INTEGRATION OF HVAC SYSTEMS AND DOUBLE FACADES IN BUILDINGS

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ABSTRACT

Nowadays the awareness concerning the environmental pollution and the demand of transparent facades in architecture, lead research in finding new solutions to increase the energy performances of the building and the installations as well. Among those, different kind of Double Skin Facades have been studied and several laboratories are still working on them to find a suitable way to apply this technology in buildings. To find out how the constructive parameters affect the performances of the Second Skin Façade and for the purpose of energy saving in building this paper studies the modelling of systems made up by Double Façade coupled with a building. These interactions between the building, the Double Facade and the external environment have been simulated using the simulation code Simulink.

The model has been set up to answer questions about: (a) the gradient of pressure along the facades; (b) flow and temperature along the façade; (c) find out the necessity for control; (d) how to split up the Double Facades in compartments in order to have benefits without serious overheating problems. The effect of the depths of the cavity has been shown to influence the Double Façade's performances.

It has found that due to the pressure gradient, different airflow at different temperature enter the room facing the Double Skin Façade. A control system is then necessary to synchronize all the components involved.

KEYWORDS

Second Skin Façade, simulation, Simulink, pressure gradient, airflow, thermal balance, stack effect, wind pressure, overheating.

INTRODUCTION

The demand of transparent facades in architecture, has given new impulse in finding new way to improve the energy performance of the buildings. Among those, different kind of Double Skin Facades have been studied and several laboratories are still working on them to find a suitable way to apply this technology in new buildings and in the restructuring of old ones.

In traditional buildings the outdoor climate is considered as an enemy, whose influence must be controlled by the Heating Ventilation and Air-Conditioning system. The technology of the Double Skin Façade coupled with an HVAC system is an attempt to achieve the opposite, namely to use the solar radiation and the wind, in an advantageous way to reduce the energy consumption and to improve the comfort at the same time. Actually the Double Skin Facades can reduce the solar gain in summer and provide thermal insulation in winter. Moreover, it can be used as a solar collector to preheat the ventilation air. Although this seems an attractive building philosophy, there are problems because the advantage of the outdoor climate is often not available at the right time or in the required amount. Consequently, the Double Skin Facades of the building should be equipped with components that can be controlled such that the best use is made of the outdoor climate. This requires intelligent controlled façades (Paassen, 1999).

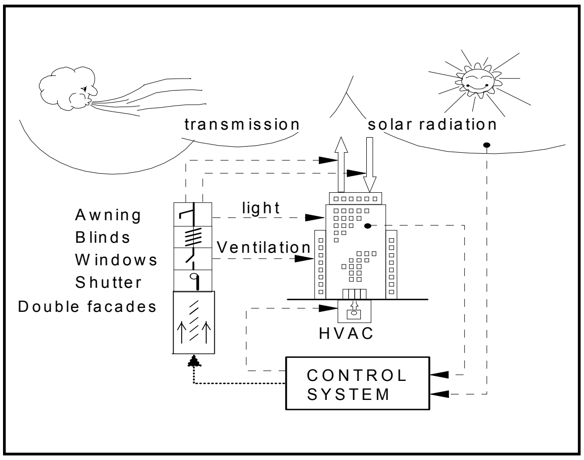

Figure 1 - Building with an intelligent façade.

Figure 1 shows in a schematic way the relation between the Double Facades, the building, the HVAC system and the weather conditions. In order to get a good integration the controlled facades should be equipped with the following components:
1) Shading devices. For the applications in the Double Skin Façade the more effective shading devices are the venetian blinds placed between the external glass element and the glass element facing the room. They act as solar collectors supplying the stack effect that is one of the main driving forces moving air inside the cavities. 2) Louvers with adjustable slats can also control sunlight entering the rooms. 3) Adjustable vent windows for ventilation and cooling with outdoor air. In case the indoor climate conditions cannot be maintained with the use of the passive components and the outdoor climate, the following active components should be available:
4) Auxiliary heater and/or cooler. 6) Artificial lighting.

The HVAC system should be equipped with heat recovery units connected with the double facades' cavities as well. The Double Skin Facades can be used as heat recovery for the HVAC system (Stec & van Paassen 2001).

MODELLING

The model used in these simulations is make up by many subsystems but as shown in figure 2 the main framework can be regarded as an interaction between the Second Skin Façade subsystem and the Thermal Model subsystem. As schematically shown in figure 2 the output variables of the Double Façade model are used as input of the Thermal Model of the Building.

The heat transfer coefficients related to external surfaces of the façade walls and the one related to the external surfaces of the double glasses are considered to be the same. They are implemented in the Alpha Generator subsystem inside the Double Façade model (Di Maio & van Paassen 2001).

The Thermal Model of the building uses these variables as inputs together with the weather data and the ventilation heat flows computed in the Ventilation Generator subsystem (see figure 2) to perform the calculations needed to calculate the air temperatures and the walls temperatures of the rooms. Iteratively the Double Façade model uses results of these calculations as inputs together with the weather data.

As an output of the coupled model, the air temperatures inside the rooms are stored in the Matlab workspace and can be plotted as shown later on.

The way the Second Skin Façade subsystem works can be found in literature Di Maio & van Paassen (2001).

The Thermal Model

The purpose of the model

The thermal model calculates the indoor temperatures and the wall's temperatures in all rooms of the building. The inputs necessary to perform these calculations are the weather data, the ventilation heat flows from the Ventilation Generator, the internal glass' temperatures and the average air temperatures in the cavity from the Double Facade subsystem. The Thermal Model of the rooms receive the airflows rate and their temperatures flowing in the cavities from the Double Façade model subsystem together with the temperatures of the glass panes facing the rooms. The Double Façade model receives the air and surfaces temperatures of the rooms from the Thermal Model of the rooms

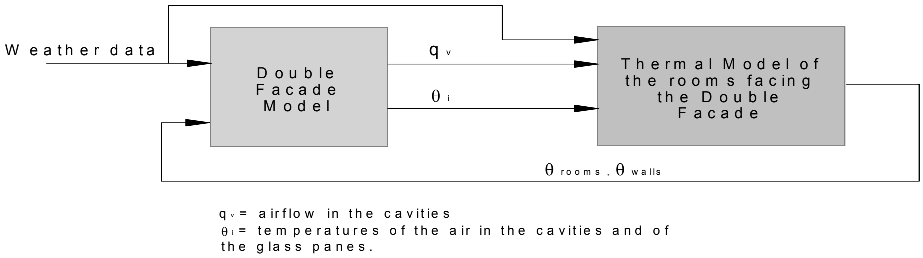

Figure 2 - Model of the rooms modelling the building's room and the Double Façade.

Model hypotheses

A network as shown in figure 3 can illustrate the heat transfer process occurring in a room. It represents the heat transfer in a room which is surrounded on both sides and above and below by identical rooms. This standard room has three interior walls in addition to the roof and the floor. The exterior wall is facing the double façade which is provided with a venetian blind as solar shading device.

Due to the complexity of the thermal network simplifications are necessary to build the model. It is assumed a good mixture of the air inside the rooms, so that only one temperature ("homogeneous temperature distribution" model usually called "One-point model") depicts the thermal response of the room to the heating and cooling loads caused by the internal sources and by the flows calculated in the Ventilation Model subsystem. Each interior surface of the room is depicted by one node. The latter assumption has been verified by Mitalas (1965).

About the first one especially in unconditioned rooms, temperature gradients have been observed. These gradients depend strongly on the air circulation inside the room (Chen, 1988). Nevertheless this assumption has been accepted for the purpose of this work. A resistance network connecting the nodes represents the heat exchange by radiation between the various surfaces and the heat exchange between these surfaces and the room air. For each node a heat balance can be set up. These heat balances result in a set of differential equations that are solved simultaneously together with the others contained in the subsystem named Double Façade model (see fig. 3).

Three types of heat transfer are taken into consideration in the modelling process. There is convective heat transfer from the window's glass, the walls, the floor and the ceiling to the room air. There is a radiative heat transfer from the window's glass to each wall's surface, to the floor and the ceiling. There is conduction heat transfer inside the walls, floors and the ceilings of the building. A ventilation heat flow from the Double Façade subsystem or from the air-handling unit is present in order to maintain the comfort condition inside the rooms.

Moreover during the working time there is an internal load inside the rooms due to the people, the lightning and the equipments. Solar radiation falls on the Double Façade. Part of it enters the room through the glasses and the sunshine device and it is assumed to be evenly divided on the entire area of the room and it will be indicated by q_{si}. Each wall in the model is simulated according to the scheme shown in figure 4.

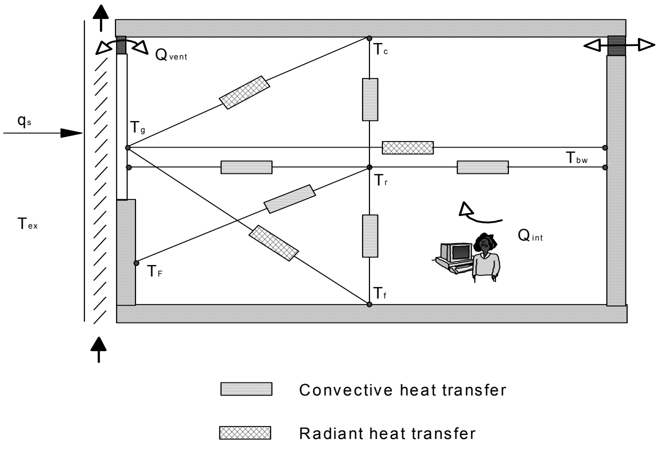

Figure 3 – Physical model of the thermal behaviour of the room

Lumped parameter assumption is adopted. This is realized by splitting the wall into some layers. In each layer, the parameters, like temperature, specific heat and conductivity, are the same. Since the parameters are actually different, the more layers the wall is split, and the closer the model is to the reality. However, too many layers make the models more complicated and lower simulation speed.

On both side of a wall there is a convection heat transfer to the air temperature (T_r), a radiant heat transfer to the surrounding surfaces and a solar load (q_{si}) depending on the surface that is taken into account. Conductive heat transfer is present inside the walls. Each wall itself is divided into three layers having its own conductivity *k,* density *ρ,* specific heat *c* and thickness *Δx*.

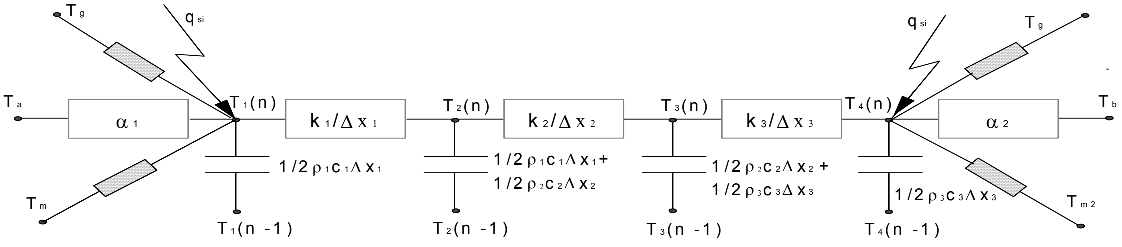

Figure 4 –Electrical R-C representation of the wall.

Where:

α_i = convective heat transfer; i = 1, 2 [W/m^2 K], k_i = conductivity of the i^{th} layer; i = 1, 2, 3 [W/m K], ρ_i = density of the i^{th} layer; i = 1, 2, 3 [kg/m^3], c_i = specific heat of the i^{th} layer; i = 1, 2, 3 [J/kg K], Δx_i = thickness of the i^{th} layer; i = 1, 2, 3 [m], T_a = air temperature in the room and/or in the cavities [K], T_b = air temperature in the room [K], T_i = temperature inside the walls; i = 1, 2, 3 [K], T_g = temperature of the glass [K], T_m = mean temperature of the walls [K].

Decomposition into subsystems

The system is composed of a segment for each storey. Each of them has basically the following subsystem:
1) The Wall, Floor, Ceiling subsystems; 2) The Alpha Generator subsystem; 3) The average Wall Temperature subsystem; 4) The Ventilation Generator subsystem; 5) The One Point Air Model subsystem

The wall, floor, ceiling subsystems

There are 21 of these subsystems in the model. Each of them has to compute the temperature on both side of the layer (wall, floor or ceiling). The temperatures between the layers in which the wall, floor or ceiling are divided are monitored as well.
There are five *Floor-Ceiling subsystems* in the model.

The One Point Air model

From a heat balance for the system showed in figure 3 it is possible to derive the differential equation 1 which calculates the air temperature in the room.

$$\begin{aligned}\rho_a c_a V_{r2}\frac{dT_{r2}}{dt} &= Q_{\text{int}} A_{fl} + Q_{vent} + \alpha_{r2}\left(T_{g2}-T_{r2}\right)A_g + \alpha_{r2}\left(T_F-T_{r2}\right)A_F + \\ &+\alpha_{r2}\left(T_{sw1}-T_{r2}\right)A_{sw1} + \alpha_{r2}\left(T_{sw2}-T_{r2}\right)A_{sw2} + \alpha_{r2}\left(T_{bw}-T_{r2}\right)A_{bw} + \alpha_{fl}\left(T_{fl}-T_{r2}\right)A_{fl} + \\ &+\alpha_c\left(T_c-T_{r2}\right)A_c\end{aligned} \tag{1}$$

Where:

A_g = total glass area [m^2], A_F = internal façade wall area [m^2],
A_{sw1} = internal side wall 1 area [m^2], A_{sw2} = internal side wall 2 area [m^2],
A_{sw2} = internal back wall area [m^2], A_F = floor area [m^2],
A_c = ceiling area [m^2], ρ_a = air density in the room [Kg/m^3],
c_a = specific heat of air in the room [J/Kg·K], V_a = volume of the room [m^3]
Q_{vent} = ventilation heat flow [W], Q_{int} = internal heat load [W/m^2]

Solving this equation the results are the air temperature in the rooms.

RESULTS

Several simulations have been carried out on the coupled model in order to investigate the usage of night cooling by opening the vents windows facing the Double Façade. The simulations have been
carried out for a four-storey, west oriented building:
-Height 13.2 m; -Width 3.6 m; - Opening angle of vent windows 45°, 25°, 15°, 0°;
- Depth of the cavity 0.4 m; - Internal load 500W in each room; - Ventilation opening area 3.2×0.155 m^2; - Pressure in the room –2 Pa;

Figure 5 shows the room temperatures at each floor together with the external temperature and the airflows through the ventilation openings (45 degree). After a four-day period with bright and warm weather eventually the temperature on the fourth floor reaches about 40 °C. With opening angles of vent windows 45° the temperature on the same floor could be reduced to about 30 °C.

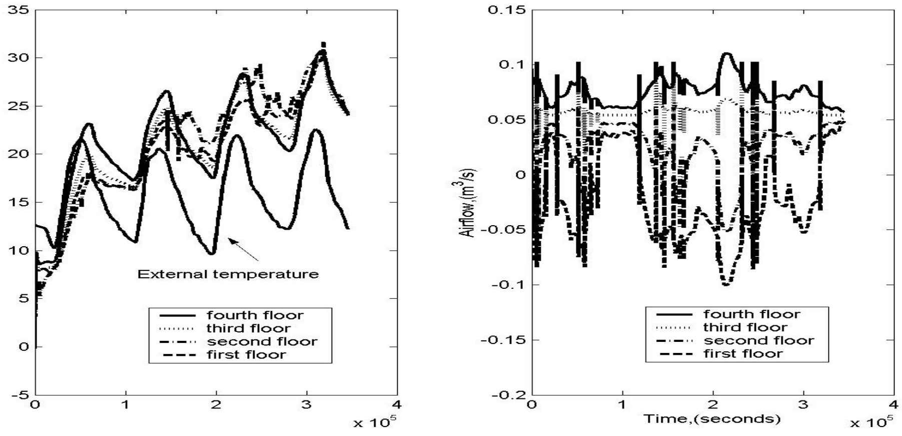

Figure 5 – Indoor and outdoor temperature. Opening angle 45°. Airflows through ventilation openings. Due to the pressure gradient along the façade, air is extracted from the rooms in the first and second storey and supplied into the above rooms.

The neutral zone of the façade is placed somewhere between the second and the third storey. Due to the pressure gradient along the cavity, air is extracted from the rooms in the first and in the second storey and supplied into the above rooms. The result is that the average indoor temperature are higher at the highest floor due to supply of warm air from the cavity, while in the first and second floor cooler air is supplied from the corridor and exhausted through the cavity.

CONCLUSIONS

The temperatures inside the rooms at different floors have been shown to be different. Highest floors have higher temperatures. Moreover, the pressure gradient and its effect on the ventilation rate through vent openings suggests a proper control of the ventilation openings and partitioning of the Double Façade to avoid overheating problems. The simulations shown that the Double Skin Facades can have a flexible use as (a) supply fan or exhaust fan; (b) preheating device for ventilation systems with natural supply through openings in the inner façade; (c) supplier of preheated fresh air for a central air handling unit.

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