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Benefits of Adjustable Shutters, Shading Devices and Vent Windows in Passive Solar Buildings

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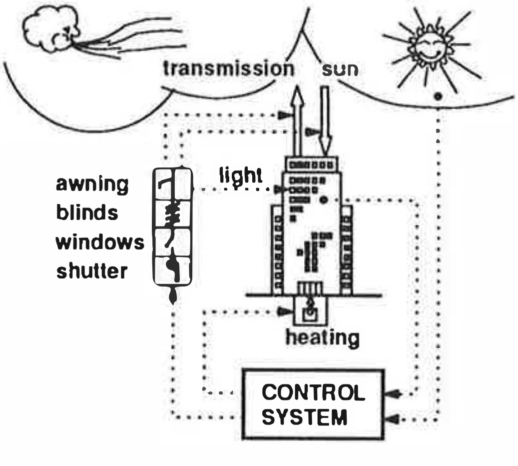
Abstract

Passive solar building are developed to take advantage of the solar heat to reduce the cost of heating. This is obtained by windows with large glass areas in the facade of the building. This idea has some disadvantages. The large window area gives large transmission losses and during warm periods of the year overheating can occur.

These disadvantages can be overcome by adding extra window components to the building, like a shutter, shading devices and vent windows. In order to study the capabilities of the building and the various components a computer simulation is developed. This paper shows the results, energy consumption and overheating, of simulations with different buildings and components.

Introduction

Passive solar buildings are developed to take advantage of the solar heat to reduce the costs of heating during the heating season. This can be realized by windows with a large glass area in the south facing facades. The idea is very simple. The large window allows large amounts of solar radiation to enter the room, which contribute to the indoor temperature of the room by heating the walls and eventually lower the energy contribution of the heating installation.



The idea can have some some disadvantages. The large window area gives large transmission losses, which are proportional to the temperature difference between the indoor and outdoor temperature and the window area. It depends on the type of window, and the type of outdoor climate if the difference between the heat gain by solar radiation and the heat loss caused by transmission is positive or not. It is not obvious for a certain type of building situated in a certain type of climate whether this is the case or not. (1)

Another disadvantage of admitting large solar heat fluxes into the building is the overheating during warm periods. The large window allows the solar radiation in large amounts, but because of the relative small transmission loss during warm periods the indoor temperature will easily increase.

The transmission heat loss and the overheating can be reduced by adding extra passive window components to the building. These components are a rolling shutter to provide extra isolation of the building at night during heating periods to reduce the transmission loss. An awning is applied to reduce the admittance of solar radiation to prevent overheating during warm periods. And ventilating windows are applied to obtain free cooling with outdoor air when overheating occurs.

CIB W67

Re: International Symposium on Energy, Moisture and Climate in Buildings, 3-6 September 1990, Rotterdam, The Netherlands.

A control system is necessary, that positions all these components and let them cooperate together to obtain an acceptable indoor temperature. It is for instance necessary to prevent the windows to open while the heater supplies heat to the room. The control system is for instance also necessary to prevent the shutter from closing while the next day cooling will be necessary. It will be clear from the examples that the control system can not only exist of traditional controllers (P or PI controllers) to position the components according to the needs, but also must incorporate some kind of logical schedule to select the components that will or will not be used to control the indoor temperature. (2)

The study, that is described in this paper, will deal with the benefits of passive solar buildings and additional components as main point of interest. The control system is therefore kept as simple as possible. 4 thermal models are developed and used for this study. Models of buildings with light interior walls and heavy interior walls are made. Each model has two types of windows with 40 and 80 % of glass area of the facade. Temperatures and energy consumption of these 4 models with components, mentioned before, are calculated and compared in order to find out the capabilities and limits of the different types of buildings and components.

The thermal models include a detailed description of the walls and the radiation heat exchange between walls and window. Also detailed absorption and emission of long wave radiation in the window is taken into account. The solar radiation that hits the facade of the building is accurately calculated from the horizontal solar radiation from the wheather data sets. (1) The behaviour of the awning and the ventilation by the windows is treated separately from the thermal building model. (5)(6) The rolling shutter is incorporated in the thermal model of the building.

To show the effect of the outdoor climate on passive solar buildings two types of climates are chosen. The TRY (Test Reference Year) of Carpentras in the south of France represents a warm climate. And the TRY of Uccle in Belgium represents a moderate climate (comparable with the Dutch climate).

Building model

The dynamics of a building are caused mainly by the dynamics of the walls of the building and the heat capacity of the room air volume. The response of the wall temperature to input signals can be approximated by a set of first order differential equations for each wall.

Two types of rooms, a light and a heavy room, are calculated for the simulations described in this paper. The size, volume and total wall area of both rooms is the same. The only difference between the light and heavy room is the interior walls. The light room has interior walls consisting of one layer of 2 cm plasterboard. The heavy room has interior walls consisting of one layer of 10 cm concrete with 1 cm of plaster on each side of the wall. All other walls (floor, ceiling and exterior) are the same. The admitted solar radiation by the window is supposed to spread equally over the walls.

Windows with two different window areas are used for each of the rooms. One window is 40% of the facade area and one window is 80%. Both windows consist of double glazing with a u-value of 3 W/m^2 K. Only static behaviour of the window is considered. The window is described as a set of linear equations giving the relations between the interiors window temperature and all other temperatures, like outdoor temperature, indoor air and wall temperatures and the solar radiation. The rolling shutter alters the static behaviour of the window. Therefore two sets of static equations are obtained, one set without shutter and one set with shutter.

he first order differential equations, that describe the wall behaviour nd the set of equations for the window are combined into one large set of irst order differential equations by calculating the heat balance of the oom. The heat conduction coefficients between the wall surfaces and the oom air are fixed at 3 W/m^2 K. The complete model of the room air temperaure is reduced to a convenient order (4 to 6 depending on the dynamic properties of the room model) (3) and written in Jordan normal form for simulation convenience (4).

The reduced model of the room is characterized as:

$$\dot{\underline{x}} = F\underline{x} + G\underline{u} \qquad (1)$$

$$T_i = H\underline{x}$$

$$\underline{u} = \begin{matrix} Q_{aux} \\ q_{si} \\ T_o \end{matrix}$$

with

F = Matrix with eigenvalues of the reduced room system
G = Command matrix
H = Observation matrix

Q_{aux} = Auxiliary (convection) heat supplied to the room [W]
q_{si} = Solar radiation reaching the window surface [W/m²]
T_o = Outdoor temperature [°C]
T_i = Interior air temperature [°C]

The awning is of an unusual type. It is exactly horizontal with a maximum swing equal to the height of the window. The model of the awning is developed by (5) and is given by a reduction factor F_d of the solar radiation q_{sv} that hits the vertical surface of the building. (1) The solar radiation that reaches the room window becomes:

$$q_{si} = F_d(x)\ q_{sv} \quad [W/m^2] \qquad (2)$$

q_{sv} = Solar radiation on vertical surface [W/m²]
x = Awning position (0 - 1)

The energy flow caused by an open window Q_v is added to the auxiliary heating Q_{aux} in the input vector $\underline{u}$. There are four ventilation windows situated in each corner of the total window. They can be opened 2 by 2 (upper or lower windows) or all 4 together.

The calculation of the cooling power of the ventilation Q_v is:

$$Q_v = \Phi_v(\alpha_w)\ (T_o - T_i) \qquad (3)$$

α_w = Window opening angle [Rad.]

The calculation of ventilation air flow Φ_v through the windows is based on the research of (6).

Control system

The control system selects and positions the components into such a position that a comfortable indoor temperature is maintained in the room. Two indoor temperature set points are used. A low set point for heating situations TSPH and a high set point for cooling situations TSPC. If the indoor temperature is between these two set points the control system puts all components in a neutral position and the indoor temperature is not controlled.

The control system operates in different modes when the building is occupied and when the building is not occupied (at night).

If the building is not occupied the control system takes the following actions:

1. The shutter is closed if there has been no cooling during the previous day and the sun has not risen.
2. If the indoor temperature rises above TSPC two actions can be taken:
   i. If the sun has already risen the awning is put in its maximum position.

   ii. The windows are controlled by a proportional controller in order to keep the indoor temperature at TSPC.
3. The start up time of the heater is calculated, based on the indoor temperature and the current time. At the beginning of the occupation period the start up time is checked for the condition if the lower set point TSPH is reached and if necessary the start up time is adjusted.

If the building is occupied the control system takes the following actions:

1. If the indoor temperature is lower than TSPH, the indoor temperature is controlled with the heater by a PI-controller.
2. If the indoor temperature is higher than TSPC two actions can be taken:
   i. If the solar radiation is higher than a minimum value SRMIN the awning is put in its maximum position.
   ii. The windows are controlled by a proportional controller in order to keep the indoor temperature at TSPC.
3. The shutter is opened.
4. In case the indoor temperature is lower than TSPC, the windows are put into a minimum position to provide a minimum amount of fresh air.

The maximum available heating power is bound inversely proportional to the outdoor temperature. The maximum window position is bound proportional to the outdoor temperature.

The awning control is on/off control between its zero and maximum position. The maximum position is equal to the height of the window.

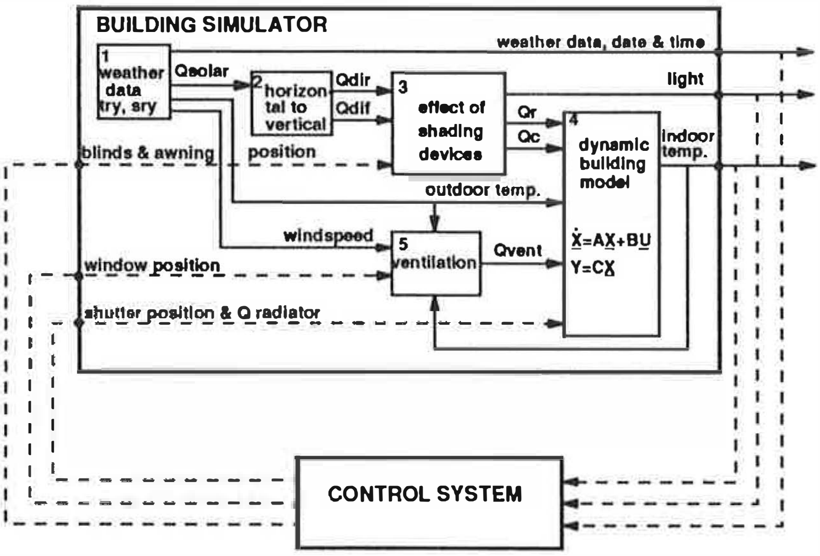


Figure 1. Building simulator and control system

Simulations and simulation results

With the described building and component models and the described control system simulations have been carried out to investigate the capabilities and limitations of the complete system as shown in figure 1. All simulations are done with the following constant factors:

Occupation period : 7:00 h to 22:00 h
Foreground : bitumen and gravel (Reflection !)
Minimum window : 5 Degrees (Minimum supply of fresh air !)
Maximum window : 35 Degrees
Facade orientation : South
Maximum radiator : 1200 W.
SRMIN : 250 W/m^2
TSPH : 21 °C

L40 = light room with 40% glass
L80 = light room with 80% glass
H40 = heavy room with 40% glass
H80 = heavy room with 80% glass

The last simulations concern different internal heat loads in the room. The H40 model is selected, which is the only model with acceptable results. The internal heat load is 100, 200 and 400 W. The control system is the same as with the previous simulations. Table III shows the results.

Table III. Energy consumption and overheating of H40 model with different internal heat loads.

	UCCLE					CARPENTRAS				
	Winter	Spring	Summer	Autumn	Year	Winter	Spring	Summer	Autumn	Year
Load										
	Energy consumption [kWh]									
100	452	88	0	132	672	59	1	0	4	64
200	337	45	0	79	461	17	0	0	1	18
400	120	3	0	11	134	0	0	0	0	0
	Overheating [h]									
100	0	0	32	15	47	0	27	650	153	830
200	0	0	70	41	111	0	52	806	244	1102
400	0	30	218	145	393	0	134	1050	487	1671
	Maximum Temperature [°C]									
100	23	25	27	26		24	27	29	28	
200	23	25	28	27		24	28	30	29	
400	24	26	30	28		25	29	32	30	

As expected the situation for Carpentras does not improve. This situation already showed problems without any internal heat load. The situation in Uccle is acceptable up to internal heat loads of 200 W, if a criterion of 130 hours of temperature exceedings is used.

Discussion and Conclusions

The idea of reduction of the energy consumption by the application of windows with large glass areas is not attractive in both situations, Uccle and Carpentras. In Uccle it does not reduce the energy consumption because of the larger transmission losses and it leads to overheating during warm periods. In Carpentras it causes problems concerning the overheating of the building throughout the whole year. Besides that the reduction of the energy consumption in Carpentras is relatively small in the absolute sense.

If only the energy consumption is observed it is better to use light interior walls in Uccle. In Carpentras heavy walls provide a lower energy consumption.

If the overheating is the main concern it is better to use heavier buildings. Heavier buildings damp the temperature swings in the building, which are more crucial when high internal heat load are expected.

If real high internal heat loads (> 200 W.) are dealt with, problems, concerning overheating, will also occur in Uccle. A solution must be searched in the direction of either the building construction or a more advanced and complicated control system or a different cooling system than only cooling by ventilating with the windows.

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