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Installing Opaque Ventilated Facades for Energy Saving in Old Buildings

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Abstract

Many buildings erected more than about thirty years ago lack of an effective facade insulation. Some of them can be seen in old residential neighborhoods, with parts of their concrete structures exposed to outdoor air and sunlight, single pane windows, thermal bridges, etc. Renovation of these facades leads to energy savings and more comfortable and healthy indoor air conditions. An opaque ventilated facade (OVF) is an easy and economic system to reduce heating energy consumption. The main objective of this paper was to obtain the reduction in heating demand in the winter season using OVF's modules. Another objective was to determine the best location in terms of climate variables to install an OVF system. In order to achieve these objectives, the thermal loads of a building with and without an opaque ventilated facade system were simulated for 12 locations in a European country in the winter season. Energy saving in the winter were found to be positive for all the locations, and the best locations to install an OVF were found to be the southern regions and the coastal areas, which were the ones with the highest levels of solar radiation. It was also found that locations with lower solar radiation levels had lower heating demand values when their temperatures levels were high and/or the average wind speed levels were low.

Keywords – heating energy saving; solar energy; ventilated facade; solar façade.

1. Introduction

Between the 40's and the 80's the building rate increased rapidly to accommodate rural population moving to big cities. The lack of normative and the necessity of housing to be cheap contributed to the creation of large suburbs of energy inefficient buildings. This leads nowadays to social degradation of these areas due to the lack of a minimum level of comfort, deterioration of structures and facades, and an increasing cost of electricity.

One of the actions needed to improve the energy efficiency of these buildings is raising the insulation of the building envelope. This can be done adding new insulation layers and/or an air cavity, or filling existent air cavities with insulation foams. An alternative or a complement to these traditional methods can be installing opaque ventilated facades (OVF) modules. An OVF absorbs solar radiation to heat the ventilation air flowing through its cavity. This heated air can be introduced inside the building in the cold season or be exhausted in the hot one.

Many types of OVF's have been studied so far, and a review of them can be checked in [1]. In some cases, the OVF is combined with other energy systems [2-4]. Some OVF's are called open joint ventilated façades [5, 6], they consist in rows or tiles separated from each other a certain distance. The benefits of using this kind of façade can be read in [7, 8]. The most popular OVF's are those in which its external layer is made of ceramic, clay or stone [9, 10], but it could be also made of metal [11].

The objectives of this piece of work are: first, to evaluate the energy saving in terms of reduction of heating demand that can be achieved by installing OVF modules on an existing traditional façade, and second, to determine the best locations for installing an OVF's system. To meet these objectives a model of a building was created and simulated under different climate conditions with and without OVF modules.

2. Methodology

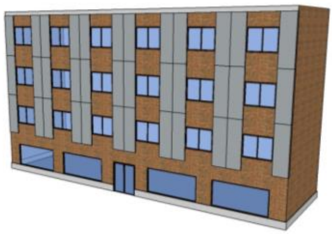
Numerical Model

An experimentally validated numerical model of OVF was used to carry out the simulations of the building energy performance. The details of this model were explained in [12]. This model was included in the building model created using the building energy simulation software TRNSYS [13].

Case study

An office building was selected for this study because office schedules are easier to establish. The selected building was a typical four storey box shaped office building, figure 1. The room studied was an office room of 8 x 7 x 3.25 m, see figure 2. The room had four OVF modules of 1 m width each, covering half of the surface of the south façade. The materials used in each wall and their properties can be seen in [12].

The room was provided with mechanical ventilation which entered the inner space through the OVF. The air gap of each module of OVF can be considered a 1 m width and 0.05 m depth duct, see figure 3.



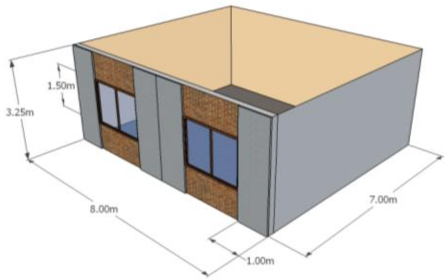


Figure 1. Building sketch.

Figure 2. Dimensions of the room studied

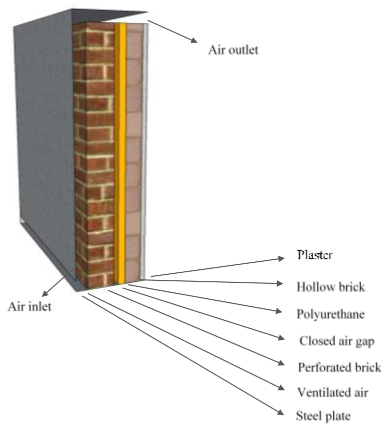


Figure 3. Façade layers including OVF

The working time schedule was established from 9:00 am to 5:00 pm from Monday to Friday. It was established a number of 6 people in the room with a degree of activity 4 according to [14] (Seated, light work, typing).

Each person used an 80 W computer terminal. The illumination consisted of fluorescent lamps with a power rate of 10 W/m^2. The light was set always on during the working time. The room air temperature was set to 21 ºC and the relative humidity to 50 % in the working time. The energy transferred to the space air to maintain these conditions were calculated in the simulations.

The ventilation airflow rate was established according to the Spanish regulation [15], corresponding to very good indoor air quality, IDA 2. According to this, 12.5 m^3 of air per person was needed. A density of occupation of 9 m^2/person was considered which made a total of 6 people and thus a ventilation air flow rate of 270 m^3/h.

The wind pressure on the external surface of the building was taken into account through the pressure coefficient C_p, which is defined with equation (1).

$$P_w = C_P \frac{\rho V^2}{2} \quad (1)$$

Where P_w is the difference between static pressure on the façade and atmospheric pressure (Pa), ρ is the air density (kg/m^3) and V is the wind speed (m/s), which is normally taken at the roof level. The pressure coefficients were calculated using the CpCalc+ software package [16].
The external convection heat transfer coefficients were calculated according to [17] using the expressions (2) and (3).

$$h_{ext}=4.8 +1.7\ V_f \text{ (windward)} \quad (2)$$
$$h_{ext}=2.6+2.5\ V_f \text{ (leeward)} \quad (3)$$

Where V_f is the wind speed at the height of the roof.

Control strategy

The inner trap door was kept always open during working time while the mechanical ventilation provided the room with the required air flow rate. During the non-working period the trap door opened following a hysteresis cycle that had a lower temperature of 21 ˚C and an upper temperature of 23 ˚C. Whenever the temperature was over the upper temperature limit the trap opened to provide the room with ventilation at a convenient temperature, whereas the trap was closed when the air temperature went down below the lower limit. Thus instability was avoided in the performance of the trap door.

The same building but without OVF modules was used to be compared with the former. In this case the ventilation was taken directly from outdoor. The same ventilation strategy as the first building was followed and the openings had the same dimensions as all the OVF trap doors in the first case. Thus, both buildings were comparable regarding the use of outdoor air for ventilation.

$$P_w = C_P \frac{\rho V^2}{2}$$

Simulations

Twelve locations were considered to analyse the influence of climatic conditions on the heating demand obtained using an OVF system during the winter season. These locations were selected according to the winter and summer severity code in Spain, since this research was developed in the framework of a Spanish Government Research Plan. The codification of locations according to their summer and winter severity can be seen in table 1 [18]. Figure 4 shows the distribution of climate zones in Spain. The results can be extrapolated to other locations where Mediterranean, continental or oceanic climate exist.

Figure 4. Distribution of climate zones in Spain according to table 1.

Table 1. Summer and Winter Severity Codes

<table>
<tr><td rowspan="4">SC (Summer)</td><td>A4</td><td>B4</td><td>C4</td><td></td><td rowspan="4">E1</td></tr>
<tr><td rowspan="3">A3</td><td rowspan="3">B3</td><td>C3</td><td>D3</td></tr>
<tr><td>C2</td><td>D2</td></tr>
<tr><td>C1</td><td>D1</td></tr>
<tr><td></td><td></td><td colspan="4">SC (Winter)</td></tr>
</table>

The weather files corresponded to typical meteorological year data extracted from the Meteonorm 5.1 software [19]. The simulation period was from December 21st to March 21st and the simulation time step was 1 h. The results obtained were the heating demands of the room in each case.

3. Results

In figure 5 the heating demand is shown on a daily basis (only working days) for the climatic zone B4 and for the same office room with and without OVF during the winter. It can be seen that the heating demand was lower using an OVF in all the working days. However, the differences of heating demand were quite dispersed. On six days there wasn't any energy demand at all whereas the demand without OVF was positive. There were also days in which the energy demand was similar in both cases. The average energy demand in the case with OVF was 3.53 kWh whereas in the case without OVF was 6.17 kWh. Thus, installing an OVF system implied an reduction of heating demand of 43 % relative to the case without OVF.

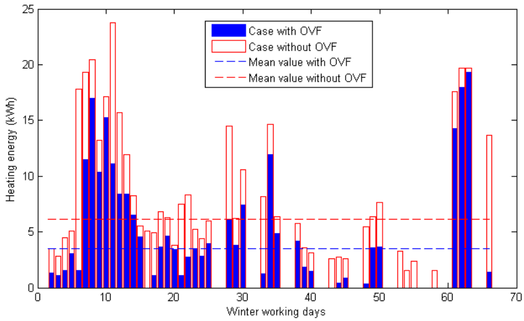


Figure 5. Comparison of heating energy demand between the buildings with and without OVF during working days in the winter season in location B4.

The variability in heating demand was due to the different weather condition each day. The most influential weather variables on the façade performance according to the numerical model were solar radiation on the façade, ambient temperature and wind speed and direction. However, the influence of each variable in the energy saving cannot be explained in a simple way. In [12], a sensitivity analysis was carried out to find out the most influential weather variables on the OVF performance. The results of this study showed that installing an OVF will be better in dry climates where sunny days prevail and the average wind speed is low, and that the advantage of using an OVF will be greater in climates with mild temperatures in the winter.

Figure 6 shows the winter energy saving evaluated for 12 locations corresponding to the 12 climatic zones in [18]. The locations were sorted by increasing winter severity and decreasing summer severity. In order to study the correspondence of these results with the previous sensibility analysis, the cumulative distribution function of solar radiation on the façade, ambient temperatures and wind speed were represented for each location in figures 7, 8 and 9.

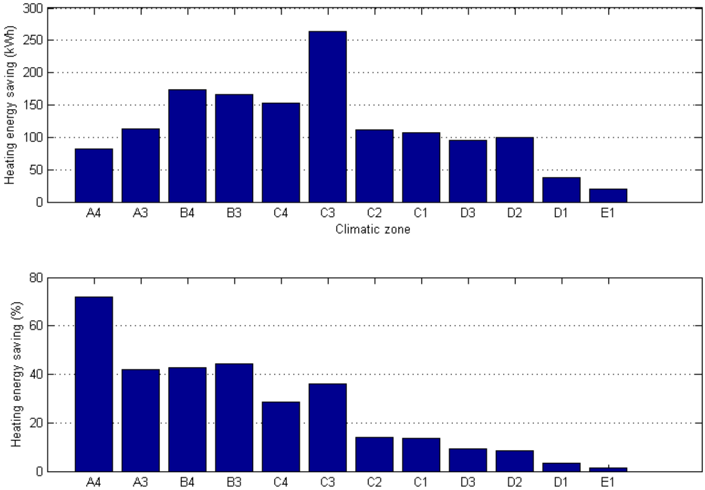


Figure 6. Winter season sensible heating energy saving in terms of reduction of heating demand using an OVF related to the same building without OVF in each location. Absolute and percentage values.

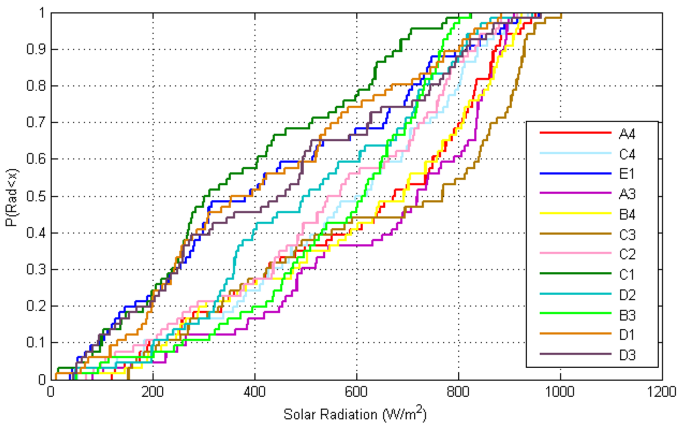


Figure 7. Solar radiation cumulative distribution functions for each location.

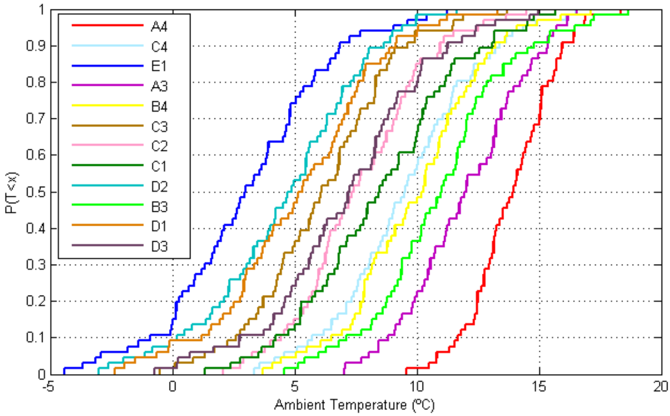


Figure 8. Ambient Temperature cumulative distribution functions for each location.

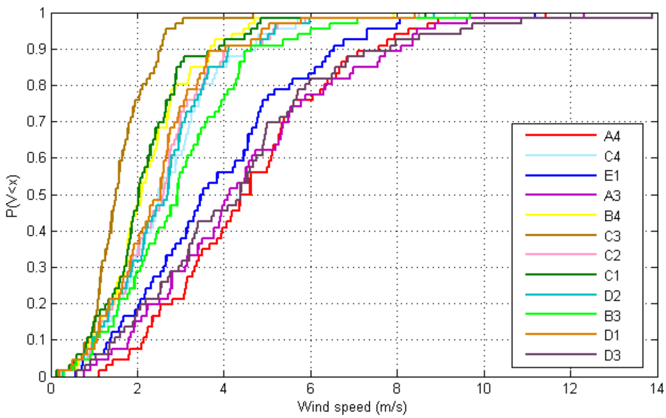


Figure 9. Wind speed cumulative distribution functions for each location.

Regarding radiation, it can be observed that the greater energy saving in absolute terms were the locations with medium winter severity. Most of the locations with high energy saving corresponded with locations with a high level of radiation. The case of location C1 is remarkable, because despite having the lowest radiation distribution function its temperature level is higher and its wind speed the lowest of all, so it had a good level of energy saving, comparable with locations with higher solar radiation levels. It's also remarkable the case of location A4. This location had the second highest solar radiation level and the highest temperature distribution, however its energy saving resulted lower because of the high wind speed levels.

Regarding temperature, in general the locations with higher temperatures corresponded with the ones with higher energy saving. The exceptions were the case of A4, described above and the case of location C3, which had a low temperature but a high radiation and low wind speed levels. Looking at the wind speed levels, again, the lower levels of wind speed corresponded with the higher energy saving locations, with the exception of location A3 aforementioned and locations D1 and D2, which had low levels of radiation and temperature.

The same results were represented in figure 6 in terms of percentage of heating demand relative to the heating demand without OVF. It can be observed that unlike the absolute values, percentages were almost inversely proportional to winter severity. The reason for this is that although energy saving could be low for low winter severity locations, the heating energy needed is also low, so most of the heating demand can be accomplished only by using the OVF. The opposite was also true for the coldest climates. The clear exception to this rule of thumb was location C3. In this case, the energy saving was high, due mainly to the high solar radiation levels, and the percentage of energy saving resulted very high despite being a location with low temperatures.

These results agreed with the sensitivity analysis. Thus, it's possible to estimate the benefits of using an OVF in a certain location by collecting information about the weather data variables of that location along the winter.

1. Conclusions

A study on the better locations in Spain to install an OVF was carried out. The main conclusions drawn from this paper were the following:

1. Energy saving in the winter were found to be positive for all the locations simulated in Spain.
2. The best locations to install an OVF in Spain were in the southern regions and the coastal areas, climatic zones A3, B3, B4, C3 and C4. They corresponded with those with the highest levels of solar radiation. Locations with lower solar radiation levels had high energy saving values when their temperatures levels were high and/or the average wind speed levels were low.

3. In general, the best locations to install an OVF were those with medium winter severity climate in absolute terms and low winter severity climate in relative terms.

Further study should be done to evaluate the impact of using an OVF in the summer period. It must also be studied the most convenient ventilation strategy in this case.

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