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CFD-SIMULATIONS OF TRANSPARENT COATED AND GAS-FILLED FACADE PANELS

R.M.J. Bokel[1], B.H.G. Peters[1,2], and M. van der Voorden[1]
[1]Delft University of Technology, Faculty of Architecture, Building Physics Group, PO Box 5043, 2600 GA Delft, Netherlands
[2]present adress: DGMR Consulting Engineers, PO Box 82223, 2508 EE The Hague, Netherlands

ABSTRACT

The tendency to impose stricter building regulations in order to further decrease energy consumption contradicts the tendency to build more transparent architecture and apply thinner façade construction elements. This contradiction can be seen as one of the driving forces of all research efforts that focus on developing translucent façade elements with high insulating values.

This work is part of the ongoing research program on ‘Climate Adaptive Skins’ and focuses on thin and transparent façade elements with gas-filled cavities. The computational fluid dynamics (CFD) computer simulation program Flovent was applied to study the air flow and temperature distribution in an insulating glazing unit.

The CFD-simulations were compared with values found in the literature. The cfd-simulations were also compared with simulations which were performed with the less sophisticated computer program Trisco. The Trisco program can only calculate the heat transfer trough conduction, using the norm EN 673 as an approximation for the heat transfer though convection in the cavity.

INTRODUCTION

Tendencies

In today’s building design practice there is a tendency to impose stricter building regulations in order to decrease the energy demand for heating and cooling and to guaranty an indoor environment that meets thermal comfort demands. On the other hand, there is a tendency towards more transparent architecture and towards thinner façade construction elements. This tendency applies to new building projects as well as to renovation projects like Peutz’s ‘Glass-Palace’ in the Dutch city of Heerlen, shown in figure 1. In general, renovation projects, especially when the original façade-construction has to be preserved, provide little space for adjustments which adapt these buildings to today’s standards (de Jonge et al,1997).

It is clear that the above discussed tendencies and quality demands are contradictory. In general, more transparent architecture causes an increase in heating and cooling demands. Besides thermal problems, more transparent architecture can also cause problems such as discomfort glare or poor sound insulation (van der Voorden et al., 2001).

Figure 1: Japanese villa by Kengo Kuma & Associates; Glass-palace by Peutz

Super insulation

The above mentioned contradiction can be seen as one of the driving forces behind all the research efforts that have focused on the development of slim and translucent façade elements with high insulation values. Those transparent materials and constructions with high insulation values are usually described as super insulation.

The development of super insulating façade panels requires special attention to heat losses through critical parts of the façade such as spacers and window frames. It is commonly known that the mean insulation value of the façade can be strongly influenced by these thermal bridges.

THEORY

The total heat transfer though insulating glazing units can be divided into heat transfer through convection, conduction and radiation. The heat exchange through long wave radiation depends on the temperatures, the sizes, the positions, and the radiation constants (ε) of the surrounding surfaces. The heat transfer by means of convection and conduction across the gas layer can be expressed by the Nusselt number:

$$Nu = \frac{q_m d}{\lambda (T_1 - T_2)}$$

with d (m) the width of the air layer, q_m (W/m^2) the non-radiative heat flow across the gas layer, T_1 and T_2 the surface temperatures of the two glass panels and λ (W/mK) the thermal conductivity of the gas.

For building physics applications, the heat transfer coefficient α for conduction and convection is generally used and this heat transfer coefficient is a function of the Nusselt number and defined as follows:

$$\alpha_{conduction+convection} = \frac{\lambda \cdot Nu}{d}$$

For the Nusselt number a lot of empirically derived relations can be found. These relationships will not be discussed here. To verify the simulations, however, the experimental estimates of Yin et al. and the European norm 673 are used.

The European norm gives the following relationship:

$$Nu_{637} = \max\left[1\,,\,0.035\left(\frac{gd^3\beta(T_1 - T_2)}{a\nu}\right)^{0.38}\right]$$

.

Yin et al. give the following relationship:

$$Nu_{Yin\ et\ al.} = 0.23\left(\frac{d}{h}\right)^{0.131}\left(\frac{gd^3\beta(T_1 - T_2)}{a\nu}\right)^{0.269}$$

$$when \quad 4.9 < \frac{d}{h} < 78.7$$

Hereby g is the acceleration of gravity (m2/s), h the height of the window panel (m), β (1/K) the thermal expansion coefficient of the gas, v (m2/s) the kinematic viscosity of the gas and a (m2/s) the thermal diffusivity of the gas.

METHOD

geometry and boundary conditions

The heat transfer between the insulating glazing unit and the indoor and outdoor environment is modeled by internal and external heat transfer coefficients with a value of 7,25 W/m^{2}K and 23,3 W/m^{2}K respectively and by prescribed corresponding air temperatures of 20 ºC and -10 ºC. The following set of adiabatic system boundaries for the façade panels were simulated (figure 2) :

1. only the insulating glazing unit
2. the insulating glazing unit including the window spacers

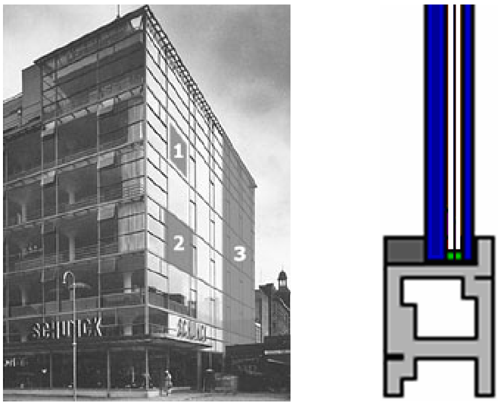

Figure 2: a. system boundaries, b. Vertical section of the model including window spacers and -frame

A large glass panel (1.8 x 1.8 m) was simulated in order to avoid radiation anomalies at the adiabatic boundaries. Both glass panels consisted of 6 mm glass with a thermal conductivity of 0.8 W/mK. The radiation constant of the glass was taken to be 0.95. Between the two glass panels, a cavity of varying depth was modeled. The surface roughness was not taken into account.

parameters

First the relationship between the total heat transfer and the cavity depth for an insulating glazing unit with an air cavity was investigated using computational fluid dynamics. This relationship was investigated for the combined model of the air cavity and the two glass layers. As modern glazing units with low total heat transfer usually apply an Argon or a Krypton filled cavity to obtain this low total heat transfer, cfd-simulations with either Argon or Krypton instead of air were also performed.

Another method to diminish the total heat transfer through a facade panel is to reduce the heat transfer through radiation. This reduction can be realized through the addition of surface coatings on the inside of the glass panels. The effect of one or more coatings and their position was also investigated through cfd-simulations.

The last simulations investigated the impact of spacers on the total heat transfer. Three different spacers at the top and the bottom of the panels were applied (a. 0.6 mm aluminum (λ = 204 W/mK) around a core of silica (λ = 0.04 W/mK) with a height of 4.8 mm and finished with a 4 mm high butyl kit, b. idem but with plastic (λ = 0.17 W/mK) in stead of aluminum, c. aluminum and silica replaced by butyl kit. The width of the spacer depended on the depth of the cavity.

simulation tools

The CFD-simulations were performed with the CFD-program Flovent (Flovent manual), which is especially developed for the building industry. The revised k-e model (for the earlier calculations in version 3.1) and the LVEL k-epsilon turbulence model with stratification (for the later calculations, version 5.1) were used. We have verified the one with the other. The model was solved for flow and heat transfer under high-accuracy radiation conditions. All simulations were performed for only two dimensions, without solar irradiation and under steady state conditions. Adiabatic boundaries were defined at the top and the bottom of the panel and perpendicular to the glass panel. The following orthogonal grid was applied: maximum grid size in the horizontal direction of 1 mm, the maximum grid size in the vertical direction of 5 mm

Heat transfer simulations were also performed with the heat transfer simulation program Trisco (Trisco manual). This program was applied to investigate the differences in results between a relatively simple program that can calculate heat transfer though conduction and radiation and a more complex cfd-program that can calculate the heat transfer through conduction, radiation and convection. Although this does not seem a fair comparison at first sight, convection is taken into account in the Trisco program by means of a λ_cavity which is calculated with the help of the European norm 673 mentioned in the theory section. The total heat transfer over the various panels and the surface temperatures of the insulating glazing unit were the results that were used in the comparison. A similar orthogonal grid was applied for the Trisco simulations: maximum grid size in the horizontal direction of 1mm, the maximum grid size in the vertical direction of 10 mm

RESULTS

Flovent simulations

In the theory section it is mentioned that the total heat transfer through the panel depends on the heat transfer coefficient of the cavity. This heat transfer coefficient depends on the Nusselt number and the Nusselt number again depends on the depth of the cavity. In order to verify the results of the Flovent cfd-program, the relationship between the Nusselt number and the cavity depth was investigated through simulations at cavity depths from 5 mm to 100 mm. The relationship found with the cfd-program was compared with relationships found in the literature (Yin and EN673). The resulting heat transfer coefficients for convection and conduction as a function of the cavity depth are shown in figure 3.

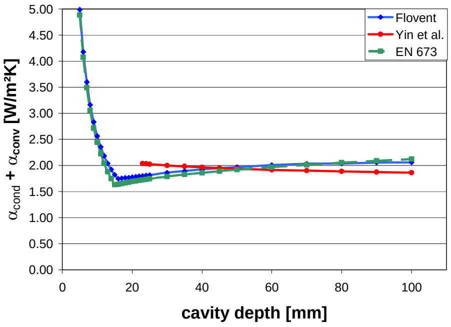

Figure 3: Relation between depth of the cavity and the heat transfer coefficient for conduction and convection for air.

Radiation modeling and adiabatic boundaries do not agree very well. Although a large panel is simulated to minimize the effects of radiation leaking out at the adiabatic boundaries, a view factor of only 0.9 is obtained for the largest width of the cavity (100 mm), causing a 10 % heat leak out of the cavity. All Flovent simulated values were therefore multiplied by the inverse of the view factor in order to compensate for this effect.

The good agreement between the literature values and the Flovent simulations was already found by Manz (Manz). With these simulations, however, it is shown that this theoretical relationship can also be found in the presence of two glass panels and when radiation is also taken into account while performing the simulations.

Impact of gas filling

When varying the depth of a cavity filled with air, Krypton or argon the U-values shown in figure 4 where obtained. Figure 4 shows that for very small cavity-depths the U-value decreases strongly till a certain point. This specific depth is 16 mm for air, 15 mm for argon and 10 mm for Krypton. After this specific depth the U-value stays almost constant. At this specific depth the lowest U-value can be reached for panels with a single cavity at the relatively smallest total thickness of the panel.

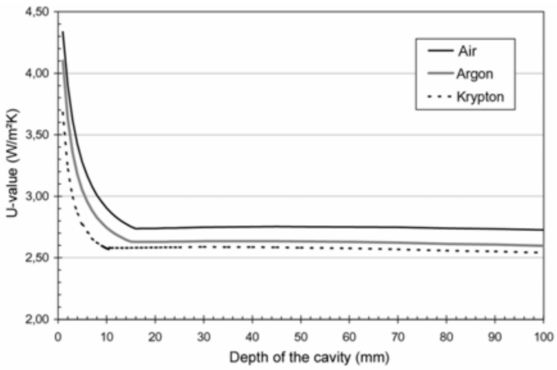

Figure 4: Relation between depth of the cavity and the U-value for different gas fillings

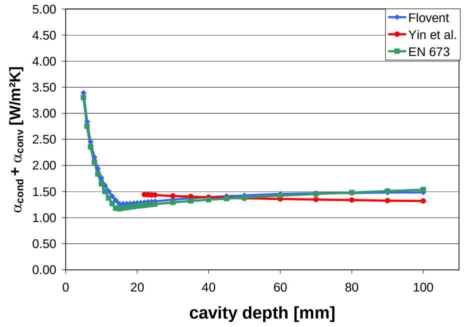

Figure 5: Relation between depth of the cavity and the heat transfer coefficient for conduction and convection for Argon

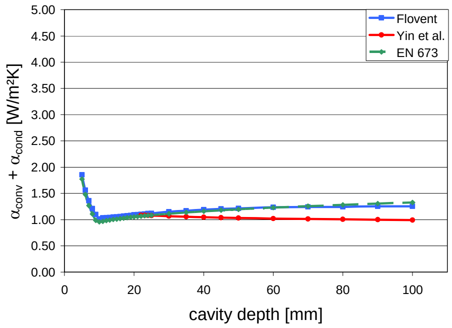

Figure 6: Relation between depth of the cavity and the heat transfer coefficient for conduction and convection for Krypton

The same goes for the internal surface temperatures; they will increase until this specific depth is reached and stay almost constant from then on.

When comparing the cfd-simulations for Argon and Krypton with the EN 673 and Yin's equation (see figures 5 and 6), again a good agreement is found between the cfd-simulations and the EN 673. The agreement with Yin's equation, however, is less. It seems possible to accurately predict the heat transfer coefficient over an insulating glazing unit with a cavity.

Trisco simulations

Due to the good agreement between the Flovent simulations and the experimental values found in the literature, the question arose whether it was possible to obtain the same result without using cfd to calculate the gas flow in the cavity. To answer this question the heat transfer program Trisco and the additional Radcon module were used. It appeared that this program is fully equipped to perform this kind of simulation. The European norm to calculate the convective heat exchange in the cavity is already incorporated in the program and with the additional Radcon module a detailed simulation of the radiation exchange is also possible.

First the impact of the cavity depth on the heat transfer coefficient was investigated. Anomalies due to radiation near the adiabatic boundary also occur in Trisco, see figure 7. The isotherms were expected to be parallel to the panel surface, as only the airflow can change over the height. In figure 7 it can be seen that the isotherms do not run parallel to the panel surface. This is caused by the fact that radiation is not correctly taken into account at the adiabatic surface. The Trisco manual states that this effect is minimized by defining extra nodes for radiation, as shown in figure 8. When comparing the Flovent simulations with the Trisco simulations, the agreement is again quite good, which is not surprising as the Trisco simulations are performed with the Nusselt relationship from the European Norm EN 673.

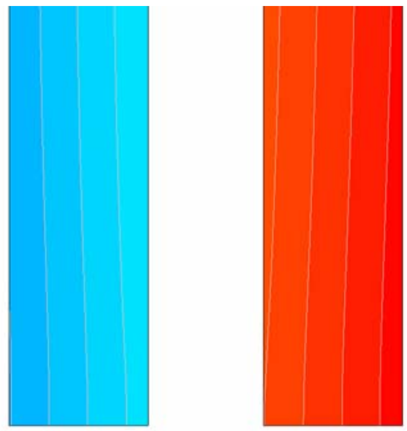

Figure 7: Effect of an incorrect calculation of the radiation heat transfer at the adiabatic boundary at the bottom of a double-glass panel, calculated with the heat transfer program Trisco.

It should again be mentioned that the CFD-simulations were corrected for the view factor correction. The Trisco-simulations, due to the elegant way in which radiation at the boundary is taken into account, did not need this correction. According tot the Trisco manual: "In case of a cavity bordering an adiabatic boundary condition, which is equivalent to a symmetry axis, the simplification of using only one additional unknown temperature (to simulate the mirror effect of the symmetry plane) will result in some underestimation of the real radiation heat transfer in the cavity. Figure 8a shows a simplification of the more correct diagram in Figure 8b. The simplified diagram has much less unknowns and interconnections and is therefore used in the Radcon module"

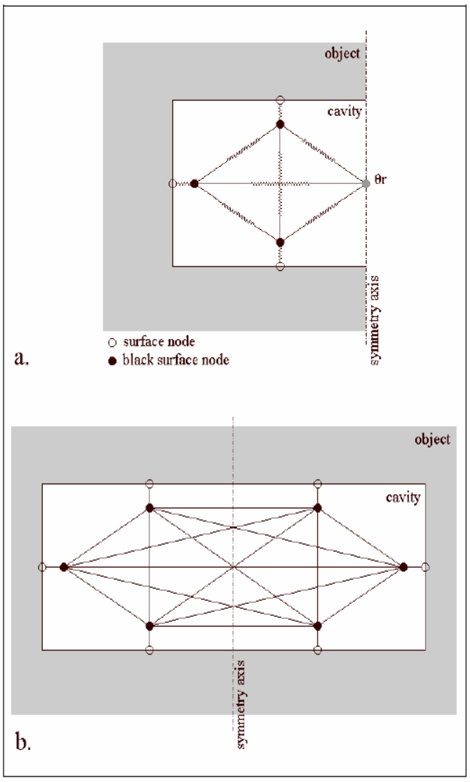

Figure 8: Treatment of a symmetry axis in the Trisco cavity calculation

impact of coatings

As we want to investigate the combined effect of radiation, conductivity and convection, simulations with low-e coatings were also performed. The simulations were performed with a cavity depth of 8 mm, 16 mm and 30 mm in order to cover the entire range between solely conduction, the transition regime and mostly convection. Due to lack off time, only the total heat transfer over the insulting glazing unit is shown in table 2 and not the heat transfer coefficients.

ε–coating left	ε–coating right	q Flovent (W)	q Trisco (W)	% diff.
0.95	0.95	296	299	1.0
0.1	0.95	210	203	3.4
0.95	0.1	210	203	3.4
0.1	0.1	203	194	4.6

Table 2a: coating-simulations, 8 mm cavity, <1mm grid

ε–coating left	ε–coating right	q Flovent (W)	q Trisco (W)	% diff.
0.95	0.95	267	278	4.0
0.1	0.95	151	164	7.9
0.95	0.1	151	164	7.9
0.1	0.1	140	153	8.5

Table 2b: coating-simulations, 16 mm cavity, <1 mm grid

ε–coating left	ε–coating right	q Flovent (W)	q Trisco (W)	% diff.
0.95	0.95	268	278	3.6
0.1	0.95	168	164	2.4
0.95	0.1	168	164	2.4
0.1	0.1	158	153	3.3

Table 2c: coating-simulations, 30 mm cavity, 2 mm grid

The agreement between Trisco and Flovent is quite good for the smallest and largest cavity depths. The difference is no more than 5 % for the 8mm and 30 mm cavities. For the intermediate cavity depth of 16 mm, the agreement is not so good, with a maximum of 8.5 % difference between Trisco and Flovent. This effect, however, can already be seen in Figure 3 where the agreement between the European norm and the cfd-simulations are displayed. As the cavity heat transfer in Trisco is calculated with the European norm, a larger discrepancy at the transition point is to be expected.

impact of window-spacers

For the modeling of the panels including the spacers and the window frames, the same dimensions have been chosen to make the simulation results easily comparable. Here discrepancies between the incoming and out-going heat-flow are negligable because material blocks in the vertical direction will block the radiation loss through the former adiabatic boundaries in the vertical direction.

Simulations were performed with a silica-filled aluminum window-spacer, a silica-filled plastic window spacer and a window spacer made of butyl kit. Surprisingly, the total heat transfer is equal to within a few percent for three different spacers, see table 3. The temperatures are similar within 2 °C. Temperature distributions for two different spacers are shown in figures 9 and 10. These simulations suggest that when one is only interested in the total heat transfer through the insulating glazing unit, is it is not quite necessary to use computation fluid dynamics simulations for an 8 mm cavity depth, as a standard heat transfer program with approximate values for the convective heat transfer in the cavity gives the same result.

spacers	q Flovent (W)	q Trisco (W)	Flovent T_{min}	Trisco T_{min}
al_silica	300	304	0.65	1.7
plastic_silica	296	304	7.3	9.6
butyl	296	299	6.35	8.6

Table 3: Simulations of the effect of spacers for Trisco and Flovent for an 8 mm cavity, 1 mm grid, ε of 0.9.

When one is also interested in the surface temperatures of the insulating glazing unit, for example in order to prevent surface condensation problems, there is, however, a difference of a few degrees between the two simulation methods. The cfd method gives lower temperatures at the bottom of the double glazing unit, this suggest that for very critical insulating glazing units one should perform cfd-calculations.

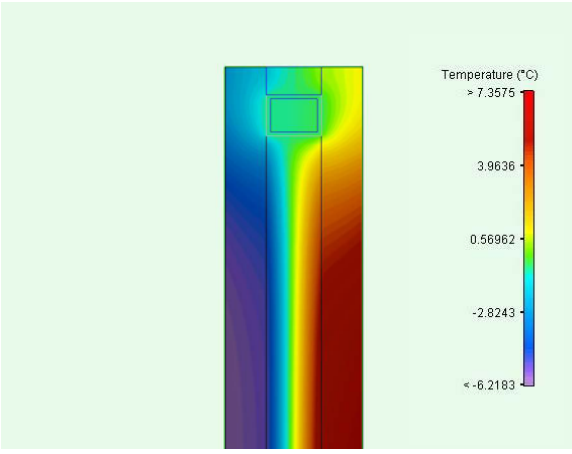

Figure 9a: Flovent simulation of the Al-Silica spacer for an 8 mm cavity.

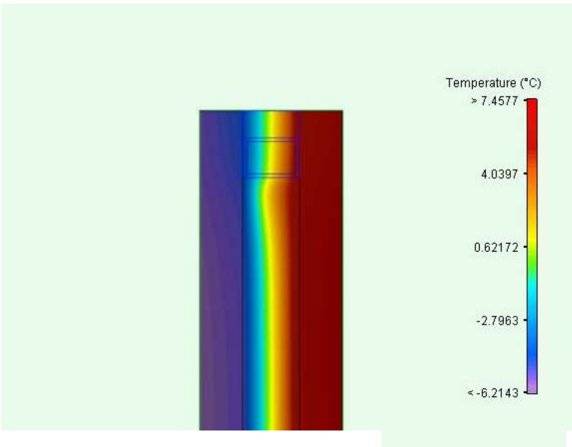

Figure 9b: Flovent simulation of the Butyl spacer for an 8 mm cavity.

DISCUSSION AND CONCLUSIONS

An insulating glazing unit can be modeled with the cfd-program Flovent even when radiation is taken into account. The resulting heat transfer coefficients agree with the European norm for air, Krypton and Argon fillings at different cavity depths.

Comparing Flovent cfd-simulations with the conduction heat transfer program Trisco (which uses the European norm to calculate the effect of convection in the cavity) the agreement in total heat transfer is good in the presence of different coatings and as a function of cavity depth. This effect was expected.

In the presence of a window-spacer, however, boundary effects due to the inhomogeneous flow at the top and the bottom of the insulating glazing unit, are observed. The effect is most pronounced for the surface temperatures where differences of a few degrees between the two computational methods were observed.

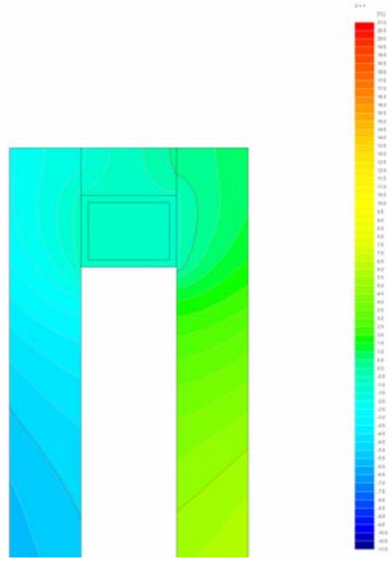

Figure 10a: Trisco simulation of the Al-Silica spacer for an 8 mm cavity.

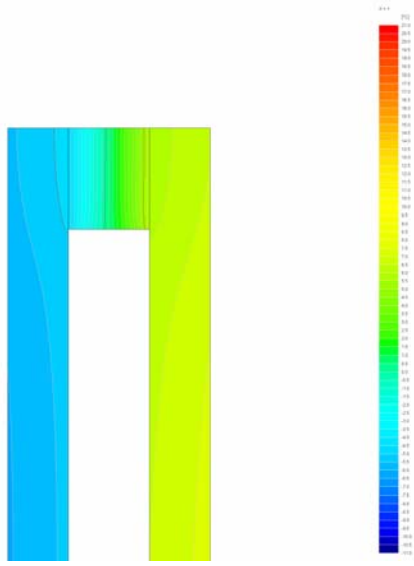

Figure 10b: Triscot simulation of the Butyl spacer for an 8 mm cavity.

Due to the large window panes (1.8 x 1.8 m) and the small cavity depth of 8 mm, the difference in surface temperatures can become more pronounced for smaller window panes and larger cavities. This should be subject of further research.

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