THE VALIDATION OF A MODEL FOR THE ENERGY PERFORMANCES OF DOUBLE FACADES

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ABSTRACT

Various types of double façades can be distinguished. In earlier work a simple simulation model for the energy performance of double facades is developed. In this paper the problem of modelling a half-open sunshade between sheets is discussed. An extensive computer exercise for long-wave radiation has been done taking all the interreflections of sheets and venetian blinds into account. Under certain circumstances it is possible to come to a simple solution and to make an estimation of the heat-exchange coefficients for radiation, which can be used in the simple simulation model.
With Flovent, a CFD program, simulations have been done to study the flow pattern around the venetian blinds.

KEYWORDS

Double facades, design and simulation tools, environmental quality of buildings.

1. INTRODUCTION

In to-day's architecture a number of innovative concepts for the building skin are introduced. Besides architectural reasons like transparency, so-called 'double façades' have been developed to improve the energy performance of a building as well as the indoor climate.
Various types of double façades can be distinguished. For instance the glass sheets of a double façade, with a sunshade in between, 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 [Voorden (1999), Paassen (2000)]. This model is developed to provide the architect with a design support tool in an early stage of the design process. The simple model only takes the effects of a completely closed or open sunshade into account. However, a partly open sunshade is a lot more common. The afore mentioned simple design tool should therefore be able to model a partly-open sunshade as well. In this paper the difficulties in modelling a half-open sunshade within this design tool are reported.
In order to study the effect of a partly-open sunshade on the computed temperatures and heat flows, -an extensive computer simulation for long-wave radiation was necessary, a computational simulation taking all the interreflections of sheets and venetian blinds into account. Under certain circumstances it is possible to arrive at a simple solution and to make an estimation of the heat-exchange coefficients for radiation, which can be used in the simple simulation model.
Also CFD-simulations have been performed to study the flow pattern around the venetian blinds.

2. THE MODEL OF THE DOUBLE FAÇADE

2.1. The 2-dimensional simulation model

The façade construction is described with a number of transparent parallel sheets. For this 2-dimensional model the façade construction with sheets and cavities is 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, convection and conduction energy transports are described as functions of the node's temperatures.
In earlier work the sunshade was modelled as a non-perforated sheet, 100% open or closed.
In this study, the effects of a partly-open sunshade on the long-wave radiation and convection are investigated in order to incorporate a partly-open sunshade in the simple design tool. The effects on the long wave radiation and convection could only be determined by assuming temperatures of the glass sheets and the sunshade. All these temperatures for both summer and winter situations in the following simulations are derived from the 2-dimensional simulation model.

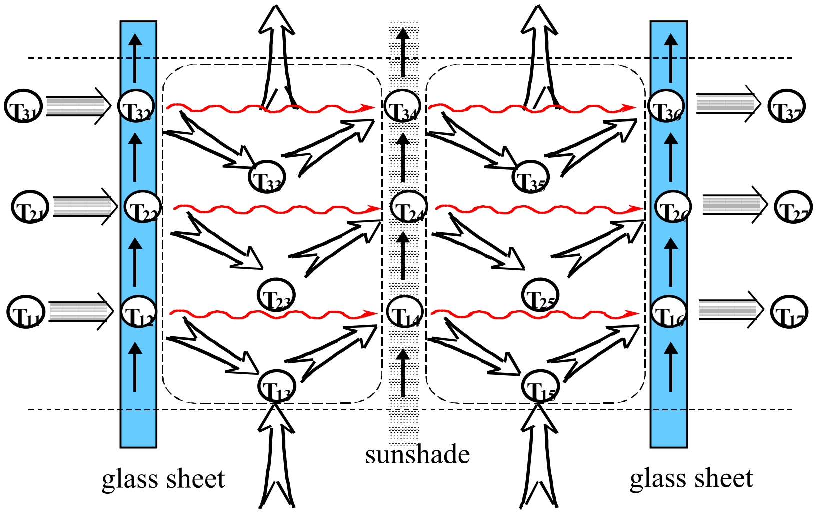


Fig. 1. Representation of sheets and air segments of the double façade by nodes, and the energy flows for each node.

2.2. The long wave radiation.

The net-radiation exchange between planes is the difference between the primary and reflective radiation contributions.
The primary long-wave radiation density q^p of a plane is provided by the (absolute) temperature T of the sheet and its radiation coefficient C in accordance with the law of Stefan-Bolzmann:

$$q^p = C\,(T/100)^4 \qquad \text{[eqn. 1]}$$

The reflective radiation of an arbitrary plane is the reflection of all received radiation sent by other planes:

$$Q_i^r = q_i^r A_i = r_i \sum_{j=1}^{n} \varphi_{ji} A_j (q_j^p + q_j^r) \qquad \text{[eqn. 2]}$$

In which: q_i^r = reflective radiation density send out by plane i [W/m^2]
A_i = surface of plane i [m^2]
r = reflection coefficient
φ_{ji} = view factor from plane j to plane i

Equation (2) can be rewritten as

$$r_i \sum_{j=1}^{n} \varphi_{ji} A_j q_j^p = q_i^r A_i - r_i \sum_{j=1}^{n} \varphi_{ji} A_j q_j^r \qquad \text{[eqn. 3]}$$

which is of the form: *vector* ***p*** *= matrix K . vector* ***q*** [eqn. 4]

In the case of a double façade without a sunshade there are 6 planes which can radiate to each other: an inner and an outer sheet and the 4 planes of the façade-frame. That means 36 view factors to be calculate and a 6 x 6 matrix K. If there is a partly-open sunshade, e.g. venetian blinds, between the two sheets, each lamella of the venetian blinds is a separate plane and thus the number of view factors increases exorbitantly. So does the size of matrix K.

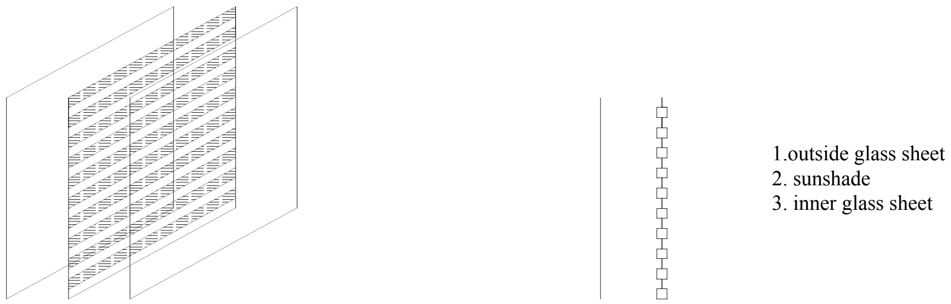


Fig. 2. A model for a double façade with a half-open sunshade.

For that reason, a simplification is proposed. The partly-open sunshade is modelled as a number of lamellae and gaps situated in one plane (fig. 2). As the next step, the inner glass sheet is approximated as being situated in the same plane and all view factors from plane 1 to plane 2/3 are easily calculated. This reduces the number of view factors and the size of matrix K significantly.

A further simplification is obtained when the distribution of lamellae and gaps is uniform: There is a linear relation between the degree of perforation and the total view factor of the sunshade (fig. 3). If x is the degree of perforation, the net radiation from glass sheet 1 to the sunshade is (1-x) times the total net radiation coming from glass sheet 1, and x times the net radiation is the radiation going to glass sheet 3, a distribution which can be easily built-in in the simple 2-dimensional double façade simulation model. The disadvantage of this model is the neglect of the interreflections between the back-side of the sunshade and the inner glass sheet.

To see the consequences of the neglect of the interreflections, computer simulations were performed with only two lamellae of 0.15 x 1.80 m^2 in the plane between the sheets (fig. 4). The energy flow due to long-wave radiation has been calculated with the equations 1, 2 and 3 taking all interreflections of sheets and venetian blinds into account. Two lamellae limit the complicated problem to a problem of 38 planes and a 38 x 38 matrix K. The façade edges between the sheets were closed, the temperature of the edges to the left of the lamellae was

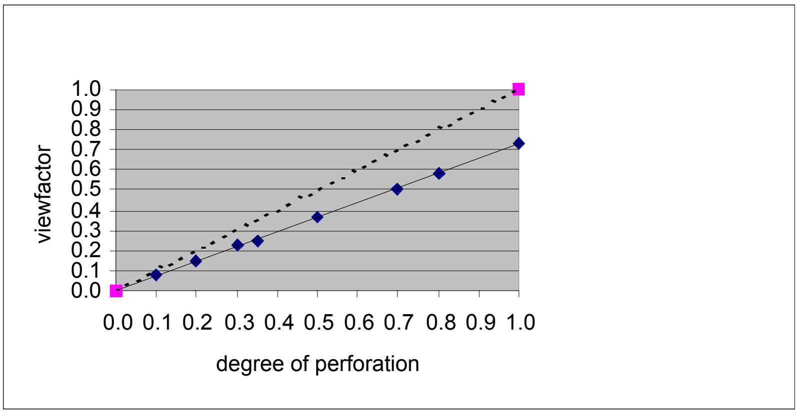
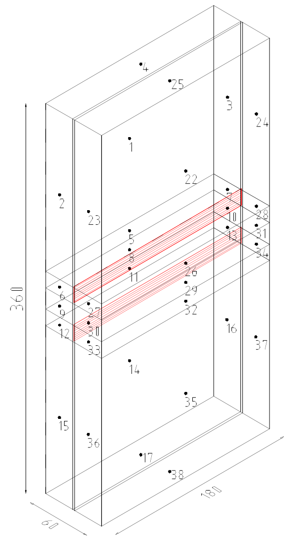


Fig. 3. The relationship between the degree of perforation and the view factor from the glass sheet (1.80 x 1.80 m2) to the sunshade. The striped line is the graph for two infinite planes.



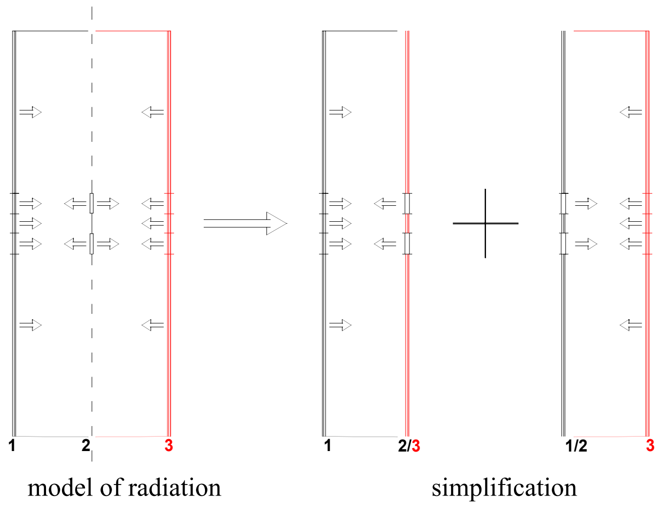


Fig. 4. In the case of 2 lamellae the minimum grid exists of 38 planes. Façade: 0.6x1.8x3.6 m^3.

Fig. 5. The simplification of the radiation model. 1=outside glass sheet, 2=lamellae, 3=inner glass sheet.

chosen to be the same as the outer sheet and the temperature of the edges to the right of the lamellae was the same as the inner sheet. All the long-wave radiation stays between the sheets. Table 1 (compl. columns) shows the results for a winter and a summer situation and different radiation coefficients of glass sheets and sunshade. The net radiation densities for the sunshade is higher then for the sheets, due to their higher temperature. This higher temperature is caused by the absorption of the direct sunlight, as calculated by the simple design tool. Table 1 shows that the value of the radiation coefficient has a large effect on the net radiation density. Interreflections have a large effect when the values of the radiation coefficients are not identical for all the planes.
A further simplification was made (fig 5), only the interreflections between planes which have a direct view to each other are taken into account. Table 1 (simpl. columns) shows the energy flows for this simpler model too. There is not a great difference between the energy flows of these two models.
The main purpose of this paper is to find the easiest and still correct model of the double facade with a partial sunshade. It is shown that in the case of a homogeneous distributions of

lamellae and gaps (fig. 2), the problem is reduced to a sunshade with a homogeneous perforated distribution. In that case the computer calculations are reduced to the solution of equation 4 with a 12 x 12 matrix K. If all planes of the façade frame have the same temperature only a 6 x 6 matrix remains. In this way energy flows were calculated for a double façade with a partly-open sunshade with the same degree of perforation as the other two models (table 1-hom. columns).
Due to the application of only two lamellae in the middle of the sunshade, some differences between the extensive model with the 38 x 38 matrix and the simplified homogeneous approach are expected. The homogenous approach does not quite apply to the two small lamellae model. Further differences are rather small. This means that the simplified homogeneous approach can be used to model the radiation energy flows of the double facade with a partly open sunshade, if the homogeneous approach is valid.
In the simplified design tool, however, temperatures and energy flows are to be calculated. The radiation energy flows should therefore be transformed into heat transfer coefficients.
In the case the radiation coefficients of glass sheets and venetian blinds are the same, the total radiation from one plane i to all the others planes j can be describes as:

$$q_i = \alpha_s \,.\, (T_i - T_{fict}) \qquad \text{[eqn. 5]}$$

In which: T_{fict} = the average of all the temperatures of the planes j, weighed with the view factors φ_{ij}.

In this way the heat-exchange coefficient α_s for long wave radiation can be calculated and can be used in the simple simulation model of the façade.

TABLE 1. The long-wave radiation contributions send out by the outer glass sheet, the inner glass sheet and the front- and back-side of the sunshade (q1, q2, qsl,qsr) in dependence of the temperatures of the inner sheet, the outer sheet and the sunshade (T1,T2,Ts) and for different radiation coefficients for the sheets and the front- and back-side of the sunshade (C1, C2, Csl,Csr).

		C1=5,5 Csl=5,2 Csr=5,2 C2=5,5			C1=0,5 Csl=5,2 Csr=5,2 C2=5,5			C1=5,5 Csl=0,5 Csr=5,2 C2=5,5			C1=0,5 Csl=0,5 Csr=5,2 C2=5,5			C1=0,5 Csl=0,5 Csr=5,2 C2=0,5		
		compl.	simple	hom.	compl.	simple	hom.	compl.	simple	hom.	compl.	simple	hom.	compl.	simple	hom.
T1=314,6 K	q1	11,1	10,7	5,4	1,4	1,6	0,7	19,9	19,6	12,2	2,5	2,7	1,7	2,6	6,8	-2,3
Ts=334,2 K	qsl	142,6	142,6	139,7	142,3	144,8	146,2	13,8	13,8	13,5	15,9	16,2	15	15,8	19,8	11,3
T2=311,4 K	qsr	162,1	162,1	159,3	162,3	165,5	159,4	162,1	162,1	159,3	162,5	162,5	159,6	147,9	154,7	115,5
	q2	-21	-21,1	-22	-9,9	-4,3	-17,7	-20,9	-21,1	-21,8	-2,7	-4,3	-11,4	0	0,8	-4,7
T1=284,6 K	q1	3,4	3,3	0,5	0,5	0,7	0,1	13,8	13,7	8,7	1,7	1,9	1,2	0,4	4,4	-3,08
Ts=314,2 K	qsl	167,7	167,7	165,9	157,4	159,1	166,5	16,2	16,2	16	17,6	17,8	17,1	16,2	20,2	13,1
T2=281,4 K	qsr	182,1	182,1	180,4	182,1	182,4	180,5	182,1	182,1	180,5	182,4	182,4	180,1	151,3	155,3	133,15
	q2	-20,3	-20,2	-19,7	-15,5	-8,1	-19,3	-20,1	-20,2	-19,6	-7,5	-8,1	-12,1	-1,7	-1,2	-5,1

2.3. The convective heat transport.

Which Flovent, a Computational Fluid Dynamics program, the air flow around the lamellae in a ventilated façade can be investigated. A turbulent model, the Revised Algebraic model, was used to solve the Navier-Stokes equations.
2-dimensional stationary simulations were done for a half-open sunshade in an open and in a closed cavity. The temperatures were chosen for a winter situation, as the temperature differences between inner and outside are greater in winter then in summer, and thus the effects larger. The sun radiation and the heat-radiation was not taken into account, only the convection, because not the absolute temperatures but the air flows were the reason that the

simulations were done. The dimensions of the façade were 0.6x1.8x3.6 m^3, the dimensions of the lamellae were 0.03x0.12x1.8 m3, the perforation degree of the sunshade was 50%.
The results showed that the velocities between the lamellae in a closed cavity are hardly influenced by the existence of the sunshade, see figure 6. The differences in temperatures and air flows are very small between the partly open sunshade and the entirely open sunshade in the closed cavity. The velocities between the lamellae for the open cavity show similar results, although here the differences between the closed, open and partly-open lamellae are very small whereas the difference between the partly-open and the closed sunshade are rather large in the closed cavity.

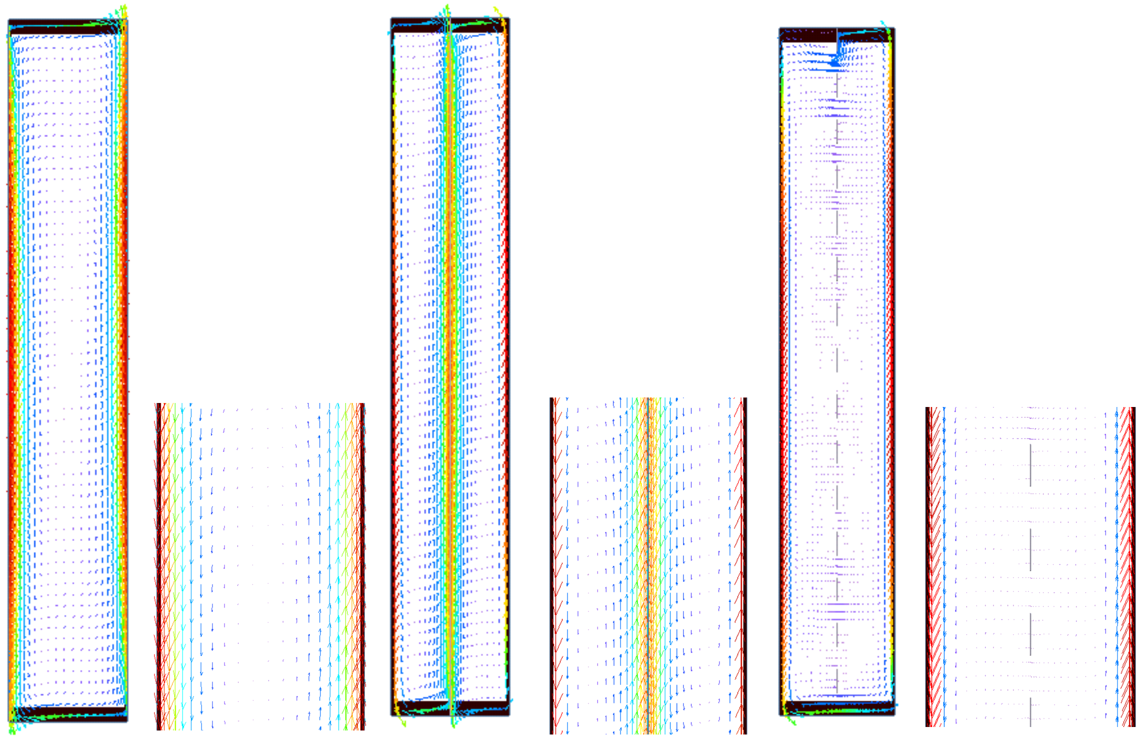


Fig. 6. The air flow in a closed cavity without a sunshade, with a sunshade and with a partly-open sunshade.

3. DISCUSSION AND CONCLUSIONS

It is possible to incorporate the radiation exchange in the simplified design tool for materials that have the same radiation coefficient. It is expected that it is possible to incorporate the radiation exchange in the simplified design tool for materials that have different radiation coefficient. This is, however, subject of further research.
The convection coefficients do only majority change in the closed cavity when an entirely closed sunshade is applied. The differences between the entirely open and the partly open sunshade are negligible.

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