CONTRIBUTION OF THE VENTILATED FAÇADE TO BUILDING ENERGY DEMAND

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ABSTRACT

The study of the interaction between a ventilated building envelope and a building is complicated and requires the use of thermal simulation tools. Simple energy demand evaluation programs such as LIDER do not envisage the ventilated façade solution. If it is desired to use such programs, it is necessary to resort to approaches that are relatively unrealistic and do not take into account the heat flux associated with the rising movement of the air in the ventilated cavity.

With a view to studying the effect of the ventilated façade, a simple building with a parallelepiped structure was modelled using the EnergyPlus program. The effect of the presence of the ventilated façade was analysed for different climate zones and building types (residential or tertiary use). The results were compared with those of an equivalent building envelope with a non-ventilated cavity and a tiled outer leaf. The effect of the absorptance of the outer leaf was also studied, since one of the constraints of LIDER is that it assumes a constant value for this property, independently of whether the surface is light-coloured or dark. The results enabled the energy evacuated through the ventilated façade to be determined. The study shows that, though the ventilated façade is efficient in summer (particularly in mild and warm climate zones), its efficiency in cold zones is more questionable.

1. INTRODUCTION

Increasing social awareness with regard to sustainable construction and energy saving in buildings is leading specifications writers and end-users to consider different thermally efficient construction solutions.

The ventilated façade is a multi-layer building envelope that is fundamentally characterised by including a ventilated cavity, delimited by two leaves: an inner leaf that provides thermal insulation and airtightness, and an outer leaf, whose main mission is to form this air cavity, assuring continuous ventilation across the entire façade surface [1]. The ventilated façade construction system with ceramic tiles improves the thermal performance of a building owing to the stack effect that reduces the wall temperature in summer, decreasing the energy needed for cooling.

Although the literature recognises the energy saving obtained by different types of ventilated building envelopes, few studies have analysed the thermal performance of these solutions integrated in buildings. Some studies have focused on analysing the thermal transfer through the ventilated envelope, from both a theoretical and an experimental standpoint [2-5]. These studies enable the operating mechanisms of ventilated façades to be understood, in addition to opening up avenues to their optimisation; however, the interaction between the envelope and the building is complex and requires the use of other tools.

A widely used program in evaluating building energy demand is EnergyPlus, developed by the U.S. Department of Energy [6-8]. Although this program does not specifically include the ventilated façade, it has a simplified ventilated feature (*Exterior Naturally Vented Cavity*), which allows this type of building envelope to be simulated in a simplified form, taking into account the air flow in the ventilated cavity [9-10].

In this paper, the EnergyPlus program has been used to study the effect of the presence of a ventilated cavity on the thermal performance of a building envelope. In addition, a simple building has been modelled to analyse the effect of the presence of a ventilated façade in different climate zones, types of buildings (residential and non-residential), and the absorptance of the outer leaf. Absorptance measures the ratio between the solar radiation absorbed by a material and the impinging radiation. The results are compared with those of an equivalent building envelope with a non-ventilated cavity and a tiled outer leaf.

2. MODELLING OF THE VENTILATED FAÇADE

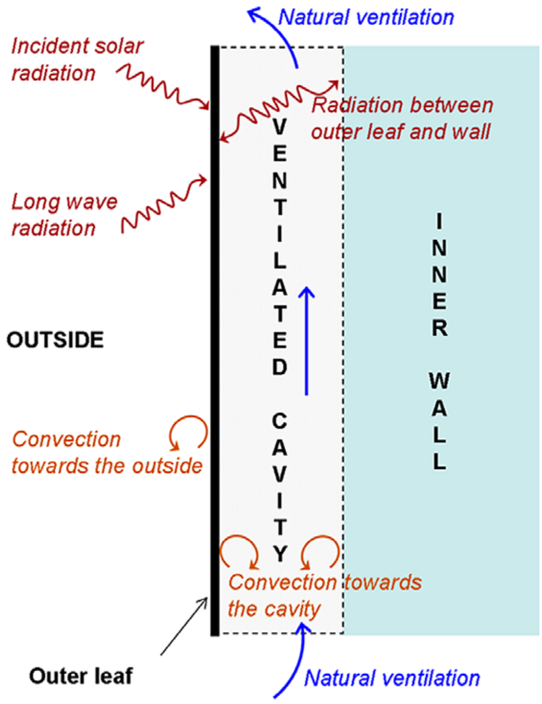

Figure 1. Scheme of the ventilated cavity implemented in EnergyPlus.

In order to model building envelopes with a ventilated façade, an EnergyPlus module called *Exterior Naturally Vented Cavity* was used. This element allows the characteristics to be entered of the outer leaf, of the ventilated cavity, and of the openings for natural ventilation (Figure 1). Detailed descriptions of the model may be found in the literature [9] and in the EnergyPlus program documentation [11].

From the viewpoint of the calculation, the presence of a ventilated cavity modifies the radiation and convection phenomena between the outside environment and the inner wall. Based on the characteristics of the ventilated cavity and the meteorological data, EnergyPlus calculates the heat transfer between the outside environment and the inner building wall.

It may be noted that the model assumes that the heating capacity of the outer leaf is negligible: i.e. there is no heat build-up on the inside of the outer leaf.

The convection and radiation phenomena are simulated using classic models implemented in EnergyPlus. In the case of the ventilated cavity, convective coefficients are used that were developed to simulate air cavities in multiple glazing [11].

Finally, to simulate the effect of natural ventilation, the air temperature in the cavity is assumed to be homogeneous. The air flow rate is then calculated in the cavity, considering both natural convection and forced convection due to the wind, from the following equation:

$$\dot{V} = C_v A_{in} U + C_D A_{in} \sqrt{2g\Delta H \frac{(T_{cav} - T_{amb})}{T_{cav}}}$$

where:

$\dot{V}$: Total volume air flow rate in the cavity (m^3/s)

C_V: Opening efficiency, which depends on opening geometry and wind direction (dimensionless)

A_{in}: Opening area (m^2)

U: Wind speed (m/s)

C_D: Discharge coefficient, which depends on geometry (dimensionless)

g: Force of gravity (m/s^2)

ΔH: Height between the centre of the bottom opening and the zero pressure point (m)

T_{cav}: Air temperature in the cavity (K)

T_{amb}: Outside ambient temperature (K)

Coefficients C_V and C_D depend on the geometry of the system considered, wind direction, and building orientation. Their average values were estimated using a preliminary calculation by fluid mechanics at a wind speed of 2 m/s.

3. PERFORMANCE OF A BUILDING ENVELOPE WITH A VENTILATED FAÇADE

3.1. Description of the studied building envelopes

In the first part of the study the performance of two construction solutions was compared: a building envelope with an airtight cavity and an equivalent envelope with a ventilated cavity. Both building envelopes exhibited the same thermal transmittance value.

The two types of studied building envelopes are schematically illustrated in Figure 2. The properties of the materials used are detailed in Table 1.

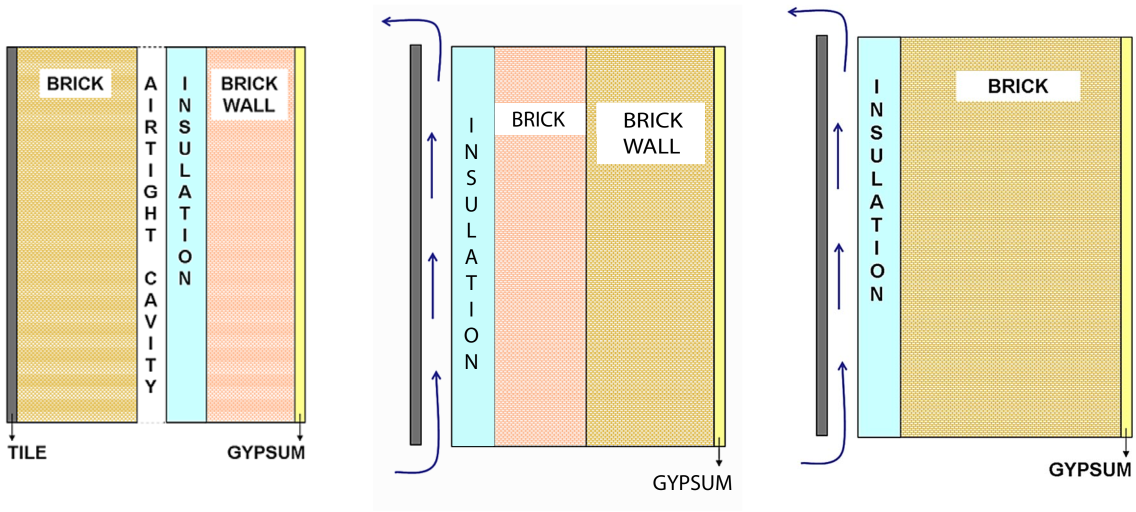

Figure 2. Scheme of the conventional building envelope (left) and of the ventilated building envelope (right).

Material	Conductivity W/(m·K)	Density kg/m³	Specific heat J/(kg·K)
Ceramic tile	1	1900	850
½ foot brick	0.694	1140	1000
Expanded polystyrene	0.038	30	1000
Double brick wall	0.432	930	1000
Gypsum plaster	0.57	1150	1000

Table 1. Properties of the materials making up the studied building envelopes.

3.2. Studied variables

In order to evaluate the effect of the ventilated cavity on the performance of the building envelope, a parallelepiped of 9x1x1 m was simulated in which all walls were adiabatic, except for one wall that was made up of either a conventional building envelope or a building envelope with a ventilated façade: i.e. all heat gains and losses took place through the studied wall. Therefore, this enclosure was the only element that significantly influenced energy consumption.

The energy required was calculated, for both heating and cooling, to keep the internal temperature between 20 and 25 ºC throughout the year, assuming that the cooling and heating systems were always switched on.

The effect of the orientation of the ventilated façade on the performance of the building envelope in three climate zones: a cold zone (E1/Soria), a mild zone (B3/Castellón), and a warm zone (A4/Almería), was also studied.

3.3. Results

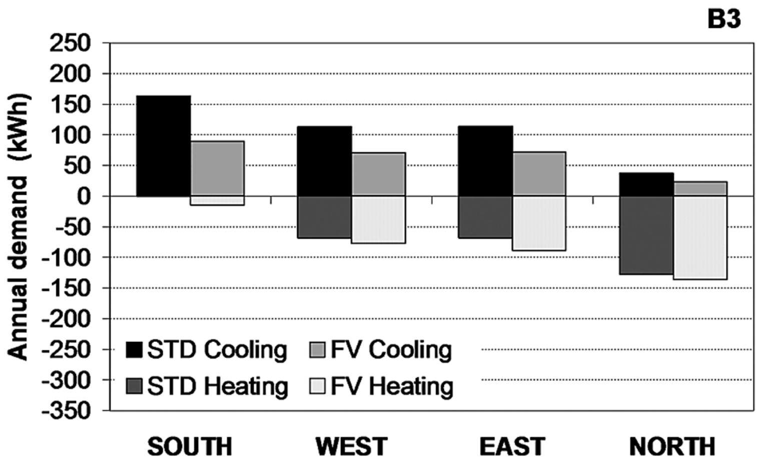

Figure 3. Annual heating and cooling demands as a function of the orientation of a conventional black building envelope (STD) and a ventilated façade (FV) in Castellón.

Figure 3 shows the annual heating and cooling demands as a function of the orientation of the active building envelope in Castellón. By convention, cooling demands are represented with positive values and heating demands with negative values.

In general, the ventilated façade significantly reduced the cooling demand, but it increased the energy required for heating. The effect of the ventilated cavity was very pronounced in the southern orientation, with a 45% reduction in cooling consumption. Indeed, the south wall was the wall that received most solar radiation, raising outer leaf temperature and, as a result, increasing air flow in the ventilated cavity.

Finally, the ventilated façade was observed to influence the cooling demand more than the heating demand.

The same general trends were observed for other climate zones (Figure 4). These results indicate that the ventilated façade effectively reduced the energy cost in warm zones where there was a significant cooling demand. In contrast, the usefulness of the ventilated façade in cold zones was more debatable, since its use entailed increased heating consumption.

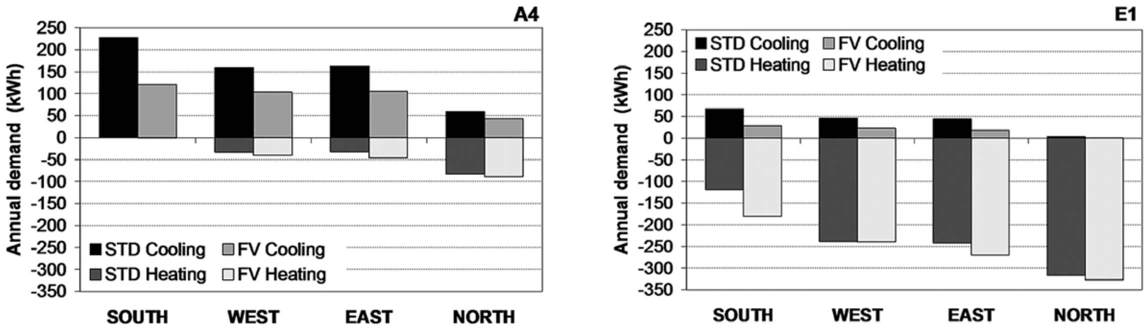

Figure 4. Annual heating and cooling demands as a function of the orientation of a conventional black building envelope (STD) and a ventilated façade (FV) in Almería (left) and Soria (right).

4. SIMULATION OF A BUILDING WITH A VENTILATED FAÇADE

4.1. Description of the building

In the second part of the study, the effect of a ventilated façade on the energy demand of a complete building was evaluated. For this, a simple building was designed. The building had four storeys of 20x20 m, in addition to a ground floor, with a height between decks of 3 m (Figure 5). All façades were identical, with 30% openings in the façades. In the calculations, the deck was assumed to touch the floor, which was adiabatic.

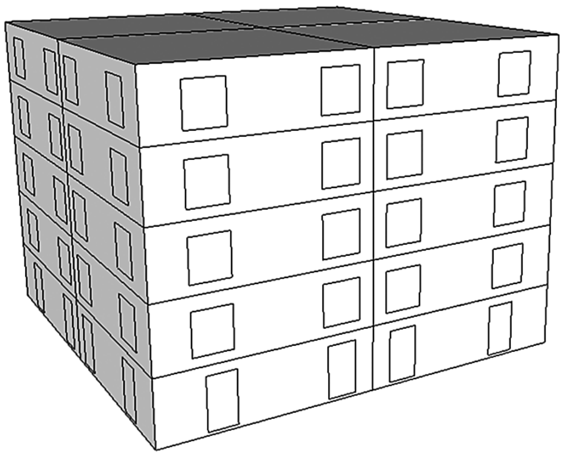

Figure 5. Scheme of the building

As in the foregoing section, the energy demand of the building with the ventilated façade was compared with that of an equivalent conventional building envelope with a non-ventilated cavity and a tiled outer leaf (Figure 2). Calculations were performed of the energy efficiency, changing the characteristics of the building envelopes as a function of the climate zone considered, in order to comply with the limit value for thermal transmittance required by the Spanish technical code for building construction (Table 2).

Climate zone	E1/Soria	B3/Castellón	A4/Almería
U (W/(m²·K))	0.56	0.81	0.93

Table 2. Thermal transmittance values for building envelopes.

4.2. Contribution of different building components to energy consumption

In order to determine the major factors that influenced the energy demand, the effect of the windows, ventilation, and the internal charges on heating and cooling energy consumption was studied. For this, the energy needed to keep a non-ventilated building without windows or internal charges between 20 and 25 ºC was calculated. The elements that contributed to the energy demand were then separately added, in order to evaluate their individual influence. The calculation was performed for three climate zones (Figures 6 and 7).

Two types of internal charges (occupation, lights, equipment) were used, based on the conditions proposed in LIDER: *residential* for residential use and *non-residential medium intensity 12 h* for tertiary use [12].

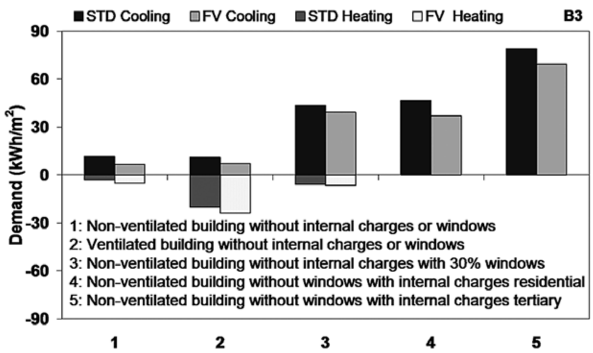

Figure 6. Annual heating and cooling energy consumption to keep the building between 20 and 25 ºC in Castellón.

When the building was ventilated, an important increase in heating consumption was observed, independently of the climate zone. A constant ventilation of 0.5 air renewals per hour was used. As a result, in winter, cold air entered, raising the energy demand to keep the internal temperature above 20 ºC. This increase was more noticeable for cold climate zones. With regard to cooling consumption, this tended to increase slightly with ventilation in warm zones (A4 and B3), owing to the entry of air at a temperature above 25 ºC; in contrast, ventilation reduced the cooling demand in the cold zone (E1), where the outside air usually did not reach 25 ºC.

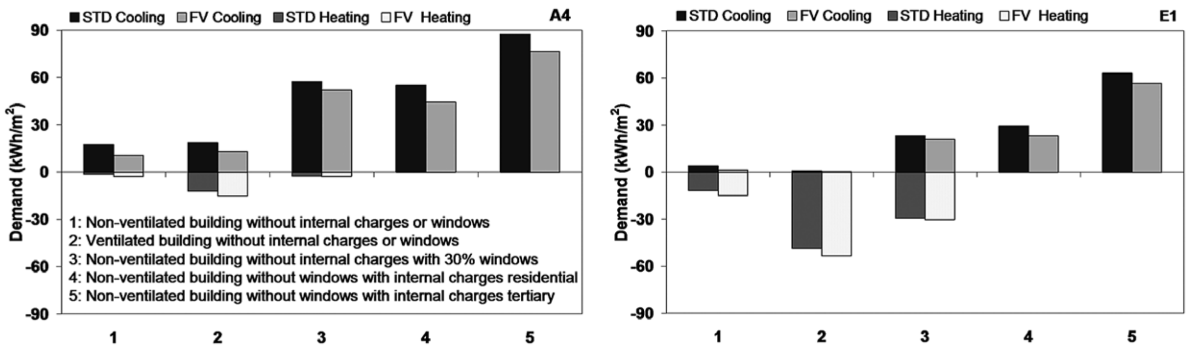

Figure 7. Annual heating and cooling demands to keep the building between 20 and 25 ºC in Almería (left) and Soria (right).

Windows are a key element in building energy demand. On the one hand, they significantly increase the solar gains of the building, but they are also an important source of heat loss. When windows were put into the building, heating and cooling demands were both observed to increase. The magnitude of these changes depended on the climate zone.

Finally, when internal charges were introduced into the building, the cooling demand increased and the heating demand decreased. Indeed, the internal charges acted as heat sources.

It may be noted that, in all studied cases, the buildings with ventilated façades displayed a lower cooling demand and a higher heating demand, though there were cases in which the heating demand was zero or practically zero and, in these situations, the ventilated façade entailed no increase in the heating demand. The differences observed became less important when windows were put in, because this reduced the façade area with the envelope.

4.3. Energy demand of the complete building

4.3.1. Studied variables

In this part of the study, complete buildings were simulated, jointly considering all the variables that influenced energy consumption (internal charges, temperature settings, and ventilation). A building's energy demand depends on the use to which it is put: a residential building and an office building will have different internal charges (occupation, equipment, and lights) and different temperature settings and furniture; they will therefore exhibit different thermal demands. In this study, buildings with two different typologies were simulated, based on the conditions proposed in LIDER: *residential* for residential use and *non-residential medium intensity 12 h* for tertiary use.

The internal charges corresponding to each type of use are set out in the document *'Acceptance Conditions of alternative procedures to LIDER and CALENER'* published by the Ministry of Housing and the IDAE (Institute for diversification and energy saving) [12]. For ventilation, 1 air renewal per hour was assumed in the case of tertiary use and 0.5 air renewals per hour for residential use. These values meet the air quality requirements of the *Spanish Technical Building Code* for an average dwelling [13] and of the *Regulation on Thermal Installations in Buildings (RITE)* for offices [14]. Furthermore, in residential use, the windows were open during the night in summer, which led to 4 air renewals per hour according to the LIDER specifications [12].

In addition, the effect of the absorptance, α, of the outer leaf was studied. One of the limitations of LIDER is that it assumes a constant value (α = 0.6), independently of whether the surface is light-coloured (low absorptance) or dark (high absorptance). In this study, three absorptance values were used, corresponding to a black façade (α = 0.9), a grey façade (α = 0.6), and a white façade (α = 0.3).

4.3.2. Effect of internal gains

The energy demands for different internal charges in a black-coloured building in different climate zones are shown in Figure 8.

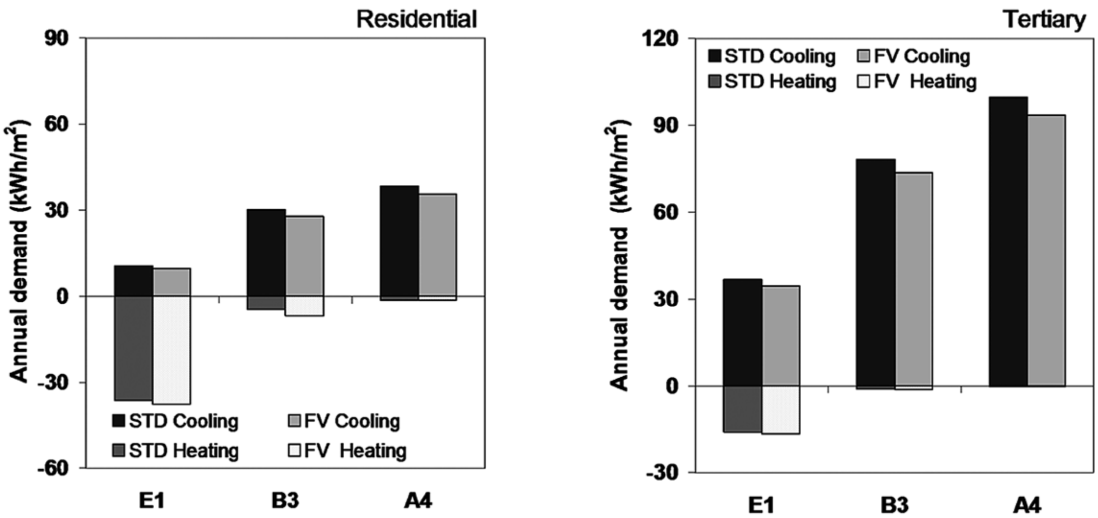

Figure 8. Energy demand for residential use (left) and tertiary use (right) in a black building.

The type of building was observed to influence its energy consumption. Buildings for tertiary use need less heating and more cooling than apartment buildings, owing to higher internal charges and different operating times of the thermal conditioning systems [12].

The ventilated façade allowed the cooling demand to be reduced in every case, this being more effective in warm zones and with higher internal charges. However, its use entailed increased heating demand, thus making it inadvisable to install this in colder climate zones.

4.3.3. Effect of absorptance of the outer leaf

The energy consumption of a residential building located in Castellón (B3 climate zone), for different absorptance values of the outer leaf, is shown in Figure 9.

As the outer leaf became darker (greater absorptance), cooling consumption increased. This effect was more pronounced in buildings with a tiled façade than with a ventilated façade, because more heat was dissipated by the black-coloured ventilated façade, thus offsetting the greater solar gain. Therefore, the reduction in the cooling demand due to the ventilated façade was greater in the dark building envelopes, while it had less influence on the cooling demand in the light-coloured building envelopes.

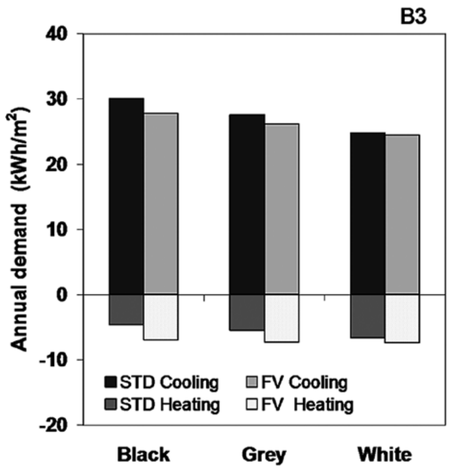

Figure 9. Energy demand as a function of façade colour in a residential building in Castellón

On the other hand, it was confirmed that the use of a ventilated façade instead of a conventional building envelope slightly raised the heating demand. This increase was more significant in the darkest building façade.

4.4. Energy performance of the ventilated façade

Energy demand is influenced by many factors, as noted above, one of these being cavity ventilation. Generally speaking, ventilated façades reduce the cooling demand, though they can slightly increase the heating demand. The reduction in cooling demand could be obtained by acting on the ventilation; however, on the level of a building envelope, the conceptually simplest parameter to use is possibly insulation thickness. An increase in insulation thickness will usually reduce both the cooling and the heating demand.

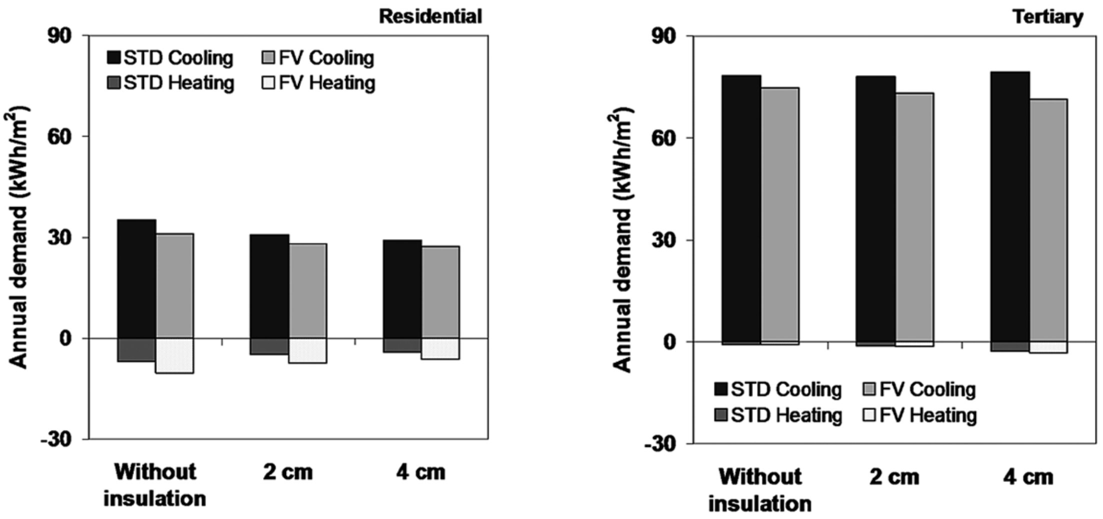

Figure 10. Residential (left) and tertiary (right) energy demand in a black building in Castellón.

The effect of insulation thickness (three levels: no insulation, and 2 cm and 4 cm thick insulation) and the effect of the ventilated façade for the B3 climate zone are shown in Figure 10. For comparative purposes, Table 3 details the increases in heating and cooling energy demands that occurred when different insulation thicknesses or a ventilated cavity were added to a building envelope without any insulation.

		Residential use		Tertiary use	
		ΔC_{cal} (kWh/m²)	ΔC_{ref} (kWh/m²)	ΔC_{cal} (kWh/m²)	ΔC_{ref} (kWh/m²)
E1	2 cm insulation	-6.3	-1.6	-7.8	+2.0
	4 cm insulation	-9.1	-2.2	-5.4	+1.3
	Ventilated cavity	+3.5	-2.1	+2.2	-3.8
B3	2 cm insulation	-1.9	-4.5	-3.5	-1.0
	4 cm insulation	-2.6	-6.0	-1.5	-1.2
	Ventilated cavity	+3.5	-4.2	+0.5	-8.0
A4	2 cm insulation	-3.6	-6.0	-0.6	-3.9
	4 cm insulation	-1.1	-8.0	-0.5	-3.6
	Ventilated cavity	+0.4	-4.9	+0.1	-10.7

Table 3. Increases in heating and cooling demands on incorporating 2 or 4 cm insulation or a ventilated façade into a building without insulation.

In zone E1, the presence of a ventilated cavity was observed to lead to the same reduction in the cooling demand as 4 cm insulation in the residential building, while in the tertiary building, the role of the insulation was very small, though in this climate zone the heating demand was more significant than the cooling demand.

The analysis in mild and warm zones, in which cooling demands are the fundamental demands, was of greater significance. In zone B3, the reduction in cooling demand in the residential building on incorporating the ventilated façade was practically the same as that of adding 2 cm insulation. In the tertiary building, the effect was even more pronounced owing to the high internal charges, while the effect of the ventilated cavity far exceeded that of the insulation. When the insulation thickness increased, the heat that entered through the building envelope decreased while less heat was simultaneously dissipated through the wall, leading to very small variations in the cooling demand; in contrast, cooling energy consumption decreased significantly when a ventilated cavity was incorporated.

5. CONCLUSIONS

At building envelope level, the calculations made in this study indicate that the ventilated façade allows the cooling energy demand to be reduced compared with that of a conventional building envelope, particularly in the case of a southern, eastern, or western orientation in Spain. In contrast, the use of a ventilated cavity entailed a slight increase in the energy needed for heating.

In a real building, the internal charges (occupation, equipment, and light), and the temperature settings and ventilation significantly influence the energy demand. All these factors need to be considered together with the type of building envelope (conventional or ventilated façade) involved.

When the absorptance of the outer leaf (darker wall) increased, cooling energy consumption rose and the heating demand decreased. The capacity of a ventilated façade to reduce the cooling demand in relation to that of a conventional building envelope was greater when the outer leaf was dark.

The ventilated façade was particularly appropriate in warm zones and in buildings with a high cooling demand, since in these cases it allowed the overall energy demand of the building to be reduced.

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