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CONTROLLED DOUBLE FAÇADE FOR PREHEATING VENTILATION

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LIST OF SYMBOLS

A_1	=	part of solar radiation absorbed by the outside glass panel (0.2)	[-]
A_2	=	part of solar radiation absorbed by the blinds inside the cavity of the double façade (0.5)	[-]
$A_{3,4}$	=	part of solar radiation absorbed by the window panes (0.01)	[-]
A_5	=	part of solar radiation entering the room (0.01)	[-]
A_{grid}	=	area of free opening in the cavity grid at floor level	[m^2]
A_{inlet}	=	area of air inlet to the cavity with width b, equal to that of a room	[m^2]
$A_{junction}$	=	area of the opening junctions in the outside skin per room.	[m^2]
α_0	=	heat transfer coefficient from the outside glass panel to the air (it is wind speed dependent: 6.2 $Wm^{-2} K^{-1}$ at 0 m/s and 23 $Wm^{-2} K^{-1}$ at 4 m/s)	[$W/m^{-2}K^{-1}$]
$\alpha_{s12}, \alpha_{s23}$	=	radiant heat transfer coefficient in the cavities (5)	[$Wm^{-2} K^{-1}$]
$\alpha_{c,i}$	=	convective heat transfer coefficient in the cavities (in cavities i= 1 and 2 it depends on the air flow q_{vi}; in the double pane cavity it is 1 $Wm^{-2} K^{-1}$)	[$Wm^{-2} K^{-1}$]
α_{in}	=	heat transfer coefficient from the inside window panel to the room air (combines the radiant and convective coefficients: (7)	[$Wm^{-2} K^{-1}$]
b	=	width of the building = width of the façade (3.6)	[m]
C_d	=	discharge coefficient (0.6)	
C_p	=	wind pressure coefficient; C_{p1} at inlet (bottom); C_{p2} at top of the cavity (roof)	
C_t	=	total resistance coefficient	
d	=	depth of total cavity	[m]
$d_{1,2}$	=	depth of the cavity 1 or 2	[m]
Δp_{tot}	=	total pressure difference between inlet and outlet of the air in the cavity	[Pa]
$)p_{wind}$	=	pressure difference caused by wind pressure	[Pa]
$)p_{stack}$	=	pressure difference caused by stack effect	[Pa]
g	=	gravity acceleration (9.81)	[ms^{-2}]
h	=	room height (2.7m)	[m]
n	=	number of storeys (1 or 10)	[-]
ρ	=	air density	[kgm^{-3}]
$q_{v,stack}$	=	air flow caused by stack effect	[$m^3 s^{-1}$]
$Q_{sun} = q_{sun}$	=	solar radiation falling on outside surface	[Wm^{-2}]
q_{v1}	=	airflow in the cavity 1	[$m^3 s^{-1}$]
q_{v2}	=	airflow in the cavity 2	[$m^3 s^{-1}$]
$q_{v,turb}$	=	air flow caused by turbulent wind pressure	[$m^3 s^{-1}$]
2	=	temperature ($\theta_{c2,i}$ = temperature in the cavity nr.2 at the floor "i.").	[°C]
$2_{in,i\ (desired)}$	=	desired temperature in the room	[°C]
2_{out}	=	temperature of air leaving the cavity	[°C]
T_f	=	average temperature in the cavity	[K]
$0_{HR,i}$	=	preheating efficiency on the floor no."i."	
ν_{wind}	=	wind velocity	[ms^{-1}]
$v_{c1,2}$	=	air velocity in the cavity	[ms^{-1}]
ν	=	dynamic viscosity of air ($15 \cdot 10^{-6}$)	[m^2/s]
WD	=	angle between wind direction and normal of the façade (weather side WD = 0)	

Subscripts:

c1	=	cavity 1
c2	=	cavity 2
i	=	inside room air
ov1(2)	=	air in cavity 1 (or 2) after mixing with outside air
o,1,2,3,4	=	outside, outside glass surface, blind, double pane surfaces respectively

SYNOPSIS

In the recent past new concepts for the building envelope have been developed with the underlying wish to improve the energy performance of a building as well as comfort conditions in the inner spaces. Examples are: solar walls, high-tech window systems, 'double facades' and integration of daylighting systems and of PV-panels. In this paper the 'double facade' concept is discussed.

This kind of facade is considered as a device to be used for pre-heating the ventilation air during winter as well as for nocturnal cooling of the building during summer. The 'double facade' concept includes different ventilation strategies as well as different ways of interaction between cavity and interior of the building and between cavity and exterior. Moreover, it is part and parcel of the indoor climate system and should be synchronised with the air conditioning system.

In order to make an evaluation of the overall energy performance of buildings with ventilated double facades, the energy performance of double facades is simulated and analysed on a year round basis. Based on simulation output the efficiency with which ventilation air can be preheated by the double façade is analysed. The effect of various parameters on the efficiency are given, such as: the dimensions of the double façade and the control of the air flow in the cavity.

1. INTRODUCTION

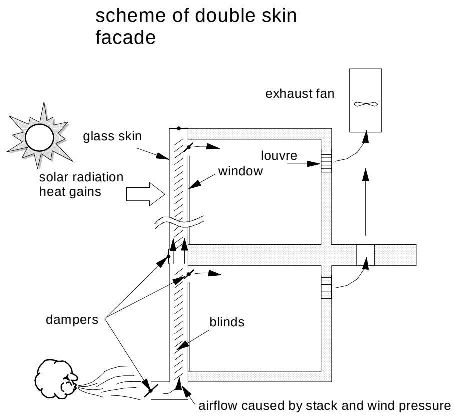
Air inside the cavity with blinds inside is heated by solar radiation. Through trickle ventilations the preheated air is supplied to the rooms. In winter the double façade concept can be considered as a pre-heater of ventilation air. The double façade can be considered as a kind of heat recovery system and can be compared with heat recovery units used in mechanical ventilation systems. Moreover in summer the double façade is an effective and robust solar shading system and together with nocturnal precooling by natural ventilation it can save a lot of cooling energy. Night cooling can easily applied by opening the windows, because the double façade allows open windows without rain/storm or burglar problems.

This paper only deals with the preheating aspects of the double façade. For various designs of the double façade its efficiency will be compared with that of a heat recovery unit.

1.1 Construction of double skin façade

In the double skin façade, a kind of air duct (cavity) is created between the two layers. The stack effect and the wind pressure cause airflow in this cavity. The double skin facade consists of the following main elements:

- Internal skin (usually double window pane)
- External skin (single glass)
- Venetian blinds (situated between the glass sheets)



Figuur 1 General scheme of the double skin façade.

Blinds are situated in the cavity protecting them from destructive weather conditions. The temperature of the blinds and the air temperature in the cavity can be controlled by changing the airflow in the cavity. In figure 1 a general diagram of a double skin façade is shown.

The flow in the cavities and the amount of ventilation air for each room is controlled by the use of five types of dampers:

- Damper on the bottom of the façade controlling the airflow in the cavities.
- Dampers in the opening between the junctions of the outside panels at each floor controlling the appropriate air temperature in the cavities
- Dampers in the inner skin at each floor controlling the desired amount of fresh air for each room (trickle ventilations).
- Damper on the top of the façade (in winter it is closed, in summer open).
- Louvers in the corridor wall for air supply to the fan or for cross ventilation in summer nights.

The heat flow can be controlled by:

- Dampers (for example lower air flows in the cavity decrease the heat exchange between interior and exterior).
- Blinds (for example open blinds let the sun radiation go through it).

During the year two main periods can be distinguished:

- Winter: the system will decrease heat losses and increase solar heat gains in the cavities and in the rooms.
- Summer: the system should keep all kinds of heat gains out of the room.

The outer glass skin, movable blinds and air layer between both skins (cavity) can give an extra insulation. Solar radiation absorbed by the double skin give the possibility to use this façade as a solar collector. Air in the cavity becomes warmer what makes it very useful for ventilation purposes.

This report concentrates on preheating ventilation air by the double skin façade. To find out the best solution the thermal and flow performance in the façade are simulated. Weather data for each hour from the Dutch reference year (1964) is used as input. The simulation allows finding the best design of the double skin façade. It will answer questions such as are dampers inside the double skin required and if this is the case how they should be controlled. Moreover the simulation can be used to design the additional HVAC systems. The simulation is made with the Matlab™ tool.

2. MODELING

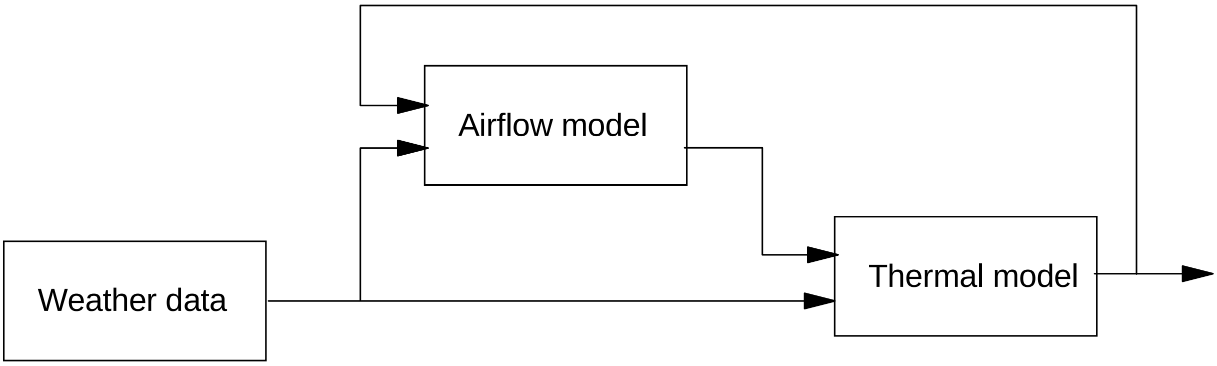


Figure 1 Scheme of construction of the simulation model in Matlab.

The general set up of the simulation is given in figure 2. Weather data (outside temperature, wind velocity and wind direction) and first approximation of temperatures in the cavity are used to calculate the differences in pressure and the airflow in the cavities. Output data from the airflow generator and the weather data (outside temperature, solar radiation heat gains) are used to make an second approximation of temperatures and heat flows inside the cavity. These temperatures are used then to make the next approximation of airflow and so on. With the final temperatures in the cavity the heat recovery efficiency is computed (definition will be given later).

2.1 Airflow generator

The airflow in the cavities is caused by stack effect and wind pressure. There is a simplification made in the model. The outside panels are installed in such a way, that the openings between the junctions exist. The air goes in and out due to the turbulence of the outside air. The higher the wind velocity, the higher this airflow will be. It is assumed that the turbulence airflow does not change the flow in the cavity. The same amount of outside air enters the cavity through the junction openings and leaves it again after mixing through the same opening. Consequently the turbulence airflow only affects the temperature in the cavity because of mixing with the cavity air. To conclude, it is not taken into account in the airflow generator.

The airflow in each cavity is calculated with the following formula:

$$q_{v,stack} = C_t \cdot \sqrt{\Delta p_{tot}} \tag{1}$$

$$\Delta p_{tot} = \Delta p_{stack} + \Delta p_{wind} \tag{2}$$

$$\Delta P_{stac} = \rho \cdot g \cdot n \cdot h \cdot \left(\frac{273 + \theta_{out}}{273 + \theta_0} - 1 \right) \tag{3}$$

$$\Delta P_{wind} = (C_{p1} - C_{p2}) \cdot 0.5 \cdot \rho \cdot v_{wind}^2 \tag{4}$$

The wind pressure coefficient C_p is based on formulas given by Swami – Chandra. The following simplified formula is used:

$$C_p = -0.0001111 \cdot (\mathrm{WD})^2 + 0.6 \qquad \textit{with the condition } C_p \geq -0.3 \tag{5}$$

C_t is a total pressure coefficient for the cavity with grids at each floor and an inlet at the bottom.

$$C_t = \sqrt{\frac{2 \cdot C_d^2 \cdot A_{inlet}^2 \cdot A_{grid}^2}{\rho (A_{grid}^2 + A_{inlet}^2 \cdot n)}} \quad \textit{with} \quad A_{grid} = 0{,}6\,(d \cdot b) \tag{6}$$

In the calculation it is assumed that WD values for the inlet and outlet of the cavity differ 180°

2.2 Heat flow generator

The network shown in figure 3 represent the heat transfer process in the cavity. With the heat balance equation for each node of the network we can find the temperatures and heat flows by solving these equations.

$$\alpha_0 (\theta_0 - \theta_1) + \alpha_{s12} (\theta_2 - \theta_1) + \alpha_{c1} (\theta_{c1} - \theta_1) + A_1 \cdot q_{sun} = 0 \tag{7}$$

$$\alpha_{c1}(\theta_1 - \theta_{c1}) + \alpha_{c1}(\theta_2 - \theta_{c1}) + \frac{pc\, q_{v1}}{hb}(\theta_{ov1} - \theta_{c1}) = 0 \tag{8}$$

$$\alpha_{c1}(\theta_{c1} - \theta_2) + \alpha_{s12}(\theta_1 - \theta_2) + \alpha_{s23}(\theta_3 - \theta_2) + \alpha_{c2}(\theta_{c2} - \theta_2) + A_2 \cdot q_{sun} = 0 \tag{9}$$

$$\alpha_{c2}(\theta_2 - \theta_{c2}) + \alpha_{c2}(\theta_3 - \theta_{c2}) + \frac{\rho c\, q_{v2}}{hb}(\theta_{ov2} - \theta_{c2}) = 0 \tag{10}$$

$$\alpha_{s23}(\theta_2 - \theta_3) + \alpha_{c2}(\theta_{c2} - \theta_3) + \alpha_{db}(\theta_4 - \theta_3) + A_3 \cdot q_{sun} = 0 \tag{11}$$

$$\alpha_{db}(\theta_3 - \theta_4) + \alpha_i(\theta_{in} - \theta_4) + A_4 \cdot q_{sun} = 0 \tag{12}$$

"$\alpha_{c,i}$ " is the convection heat transfer coefficient. This value is variable, and depends on the airflow in the cavity and dimensions of the cavity, The formula from Recknagel (1997) is used.

$$\alpha_c = \left[4.13 + 0.23 \cdot \frac{T_f}{100} - 0.0077 \cdot \left(\frac{T_f}{100} \right)^2 \right] \cdot \frac{v_{c1,2}^{0.75}}{D_{hydr}^{0.25}} \tag{13}$$

$$D_{hydr} = \frac{2 \cdot b \cdot d}{b + d} \tag{14}$$

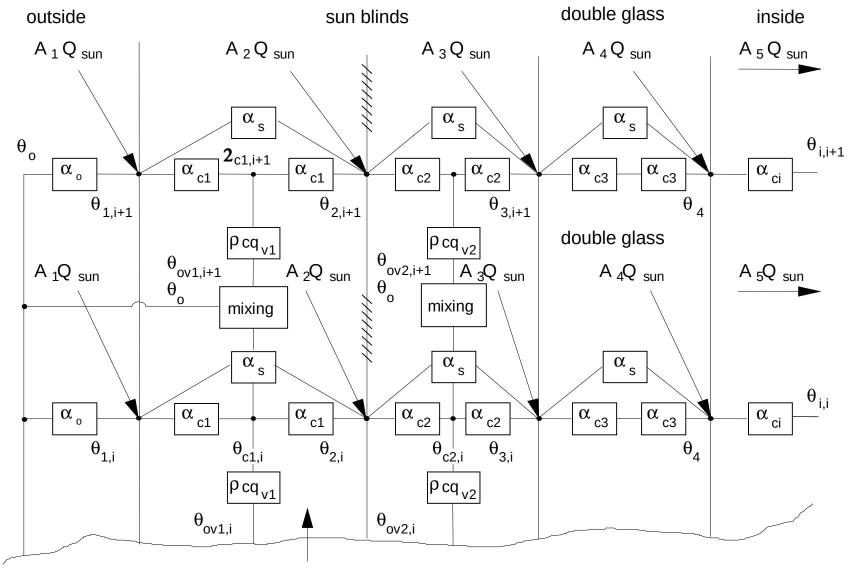


Figure 3. Heat exchange network in double façade.

The temperatures are found by solving the equations (7-12). Here it is done in a analytical way resulting in the equations (15-20). The coefficients "*C*" are functions of the coefficients of the heat balances (7-12).

$$\theta_1 = C_{38}\,\theta_0 + C_{39}\,q_{sun} + C_{40}\,\theta_i + C_{41}\theta_{0v1} + C_{42}\theta_{0v2} \tag{15}$$

$$\theta_{c1} = C_{32}\,\theta_0 + C_{33}\,q_{sun} + C_{34}\,\theta_{in} + C_{32,0}\theta_{0v1} + C_{32,1}\theta_{0v2} \tag{16}$$

$$\theta_2 = C_{26}\,\theta_0 + C_{27}\,q_{sun} + C_{28}\,\theta_{in} + C_{26,0}\theta_{0v1} + C_{26,1}\theta_{0v2} \tag{17}$$

$$\theta_{c2} = C_{35}\,\theta_0 + C_{36}\,q_{sun} + C_{37}\,\theta_{in} + C_{35,0}\theta_{0v1} + C_{35,1}\theta_{0v2} \tag{18}$$

$$\theta_3 = \frac{C_{23}}{C_{22}}\theta_0 + \frac{C_{24}}{C_{22}}q_{sun} + \frac{C_{25}}{C_{22}}\theta_{in} + \frac{C_{23,0}}{C_{22}}\theta_{0v1} + \frac{C_{23,1}}{C_{22}}\theta_{0v2} \tag{19}$$

$$\theta_4 = C_{29}\,\theta_0 + C_{30}\,q_{sun} + C_{31}\,\theta_{in} + C_{29,0}\theta_{0v1} + C_{29,1}\theta_{0v2} \tag{20}$$

In case open junctions are applied cavity air is mixed with outside air due to the turbulence of the wind. This is the case in systems S3 and S4 to be discussed later on.

$$\theta_{ov1,2(i)} = \theta_{c1,2(i-1)} \tag{21}$$

For the systems S3 and S4 (with opened junctions) the temperatures of mixed air flows can be found with equations (22-23). The following simplification was made to account these temperatures. In the opened junction there is only exchange of the heat. There is no change of the airflow in the cavity. That means, that the same amount of outside air goes to and out from the cavity.

$$\theta_{0v1} = \frac{q_{v,stack}}{q_{v,stack} + q_{v,turb}} \theta_{c1}(i-1) + \frac{q_{v,turb}}{q_{v,stack} + q_{v,turb}} \theta_0 \quad (22)$$

$$\theta_{0v2} = \frac{q_{v,stack}}{q_{v,stack} + q_{v,turb}} \theta_{c2}(i-1) + \frac{q_{v,turb}}{q_{v,stack} + q_{v,turb}} \theta_0 \quad (23)$$

According to Paassen (1998):

Weather side:

$$q_{v,turb} = 0.05 A_{junction} + 0.035 v_{wind} A_{junction}^{0,39} \quad (24)$$

Lee side:

$$q_{v,turb} = 0.05 A_{junction} + 0.009 v_{wind} A_{junction}^{0,16} \quad (25)$$

2.3 Analyses of heat recovery efficiency

The task for the double skin façade is to decrease the energy expanses for preheating the ventilation air. The efficiency, with which the second skin façade can fulfil this task, will be expressed by a heat recovery factor. This factor is equivalent to that used for mechanical systems, so that both possibilities can be compared.

Heat recovery efficiency is accounted by comparing relevant temperatures. The difference in temperature between the inside and outside air is a measure for the energy needed for preheating the ventilation airflow if no double façade was available. The difference between the temperature in the cavity and outside is a measure for preheating by the double façade. The ratio of this two differences gives the efficiency of preheating ventilation air. It is called heat recovery efficiency and is computed with the following formula:

$$\eta_{HR,i} = \frac{\theta_{c2,i} - \theta_o}{\theta_{in,i(desired)} - \theta_o} \quad (26)$$

3. SIMULATION OF DOUBLE SKIN FAÇADE IN WINTERTIME

The model is simulated with the tool Matlab, Simulink. With this simulation year round analyses can be made. Weather data of the Dutch reference year (summer of 1964 and winter 1965) with hourly weather data is used. The results are based on office hours, between 9.00 – 17.00 o'clock. The parameter values used in the simulation are mentioned in the symbol list as values between brackets.

For the winter period the most significant parameter should be the heat recovery efficiency. It will show the usability of the cavity air for ventilation purposes. With the simulation one can define how the heat recovery efficiency depends on:

- Outside conditions.
- Dimension of the cavity, (width of the cavity is taken into account).
- Area of inlets and outlet of outside air.
- Height of the building. (number of floors).

Preheating ventilation air through the second skin can be realised in many ways. Four solutions are chosen:

S1) Double façade with controlled airflow through the cavities (figure 4). There are no opening junctions in the outside glass surface at the level of each floor. There is only one inlet for the ventilation airflow at the bottom of the façade. It is controlled by an air damper such that the air supply to the cavity is just enough for ventilating all the rooms above. The controlled trickle ventilator delivers the desired airflow to each room (80 m^3/h).

S2) There are no open junctions on each floor, no controlled airflow in the cavity and no dampers at all in this system (figure 5).

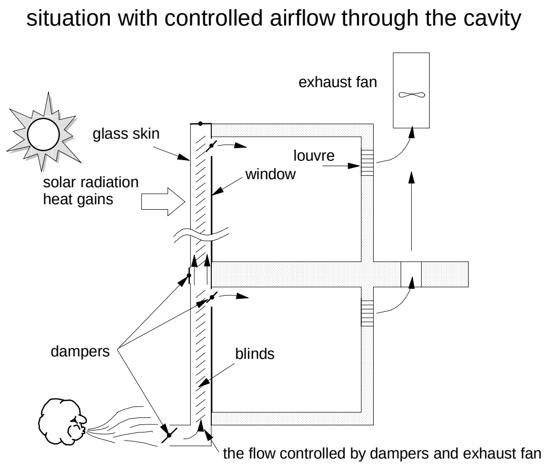


Figure 4. Controlled airflow in the cavity

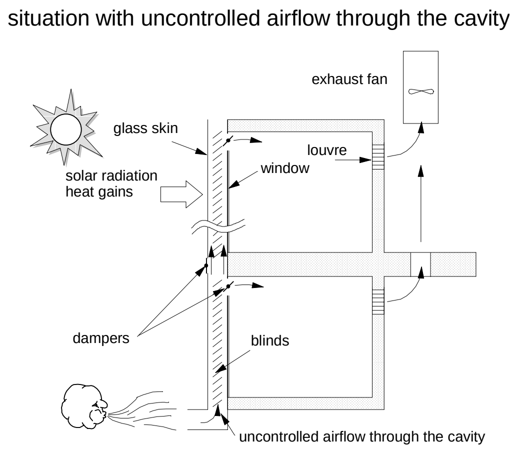


Figure 5. Uncontrolled airflow in the cavity

S3) There are open junctions on each floor, which cause heat exchange between air inside the cavity and outside air as discussed before. The main airflow is the same as in the second system (figure 6). This should be the best system for summer time when cooling is required, but due to the open junctions preheating of the cavity air will be much lower than in the other systems with closed junctions.

S4) There are open junctions on each level, but each storey is separated from each other (figure 7). Consequently each storey creates its own system. In practice this will be the most convenient system because the same module can be used on each storey. Also the problems due to large temperature gradients in different height of the cavity can be avoided (on each storey there is more or less the same temperature in the cavity)

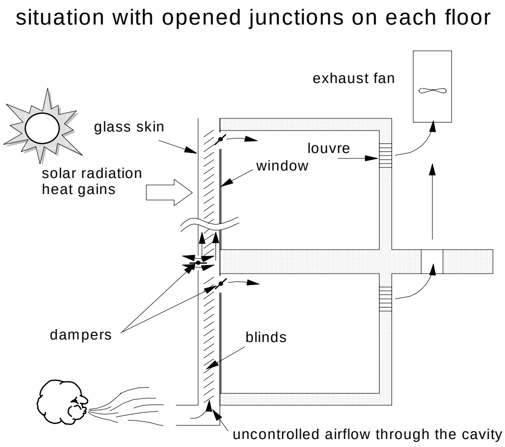


Figure 6. Open junctions on each floor

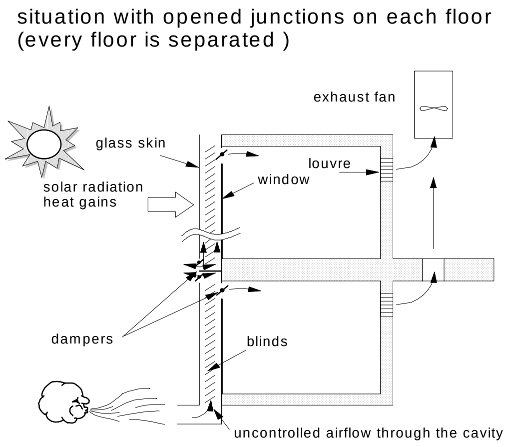


Figure 7. Each storey is separated

4. RESULTS FOR THE WINTER PERIOD

The task of the simulations is to find the connections between the heat recovery efficiency and the design parameters of the double façade. The next two graphs in figures 8 and 9 show that the average efficiency for the whole building depends on the dimensions of the cavity, and the numbers of storeys in the building.

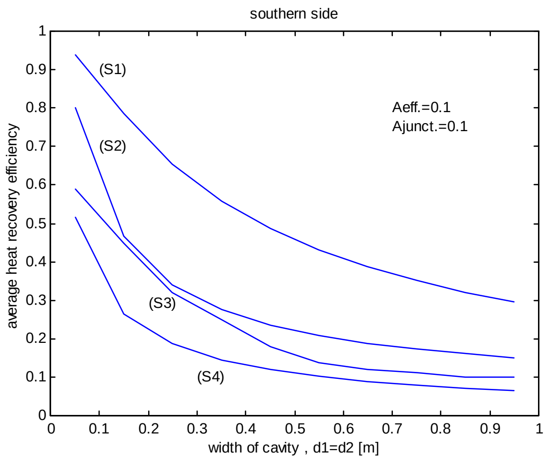


Figure 8. Efficiency η for a ten storey building.

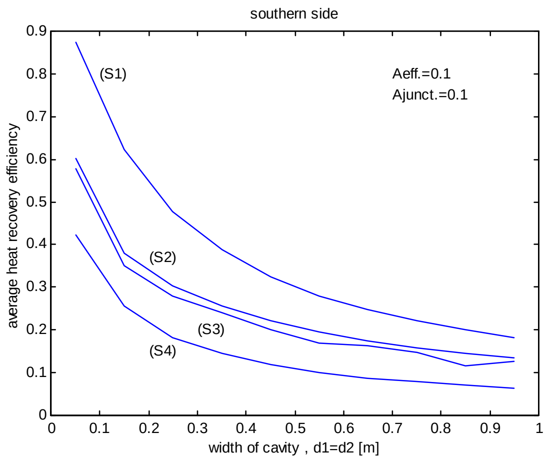


Figure 9. Efficiency η for a four storey building.

The highest values of heat recovery efficiency are found for thinner cavities. Thin cavities have higher air velocity inside and therefore higher heat transfer coefficients. Consequently more solar energy will be transferred to the ventilation air inside the cavity.

Figure 8 shows the results for all the systems for a 10 storey building. The highest efficiencies are found for the system (S1) with controlled airflow in the cavity. Cavities with depths of $d_1 = d_2 = 0.05$m values of 95% can reached. However, such a thin cavity may be too small to get enough ventilation at the highest floors. Much lower efficiencies are found for a system (S2) with uncontrolled airflow in the cavity.

The results for the system (S3) with opened junctions on each floor are slightly worse than for the previous system (S2). Nevertheless there are no limitation imposed on the dimensions as it is in the system S2. Even very small junctions can ensure enough amount of fresh air in the cavity.

Figure 9 shows the results for the same systems as in figure 8, but now for a four-storey building. The system with controlled airflow (S1) has a slightly lower efficiency than was found for the ten-storey building, but in this case there was no problem to ensure the desired ventilation airflow in thin cavities. In general the difference in efficiencies between the low and high building is small when thin cavities are applied. However, high buildings give large temperature gradients inside the cavity, which will cause problems in the warmer periods. Therefore, it can be concluded to split the cavity of high rise buildings in separated parts by combining for example four storeys with their own inlets and outlets.

Both figures 8 and 9 show the heat recovery efficiency for the system (S4) with a separated cavity for each floor. The results are much worse than for systems S1-S3.

In this paper the summer situation is not mentioned. The sun shading properties and the possibilities to use the second skin for night cooling are discussed in another paper (Paassen, 2000). In this paper it is stated that the requirements for night cooling are in contradiction with that of ventilation. Night cooling by natural ventilation requires large open junctions in the outer façade (2% of the floor area) while for effective preheating there should be no openings at all in the outside façade. Consequently, in order to use the double façade as well as for night cooling as for heat recovery controlled dampers in the open junctions are necessary.

5. CONCLUSIONS

- A compact model of the double façade could be derived from the heat balances and airflow models. It shows the sensitivity of various input variables.

- The most important parameters in designing the double skin façade are dimensions of the cavity, its height and width. Dimensions have the greatest influence on the heat and flow performance in the double skin façade.

- More useful are thin cavities, because they can ensure the desired ventilation airflow in the cavity and has the highest efficiency for preheating the ventilation air.

- A high rise building with a very thin cavity may not ensure the air flow in the cavity needed for ventilation purposes.

- In general double façades with airtight junctions and properly airflow control in the cavity is an interesting preheater for ventilation air. In a four storeys building and a cavity width of 0.2 m an overall heat recovery efficiency of 49% can be obtained. This efficiency can be increased to 75% if the ventilation flow inside the cavity is properly controlled. In that case the second skin can compete with a mechanical ventilation system with heat recovery. A disadvantage is the vertical temperature gradient inside the double façade. It gives less comfort or higher cooling capacities at higher floors.

- From the previous conclusion and simulation results it can be concluded to split cavities of high rise buildings in separated parts by combining for example four storeys with their own inlets and outlets. If this is done for each floor the efficiency will drop to 35%.

- In order to use the double façade as well as for night cooling as for heat recovery controlled dampers in the open junctions are necessary.

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