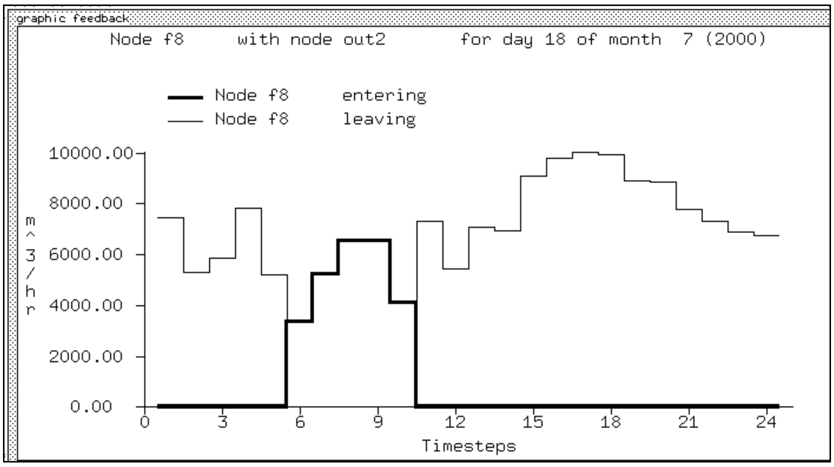

Figure 7: Case B (as designed) air flow rate through the double-skin façade during an extreme summer day. The thin line indicates upward flow in the cavity. The thick line represents downward flow in the cavity. Note that 10000 m^3/h corresponds to an average cross-sectional air velocity of about 0.7 m/s in the cavity, about 1.3 m/s in the outlet, and about 2.0 m/s in the inlet opening of the double-skin façade.

In general, the double-skin façade acts as a thermal buffer in front of the offices. This has two counteracting thermal effects for the offices.

1. The air temperature in the double-skin façade will be higher than outside during most of the time. This will result in lower conductive heat losses (heating season) and higher conductive heat gains (summer) depending on ambient temperatures and solar radiation levels.
2. The extra outside pane of glass of the double-skin façade will effectively reduce the amount of solar radiation on the inside façade, thus reducing the solar radiation load of the offices due to radiation transmission via the windows.

Table 1 Maximum sensible cooling loads for the offices adjacent to the double-skin façade during an extreme summer day for cases A and B (i.e. as designed

Floor level	Maximum sensible cooling load		Additional maximum sensible cooling load due to double-skin façade	
	Case A kW	Case B kW	W	W/m^2 floor
8th	2.41	3.29	880	23
7th	2.40	3.24	840	22
6th	2.40	3.20	800	21
5th	2.39	3.14	750	20
4th	2.37	3.08	710	19
3rd	2.31	2.95	640	17
2nd	2.16	2.67	510	14

Which of these two effects 'wins' at a particular point in time depends on complicated dynamic thermal interactions between the façade, temperatures and air flow in the double-skin façade, and outside. As can be seen in Table 1, for the offices adjacent to the façade the result is increased maximum cooling load during hot summer days. Of course, even larger differences would occur in case the outlet damper would be closed.

It is important to note that it can be argued that this is an academic comparison. In practice the choice is often between a building with no or with internal shading, and external shading in a double-skin façade structure. In such a comparison the construction with the double-skin façade will result in lower maximum cooling loads for the adjacent offices.

In conclusion

A strong thermodynamic coupling exists between the air flow through the naturally ventilated double-skin façade and the air temperature difference between the cavity of the double-skin façade and outside. This interaction can only be predicted by sophisticated and state-of-the-art building energy modelling and simulation techniques as was done in the current study.

We feel that this study is yet another demonstration of the fact that modelling and simulation is a discipline, not a software package, which critically depends on two essential skills.

1) The ability to understand a complex system and its inter-relationships.
2) The ability to translate this understanding into an appropriate logical representation understood by the simulation software.

We also feel that this study demonstrates that for effective use of building simulation in a design context, there are three important conditions to be noted.

1) Choosing the appropriate model in terms of levels of complexity and of integration.
2) Making sure that the model is validated and calibrated.
3) Using simulation to (relatively) compare alternative solutions or design options.

If any of these prerequisites is not satisfied (ie. the model detail is not correct, or the model is not valid, or the results are regarded absolute rather than relative) the quality of the results can not be assured.

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