A SIMPLIFIED DESIGN TOOL FOR EVALUATION OF THE ENERGY PERFORMANCE OF 'DOUBLE FACADES'

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ABSTRACT The wish to improve the energy performance of a building as well as to improve indoor climate can be mentioned as one of the main driving forces behind the introduction of so called 'double facades'. Various types of double facades can be distinguished; the number of possible double facade variants is large. This raises the question in what way the performance of double facades can be predicted during the design process and how well-considered design decisions can be made. To answer this question the faculties of Architecture and Mechanical Engineering of Delft University of Technology have started a joint research project aiming at development of global but reliable computational tools, which can be used during the design process.

1 Introduction

In today's architecture so called 'double facades' are frequently used. Besides specific architectural reasons for the introduction of double facades in building design, the wish to improve the energy performance of a building as well as to improve the indoor climate can be mentioned as one of the main driving forces. In order to achieve such improvements an insight is required during the design process into the impact of relevant design parameters on heat losses and heat gains through double facades, as well as on temperatures occurring in all facade elements. Various types of double facades can be distinguished. For instance the skins of a double facade can be completely airtight or the can allow air exchange with the interior or with the outside. Furthermore various ventilation strategies and various translucent materials can be applied for the two skins. As a consequence the number of possible double facade variants is large. This raises the question in what way the performance of specific double facade concepts could be predicted and compared during the design process and how well-considered design decisions could be made.

The energy transport in double facades is determined by three different heat transfer mechanisms: radiation, convection and conduction. For prediction of each of the corresponding heat flows, high-tech simulation tools are available, based on advanced computational models. It is however a well-known fact that due to the complexity of these tools, their integration in the design process is generally impossible.

One of the possibilities to minimize this gap between the design process and simulation processes could be the development of more global tools based on simplified computational models. The faculties of Architecture and Mechanical Engineering of Delft University of Technology have started a joint research project aiming at development of global but reliable computational tools which can be used during the design process to study the impact of specific design decisions on the energy performance of double facades. Use will be made of results obtained during the EC-project NATVENT [Paassen 1998]. The approach of this project as well as preliminary results obtained will be discussed and illustrated in this paper.

2 Approach

The following stages will be distinguished in the research project::

1) Distinction of a number of categories of double facade constructions, depending for instance on the air-tightness of the cavity skins.
2) Development of a simplified computational model for each of the categories of facades.
3) Analysis of the impact of relevant modeling parameters and of simplified modeling assumptions on obtained computational results.
4) Validation of the computational models by comparison of computational results with results obtained by using an experimental set-up.
5) Adjustment (if necessary) of modeling parameters.
6) Analysis of the impact of relevant design parameters on the performance of double facades.

For one specific category of double facade constructions stages two and three will be discussed in this paper.

3 Computational model

The double facades considered all consist of a number of transparent and parallel sheets (skins). In case of a sun-blind in the cavity, the blind is considered to be a non-perforated sheet. In vertical direction the facade construction (sheets and cavity) will be subdivided into a number of segments. In the computational model all sheet segments and all air segments will be represented by nodes. For each node all incoming and outgoing energy flows and mass flows will be described respectively as a function of node-temperatures and node-air pressures. See Fig.1. In this paper only double facade constructions with airtight skins will be considered.

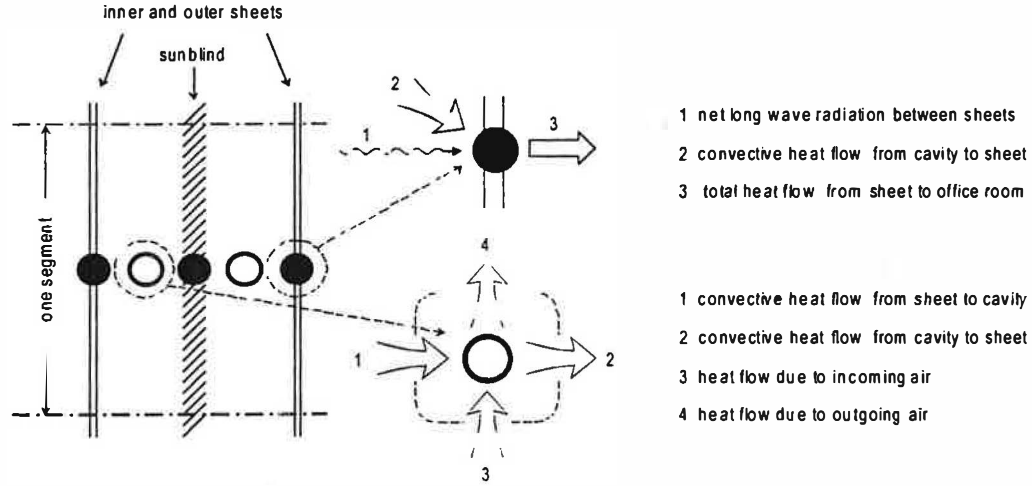

Fig.1 **Representation of sheet segments and air segments by nodes and description of all energy flows for two arbitrary nodes**

Conductive heat flow in the sheets is modeled as a 2-D steady heat flow; the temperature gradient in the sheets in the direction of the airflow is taken into account. Because of the very modest thickness of all sheets the thermal resistance in the direction perpendicular to the sheet is very small. The temperature gradient in that direction is therefore neglected.

Convective heat transport from the sheets to the airflow in the cavity, as well as the net radiation transport between two sheets can be described by the following simple formulae:

$$q_{convection} = \alpha_{convection} * (T_{sheet} - T_{air}) \quad \text{and} \quad q_{radiation} = \alpha_{radiation} * (T_{sheet,1} - T_{sheet,2})$$

The value for the convective heat exchange coefficient $\alpha_{convection}$ is determined as a function of the Nusselt number and the Prandtl number. The radiation heat exchange coefficient $\alpha_{radiation}$ is determined as a non-linear function of sheet temperatures and of sheet radiation numbers, assuming large parallel sheets with uniform surface temperatures. Since temperatures are the unknown parameters, iteration will be part of the computation process.

Absorption of solar radiation by the sheets is also taken into account. The scattering of reflected solar radiation in the cavity by glazed sheets and sun-blind has so far been neglected.

The average air velocity in the cavity can be computed by means of the following formula:

$$v_{air} = C_{d.tot} \cdot \sqrt{\frac{2}{\rho} . \Delta p_{tot}}$$

with:

v_{air} : average air velocity [m.s^{-1}]
$C_{d,tot}$: total resistance coefficient [-]
A_{eff} : effective (free) opening [m^2]
ρ : specific density of air [kg.m^{-3}]
Δp_{tot} : total pressure difference [Pa]

For various types of cavities and grids values for A_{eff} and resistance coefficient can be found in the literature [BS 5925,1980]. The total resistance coefficient can be computed by 'adding' the values of each individual resistance coefficient in the cavity according to the formula in Fig.2. The total pressure difference Δp_{tot} can be caused by differences in wind pressure between inlet and outlet of the cavity or by differences in temperatures between air in the cavity and outside air. The pressure difference due to wind pressures (Fig.2) can be computed as follows [Swami,1994]:

$$\Delta p_{wind} = p_{w1} - p_{w2} = 0{,}5 \; . \; \rho \; . \; v_{wind}^2 . \; (C_{p1} - C_{p2})$$

with:

C_{p1} : pressure coefficient on the weather-side [-]
C_{p2} : pressure coefficient at the roof [-]

For pressure difference due to stack effect the following formula can be used [Liddament,1996]:

$$\Delta P_{stac} = \rho \, g \, n \, h \left(\frac{273 + \theta_2}{273 + \theta_1} - 1 \right)$$

with:

ρ : specific density [kg.m^{-3}]
g : gravity acceleration (9.81) [m.s^{-2}]
n : number of floors [-]
h : floor height [m]
θ_1 : temperature of outside air [^{0}C]
θ_2 : air temperature in the cavity [^{0}C]

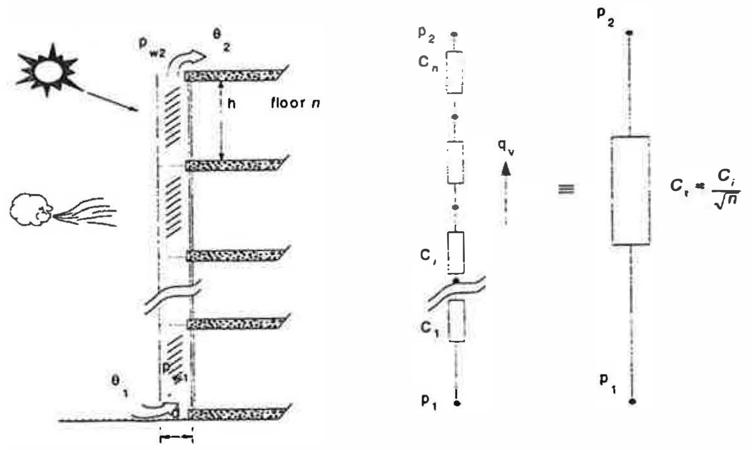

Fig. 2 Air flow through a double facade taking all grid resistance coefficients into account.

In case of a cavity with airtight sheets and an airflow due to wind pressure a set of N equations containing N unknown node-temperatures can be derived by describing the energy balance for each of the N nodes. For given boundary conditions the set of equations can be solved directly. In case of airflow due to stack effect an iteration process has to be performed, using the same set of equations.

For the category of ventilated double facades here discussed a simplified 'tool' has been constructed, the applicability of which will now be discussed.

4 Results

Use of the simplified tool is demonstrated by considering a six storey building with the following double facade construction: airtight sheets (cavity width 0.5m, single glazed on the outside and double-glazed on the inside), grids at floor level and sun-blind. For given climatic conditions (solar irradiance: 800 W/m^2; average wind speed on the weather-side of 5 m/s; outside air temperature and air temperature in the office are 35^{0}C and 25^{0}C respectively), given pressure coefficient values (on the weather-side 0.6 and at the roof -0.3), given resistance coefficient value for each grid (0.6), an air velocity value of 1,27 m/s is found using the model described above. Computed temperatures and energy flows are shown in Fig.3.

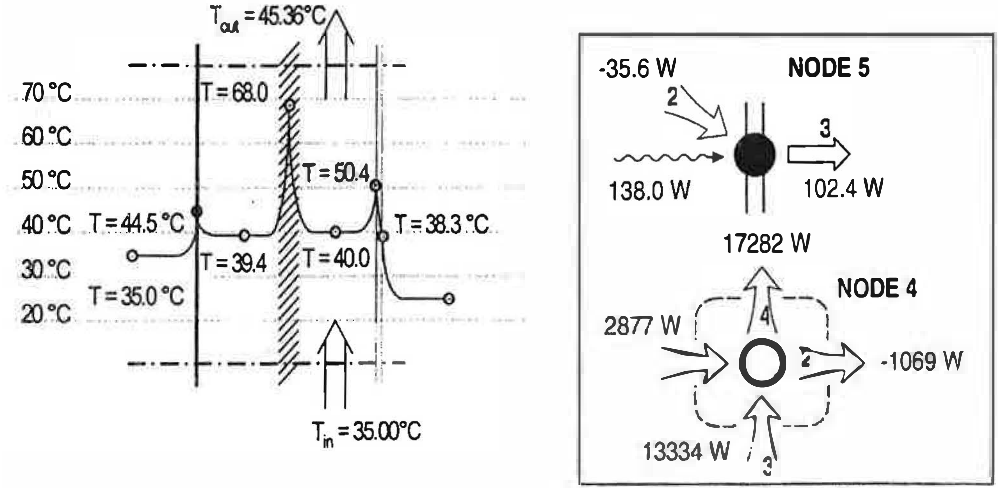

Fig.3 Temperatures and energy flows in a double facade for summer and winter conditions

The example clearly shows that for each node all energy flows are 'in balance' and that under the given conditions extreme temperatures can be expected.

For various sheet materials with completely different conduction properties the temperature gradient in the direction of the airflow appears to be very small. Though in general small temperature gradients in highly conductive materials may correspond with large energy flows, so far the energy flows in the sheets appear to be relatively small. This might lead to the conclusion that 1D-models instead of 2D-models could be used. To be sure this hypothesis has to be investigated more thoroughly.

The necessity of an iteration process to compute the value for the radiation heat exchange coefficient $\alpha_{radiation}$ has been investigated. Computed values for $\alpha_{radiation}$ (for the cavities on the left side as well as on the right side of the sun-blind), for the node temperatures and for the heat flow through the inner and outer sheet are shown in Table 1 for each iteration step . It is clear that already after one iteration step accurate values are obtained.

TABLE 1 **Impact of refinement of $\alpha_{radiation}$ on temperatures and on heat flows**

step	$\alpha_{rad,L}$ $[Wm^{-2}K^{-1}]$	$\alpha_{rad,R}$ $[Wm^{-2}K^{-1}]$	T_1 $[^0C]$	T_2 $[^0C]$	T_3 $[^0C]$	T_4 $[^0C]$	T_5 $[^0C]$	$q_{inner\ sh}$ $[Wm^{-2}]$	$q_{outer\ sh}$ $[Wm^{-2}]$
1	5.94	5.94	44.0	40.7	71.6	41.3	49.6	099.1	229.5
2	7.74	7.94	44.6	39.3	67.8	40.0	50.4	102.5	242.9
3	7.63	7.84	44.5	39.4	68.0	40.0	50.4	102.4	242.1
4	7.64	7.84	44.5	39.4	68.0	40.0	50.4	102.4	242.2

As stated before, the value of $\alpha_{convection}$ is computed as a function of the Nusselt and the Prandtl numbers. It can be expected that in general the actual value for $\alpha_{convection}$ will be different. For two arbitrary air velocity values Table 2 shows the impact of an underestimate of $\Delta\alpha_{conv}$=0.5 $[Wm^{-2}K^{-1}]$ on sun-blind temperature T_3 (ΔT_3) and on the energy flow ($\Delta\ q_{inner\ sh}$) through the inner sheet.

TABLE 2 **Impact of an underestimate of $\alpha_{convection}$ on sunblind temperature and on heat flow through inner sheet**

v_{air} $[ms^{-1}]$	α_{conv} $[Wm^{-2}K^{-1}]$	T_3 $[^0C]$	ΔT_3 $[^0C]$	$q_{inner\ sh}$ $[Wm^{-2}]$	$\Delta\ q_{inner\ sh}$ $[Wm^{-2}]$
0.2	0.75	85.7	-3.1	156.7	-8.9 (5.7%)
1.0	2.75	71.1	-1.9	116.6	-10.2 (8.8%)

6 Conclusions and remarks

- By using this computational model a good insight can be obtained into temperatures and heat flows occurring in double facades with airtight sheets.
- The impact of possible inaccuracy in assumed value for the convective heat exchange coefficient on computed temperatures and heat flows is clear but relatively small.
- Although not discussed explicitly in this paper it has become clear that this model also allows simple and fast evaluation of the impact of design decisions on temperatures and heat losses. Comparison of various design options can be done easily during the design process.
- The discussed approach can (and will) be applied to other categories of double facade constructions.

- So far the temperature gradient in the sheets as well as the corresponding heat flow in the direction of the airflow turns out to be negligible. If this preliminary conclusion can be generalized, further simplification of the computational model will be possible.

7 References

Paassen A.H.C, Liem S.H, Gröninger B.P, (1998): Control of night cooling with natural ventilation, *19th Annual AIVC Conference*, Oslo, Norway.

British Standard BS 5925, (1980):*Code of practice design of buildings, Ventilation Principles and Design for Natural Ventilation*, London.

Swami M.V, Chandra M.V), (1994): Correlations for pressure distributions on buildings and calculation of natural ventilation airflows *ASHRAE Transactions* 94(1.

Liddament M.W, (1996): *A guide to Energy Efficient Ventilation*, Air infiltration and Ventilation Center, University of Warwick.