Airflow simulations in double façades with a perforated inner sheet.

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Abstract
In today's architecture, innovative concepts, such as double skin facades, for the building skin are developed to improve the energy performance of a building and at the same time improve the indoor climate of the building. Various types of double façades can be distinguished. The glass sheets of a double façade, with sun-shading lamellas in between, can be completely air-tight or one of the sheets can allow air exchange with either the interior of the building or with the outside of the building. Double facade buildings are expensive on account of the extra glass sheet. But, most of the time, these buildings are prestigious buildings where economic arguments are not always decisive. For lower budget buildings, alternatives for the extra glass sheet are looked for. An inner sheet which consists of a textile material or consists of a perforated sunshade are possibilities. These options have the advantage that the inner sheet is also a sunshade, the disadvantage is that the view which the building's user has of the outside may be nearly blocked. In this paper cfd-airflow simulations are reported in double facades with an inner perforated sheet in order to research how the main airflow is interrupted by the holes. Naturally, a higher percentage of holes in a non-transparent sheet provides the building's user with a room with a view and also decreases the need for artificial lighting by providing daylight into the room.

1. INTRODUCTION

A double skin facade is said to improve the energy performance and the thermal comfort of a usually transparent building. In this paper double skin facades with an air exchange with the interior of the building (also called air flow windows) is investigated. In cold winters, this glass outer facade skin suffers from a cold downward airflow, thus causing cold feet for those persons sitting right next to the window. With a double skin facade the second skin decreases the cold airflow by forcing the warm air through the small inlet under the inner glass pane. This warmer air is then ventilated out at the top of the cavity. If the velocity of the warm air is high enough (thus the inlet small enough), this warm upward airflow counters the cold downward airflow and the air temperature right next to the double skin facade is significantly higher, thus creating a more comfortable climate for the inhabitants. In hot summers a sunscreen can be lowered in the cavity between the two skins. This sunscreen heats up and can reach very high temperatures. By ventilating this cavity, as in the winter situation described above, it is expected that the excess heat is ventilated out thus creating a cooler indoor climate and thus more thermal comfort.

Double facade buildings, however, are expensive on account of the extra glass sheet. But, most of the time, these buildings are prestigious buildings where economic arguments are not always decisive. For lower budget buildings, alternatives for the extra glass sheet are looked for. An inner sheet which consists of a textile material or consists of a perforated sunshade are possibilities. These options have the advantage that the inner sheet is also a sunshade. A woven cloth can also be perceived as an esthetical addition to the interior space. In addition, the acoustical qualities of a textile material are different from a standard glass pane. The disadvantage of using a non transparent screen, however, is that the view which the building's user has of the outside may be nearly blocked, which can cause disastrous effects [Hendriks, 2004] on the perceived thermal comfort. The benefits of a double skin façade have been shown for an inner facade skin that is impermeable to air, such as a glass inner facade skin. In this paper a screen inner facade skin is investigated. And screens, especially those made from woven or knitted textile materials, are permeable to air. And permeable screens combined with a forced airflow can lead to totally different airflows in a room.

2. METHOD

2.1 Model geometry

In order to investigate the beneficial effects of an air flow window where the inner glass pane is replaced by a permeable sunscreen, computation fluid dynamics simulations have been performed. Due to increased computer power it is now possible to model the entire room and not only the airflow window. This is also necessary when a permeable screen is used. The room dimensions are 5.4 x 1.8 m2 and a height of 3.0 m, see figure 1. The distance between the outer glass pane and the screen is 0.1 m. The entire outer glass pane is made of glass with an U-value of 3.7 W/m2K. All other walls, the floor and ceiling consist of 0.2 m concrete. In the wall opposite the window an air inlet is constructed at a height of 0.5 above the floor and its size is 0.5 x 1.8 m2. On the outside of the air inlet the air has a temperature of 20 °C. At the top of the cavity between the outer glass pane and the screen an exhaust is modelled with a total forced air flow of 97.2 m3/h (54 m3/h per meter). Outside temperatures were 0 °C for the winter situation (an optimistic representation of the Dutch weather). According to the Novem regulations [Novem brochure], the opening under the screen is 5 mm for a cavity width of 0.1 m. The screen thickness is 5 mm. The inlet for the double skin facade should be over the entire width of the facade to obtain the least turbulent airflow in the cavity. The inlet should be positioned at the bottom for an upward air stream and the inlet should have a limited width (5 to 10 mm) depending on the air exchange rate of 20-60 m3/h per meter cavity width [Novem brochure].

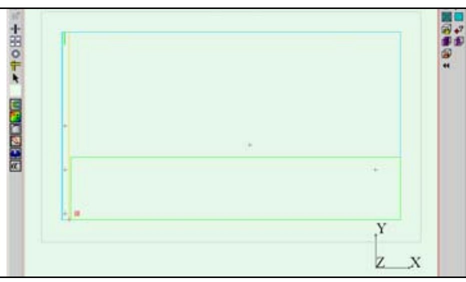
	
point 5	point 6

Figure 1: Geometry of the model, the double façade is situated on the left.

2.2 Modelling characteristics

All CFD simulations have been performed with the commercially available package Flovent [Flovent manual]. As we are only interested in the air flow over the airflow window, thus only in the air flow perpendicular to the air flow window, all simulations were performed in only two dimensions. This also allows us to cut down significantly in computer time. All simulations have been performed with the turbulent k-ε model and rectangular grid. The minimum grid size is 2 mm, the maximum grid is 0.05 m in the horizontal direction and 0.01 m in the vertical direction. This leads to a total of around 67000 grid cells. The walls, ceiling and floor were modelled as adiabatic in the winter situation. The air inlet into the room is modelled as a planar resistance, due to convergence problems when both the air inlet and outlet are modelled as a fixed flow. This, however, has the disadvantage that it is possible for the air to flow out through the planar resistance, which is not expected to be a realistic situation. The sunscreen is modelled as an impermeable solid material for the reference simulations. The permeable sunscreen is modelled as a planar resistance with a given permeability. Although this means that there is a homogenous permeability over the screen which will not always be the case in practical situations, results were interesting enough to mention in this paper. On the other hand, simulating clearly defined holes in the screen is much more difficult and will take much more computing time than available.

Eight variants, which are shown in figure 3 and table 1, were simulated. For reference reasons a room without a screen was modelled as well as a room with an impermeable screen. Further a screen with a permeability of 5 % and a screen that is impermeable at the top and the bottom and has a permeability of 15 % in the middle. All these screen variants were modelled in a winter situation, where the winter situation is also modelled with a heating device at the bottom of the cavity of 500 W.

3. RESULTS

From figure 2 it can be seen that there are significant differences between the different variants. The warm air from the air inlet in the wall will immediately rise up to the ceiling when there is no screen present. This is not surprising, as the downward airflow near the window is quite large due to the low U-value of the window and the low outside temperature of 0 °C. In the presence of an impermeable screen the warm air still rises up near the wall, but the small opening under the impermeable screen effectively counters the cold downward air stream near the window. This positive effect of the impermeable screen can also be seen when the temperatures are compared for the variants with and without an impermeable screen. The temperature near the screen in the room (point 5 in table 1) shows a temperature of 19.4 °C for the impermeable screen which is much higher than the temperature of 15.6 °C for the room without a screen. A permeable screen with only a permeability of 5 %, however, performs much worse than the impermeable screen. Both the airflow pattern and the temperature values resemble the situation without a screen. A permeable screen with only a permeability of 5% is thus not suitable to counter the effect of the cold downward airflow. The next variant is the variant where the screen is impermeable at the top and at the bottom. The bottom part is closed in order to contain the cold downward airflow behind the screen. The top is closed in order to prevent the warm air to disappear immediately though the top of the screen. The middle part is made more permeable to air, which for most screens also means that it is easier to look through, thus improving the inhabitants view. From figure 2 it can be seen that the downward airflow is indeed countered more effectively, and from table 1 it can be seen that the temperatures are higher than for the totally permeable screen, but the improvement is much less than the situation with the impermeable screen.

Screen	Winter, no heating			Winter, 500 W heating		
	T_ 5	T_6	T_exhaust	T_ 5	T_6	T_exhaust
No screen	15.6	17.3	17.6	23.7	21.3	20.9
Impermeable	19.4	19.6	13.2	21.0	21.1	21.2
5% permeable	14.6	17.8	17.1	21.5	21.6	20.2
0% - 15% - 0% permeability	15.2	18.2	16.0	21.7	21.7	19.9

Table 1: Temperature results for various screen configurations.

The more traditional way to counter the cold downward airflow near the facade. is to put a heater under the window. It is now investigated whether a combination of the traditional heater supplied at the bottom of the cavity with a power of 500 W over the entire width of 1.8 m and a screen will increase the thermal comfort. Again air with a temperature of 20 °C was available at the inlet in the wall opposite the window. The

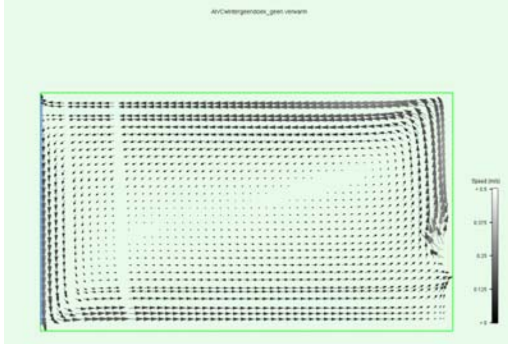
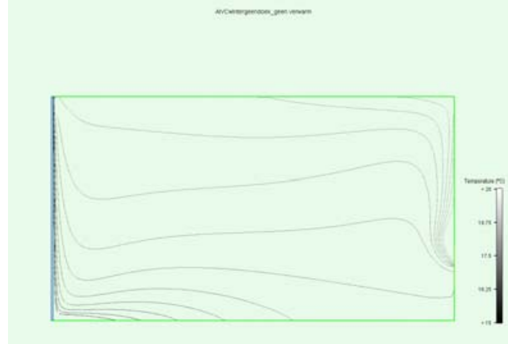
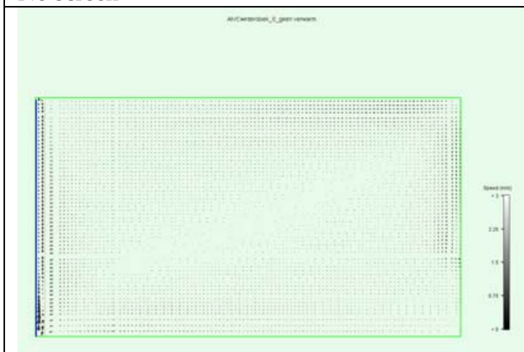
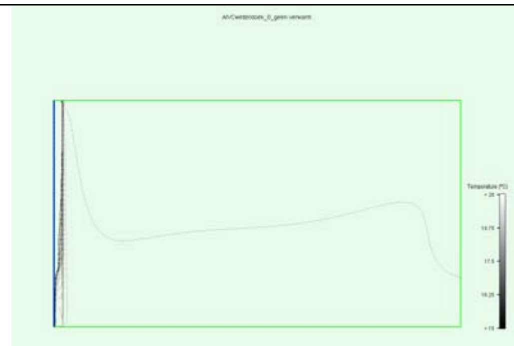
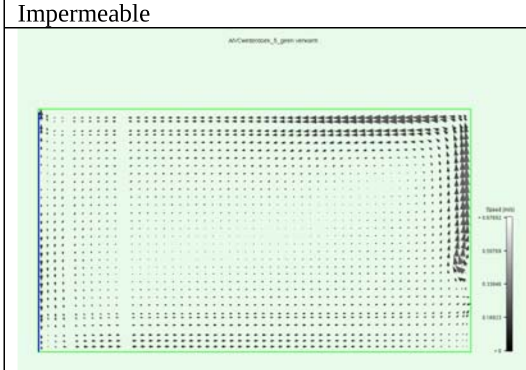
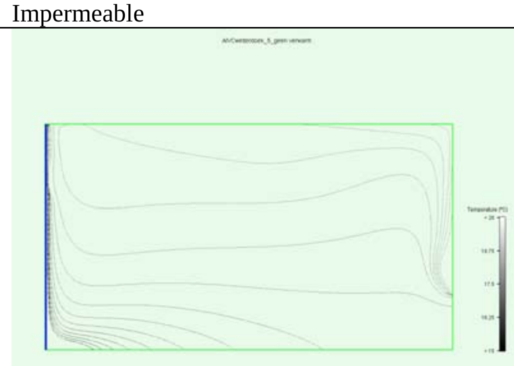
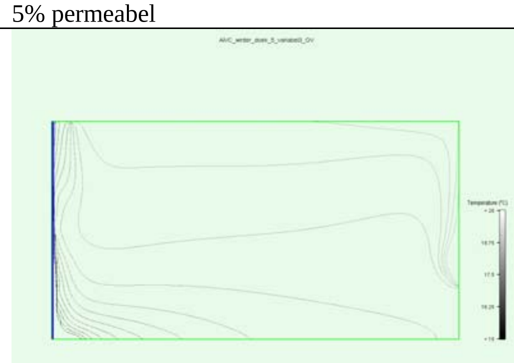
	
No screen	No screen
	
Impermeable	Impermeable
	
5% permeabel	5% permeabel
	
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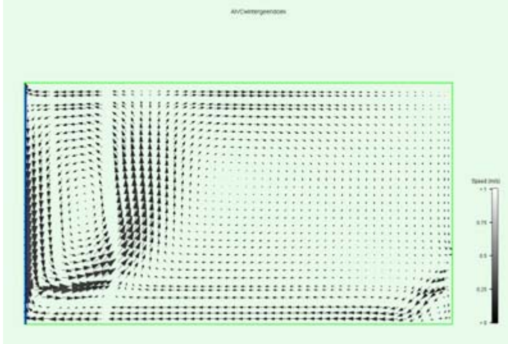
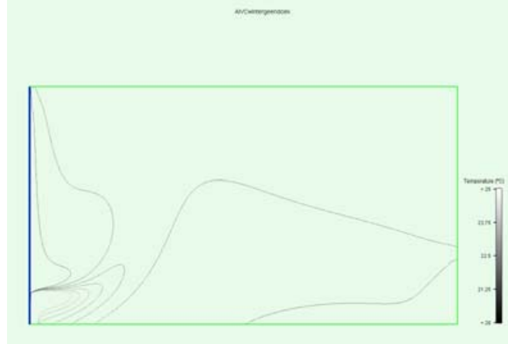
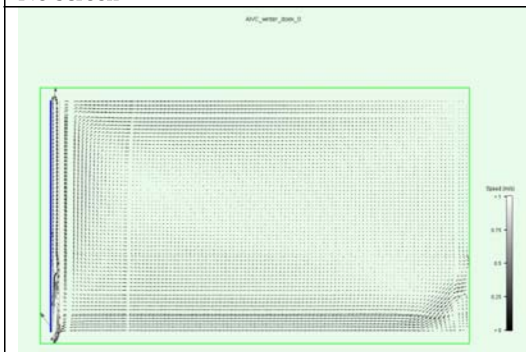
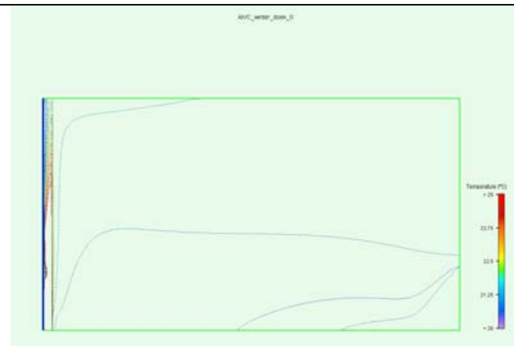
Figure 2: CFD simulations in the winter situation without heater for different screen variants. Left are the simulated air speeds, right the simulated isotherms.

	
No screen	No screen
	
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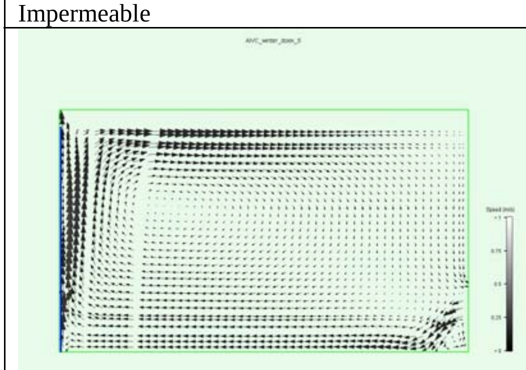	
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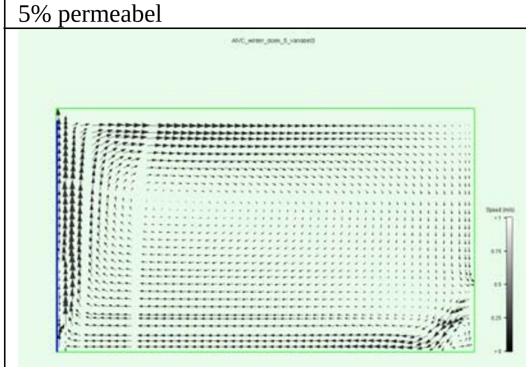	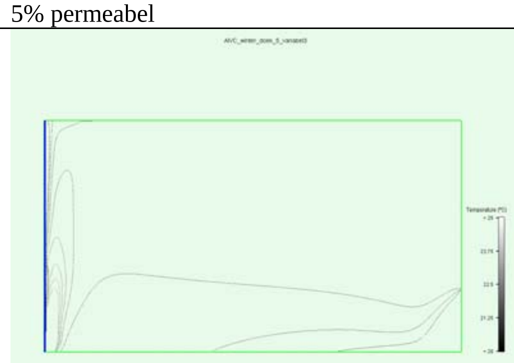
0% - 15% - 0% permeability	0% - 15% - 0% permeability

Figure 3: CFD simulations in the winter situation with 500 W heater for different screen variants. Left are the simulated air speeds, right the simulated isotherms.

results of these calculations are shown in figure 3 and table 1. Due to the presence of the heater all temperatures are higher than in the preceding variants without a heater. This is a positive thing as it should now be possible (not calculated) to decrease the inlet temperature, thereby saving energy which can be used for the heater. Comparing all 4 variants, there are no large differences in the temperatures. The presence of the screen does have an effect on the airflow, however. The screen combined with the low energy heater keeps the cold downward airflow contained in the cavity. In this situation the screen does improve the thermal comfort by creating lower air velocities near the screen. The inhomogeneous screen variant more effectively counters the cold downward airflow, as can be seen in figure 3.

4. DISCUSSION AND CONCLUSION

It was assumed that a screen, even one partly permeable to air, improves the thermal comfort in a room in winter. Problems were expected in the summer situation when the users of the building open the screen for view, thus allowing large amounts of solar heat inside, as reported for the Mercator building in Nijmegen (Netherlands) [Hendriks, 2004]. The initial aim of this research was to investigate various combinations of light and air permeability of the screen in order to improve both view and thermal comfort. However, problems in the winter situation already arose. The CFD-simulations show that the differences between no screen and a permeable screen are small when no extra heating is applied to counter the cold downward flow. When an additional heater is applied at the bottom of the cavity thermal comfort increases with the presence of a permeable skin. Likewise, Tanimoto and Kimura showed that thermal comfort with a screen second skin could be increases by increasing the amount of air flow. In both cases the inlet air temperature can be lowered and the energy saved in this way can be used to heat the heater at the bottom of the cavity or heat the larger volume of air flow. Thermal comfort is thus a very fine balance between the total amount of energy applied to the various air conditioning devices and the distribution of the total amount of energy over the various air conditioning devices.

CFD is very sensitive to the way in which the screen is simulated, as is already described by Safer et al. [2004] and simulations should preferably be checked with experimental data. However, simulations by Tanimoto and Kimura [Tanimoto and Kimura, 1997] using a more simple combined heat and air flow network model, showed that it was impossible to completely avoid the cold draft transmitted with a permeable screen during normal operating conditions, which supports the CFD predictions. Further simulational research should consider the influence of internal heat such as humans and computer, and the influence of infiltration through the edges of the screen.

A screen with a variable permeability creates better comfort in winter. When it is assumed that there is a strong correlation between the air and the view permeability of the screen, a better view is obtained with a more permeable area of the screen in the middle of the screen in the vertical direction. As a future project it is hoped to present the results of the summer situation with a permeable screen as well.

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