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Evaluación de la eficiencia energética de edificios con DSF-PCM: un estudio de caso en Valencia, España

DSF-PCM building energy performance assessment: a case study in Valencia, Spain

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Resumen— Las fachadas de doble piel (DSF) y los materiales de cambio de fase (PCM) son formas prometedoras de reducir la demanda energética de los edificios. En este trabajo se han estudiado los efectos del tipo de acristalamiento teniendo en cuenta la orientación del edificio sobre su rendimiento energético. Se ha seleccionado como caso de estudio un edificio de oficinas de cuatro plantas en Valencia, España, y se ha simulado utilizando el software EnergyPlus. Los materiales de la envolvente del edificio para el caso base de estudio se seleccionaron teniendo en cuenta el nuevo código español CTE-DB-HE 2019, que clasifica a Valencia en la zona climática B3. La carga de calefacción fue mínima cuando el DSF estaba orientado al sur, mientras que la carga de refrigeración mínima se produjo cuando el DSF estaba orientado al norte. El consumo anual de energía alcanzó su valor más bajo cuando el DSF estaba orientado al norte. El PCM se aplicó a diferentes capas de la pared, encontrándose que el PCM situado en la capa más interior tenía un mejor comportamiento que en el resto de las capas.

Palabras clave— fachada de doble piel; material de cambio de fase; evaluación de la eficiencia energética de los edificios; optimización de la eficiencia energética de los edificios; ahorro de energía en los edificios..

Abstract— Double skin facades (DSFs) and phase change materials (PCMs) are promising ways to reduce the energy demand of buildings. In this work, the effects of glazing type considering the orientation of the building on its energy performance have been studied. A four-story office building in Valencia, Spain, has been selected as the case study and has been simulated using EnergyPlus software. The materials for the building envelope for the base case study were selected considering the new Spanish code CTE-DB-HE 2019, which classifies Valencia in the B3 climate zone. The heating load was minimum when the DSF was facing south, while the minimum cooling load occurred when the DSF was facing north. Annual energy consumption reached its lowest value when the DSF was facing north. PCM was applied to different wall layers, finding that PCM located in the most inner layer performed better than in the other layers.

Index Terms— double skin facade; phase change material; building energy performance assessment; building energy efficiency optimization; building energy savings.

I. INTRODUCTION

Nowadays, global warming, the energy crisis, air pollution and climate change are possible the most critical world problems (Preet et al., 2020), with buildings being responsible for approximately 40% of global energy consumption (Kim et

al., 2018). Accordingly, reducing energy demand in this sector is of great importance. One of the most popular solutions are Double Skin Façades (DSF), which contain two layers of glass with a cavity between them. The performance of DSFs is highly affected by climate conditions and design parameters, such as

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glazing type and cavity depth (Ziasistani et al., 2019), so their benefits can disappear if the design is not adequate (Jankovic et al., 2021). DSF performance may be increased if combined with Phase Change Materials (PCMs). PCMs can reduce the energy demand of buildings by releasing or storing heat during a solid-liquid phase transition.

Several studies in the literature have focused on DSF, as well as on PCM integration in buildings. For instance, the energy and daylighting performance of a DSF integrated into an office building in South Korea (Kim et al., 2018) was studied using EnergyPlus, finding a decrease in heating, cooling, and total loads of 40%, 2%, and 5% respectively. Three different proposals for an official building with a simple façade, a DSF and a DSF with PCM were investigated in the cities of Jeddah, Tabuk, and Abha in Saudi Arabia (Alqaed et al., 2022). The application of DSF decreased heating demand by 18% in comparison to a normal façade, whereas, in combination with PCM, the demand was reduced by 25%. With few studies considering PCM and DSF together, not so much attention has been paid to the effects of the glazing type and the building orientation on the energy performance of buildings with this envelope.

In this work, the effects of the glazing type and building orientation on the building energy performance have been studied. An office building in Valencia (Spain) has been selected as the base model for the study, evaluating the effect of the glazing type, the building orientation and the PCM configuration on the energy performance.

II. METHODOLOGY

A. Base case study: four-story office building

To study the effect of the PCM and DSF configuration on the building energy performance, a four-story office building in Valencia (Spain) has been analyzed, using the EnergyPlus (Energyplus, 2023) engine to simulate the behavior of the building. As shown in the building floor plan in Figure 1, the surface of each floor is 305 m², comprising a conference room, a toilet, a kitchen and 10 office rooms.

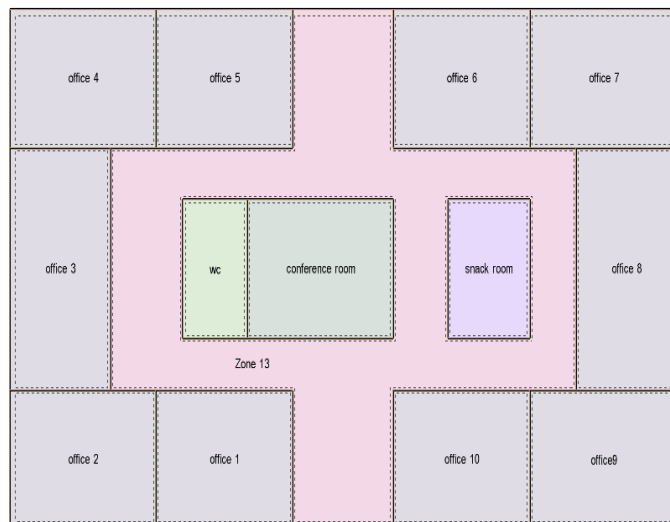


Fig. 1: Plan of the building floors

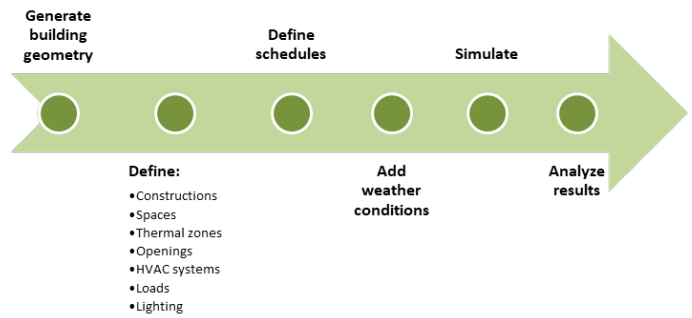


Fig. 2: Methodology followed in this study for building simulation

The 3D model of the building, built from the floor plans, is shown in Fig. 3. The properties of the building components and global thermal transmittances (U-values) are collected in Table 1. These values have been selected with respect to the new Spanish Building Technical Code CTE-DB-HE 2019 (Soto Francés et al., 2020). According to this standard, the heating system in winter works from November to March, whereas, in summer, the cooling system works from April to October. Setpoint temperatures for summer and winter are 26°C and 21°C, respectively. The occupancy schedule is from 9 am to 17 pm, as it is an office building. On Saturdays and Sundays, the building is closed. The HVAC system includes a fan coil unit (4-pipe), which helps to circulate the cooled or heated air throughout the space by two separate water loops and air ducts for supply and return air. The system is connected to a central chiller and boiler plant, which supplies chilled and hot water to the fan coil units through a district network. Gas is used to supply the heating demand, whereas electricity is used to provide cooling needs.

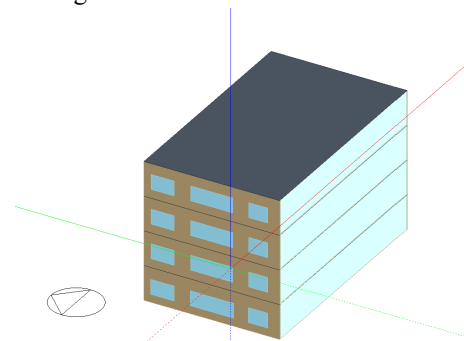


Fig. 3: 3D model of the building.

TABLE I
CONSTRUCTION MATERIAL USED IN THE BUILDING

Component	Layers	U[W/(m ² ·K)]	Thickness(m)
External walls	Brickwork Outer	1.698	0.115
	Standard insulation		0.0065
	Brick		0.05
	Gypsum Plastering		0.02
Floor	Concrete	3.71	0.03
	Mortar		0.0318
	Granite		0.03
Roof	Roof Tile	1.599	0.02
	Mortar		0.01
	Roofing Felt		0.005
	Concrete Roofing		0.0678
	Slab		

Weather conditions have been introduced in the model considering the climate zone of Valencia (Spain), where the building is located, according to the Spanish Technical Code (Soto Francés et al., 2020). Table 2 gathers the main details about the city regarding the inputs of the model.

TABLE II
PROPERTIES OF THE NITINOL MATERIAL

Location	Valencia – Spain
Elevation	62 m
Standard Pressure at Elevation	100.582 kPa
Climate zone according to CTE	B3

After introducing the required data into the model of the base case, the EnergyPlus engine was run, and the simulation results were analyzed. Each simulation takes a few minutes, so computational times are not an important issue. An annual heating load of 22.56 MWh, a cooling load of 36.39 MWh, an electricity consumption of 96.80 MWh, and a natural gas consumption of 26.54 MWh were obtained, resulting in a total energy consumption of 147.65 MWh. Fig. 4 shows the annual distribution of the building energy consumption

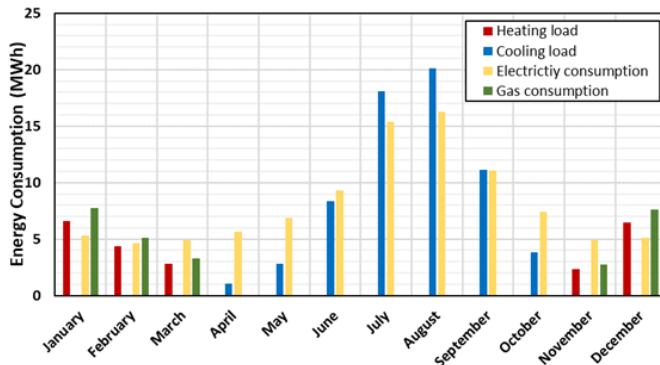


Fig. 4. Energy consumption for the base case study.

B. Integration of Double-Skin-Facades

After obtaining the results for the base case study, the integration of different DSF configurations was studied. As DSF performance is highly dependent on the building orientation and glazing type, three different glazing types were studied to observe their effect on the improvement of the building energy performance: Single Clear 3mm, Double Clear 3/13mm Air and Triple Clear 3/13mm Air. Each glazing type is represented by single, double, or triple depending on the number of glass layers, with the first number (3) representing the glass thickness and the second number (13) representing the depth of the cavity between the glass layers. The building was rotated in 10° increments, to evaluate the effect of building orientation. Heating and cooling loads, as well as electricity and natural gas demand, were analysed.

C. Integration of Double-Skin-Facades with Phase Change Materials

Finally, the effect of integrating PCMs into the building exterior walls for the best glazing and building orientation was studied. The selected PCM, suitable for the temperature range in Valencia, is M182/Q21, where M is the thermal energy

storage capacity in BTU/ft², and Q is the melting temperature of the material in °C. The PCM was integrated into the building with the DSF that showed the best performance among the previously studied. As the external wall is composed of four layers, the effect of the placement position of the PCM was analyzed by performing simulations with the PCM located in the five different positions shown in Fig. 5. The Conduction Finite Difference (CondFD) algorithm has been used to simulate the heat transfer processes of the PCM, dividing the building envelope into nodes and solving the heat transfer equation numerically (Markarian et al., 2019).

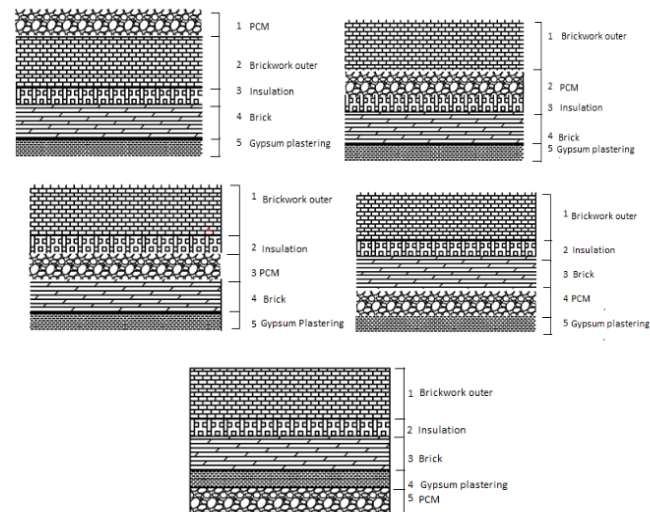


Fig. 5: Placement positions of PCM in the external building walls.

III. RESULTS AND DISCUSSION

This section presents and discusses the results from the analysis of the integration of DSF and DSF with PCM into the building envelope

A. Influence of DSF glazing type

As previously commented, three different glazing types at the inner and outer layers of the DSF were applied and their effects on heating, cooling, electricity, and gas demand were analysed.

Fig. 6 shows the evolution of the cooling demand throughout the year. Although the cooling period spans from March to October, the maximum cooling demand happens between July and September. The lowest cooling demand is achieved with the thickest glazing type, Triple Clear 3/13mm Air, with the effect of the trapped air cavities increasing the building thermal resistance.

The evolution of the monthly heating demand is shown in Fig. 7. Heat is only required from November to March. In this case, the thinnest glazing type, Single Clear 3mm, results in the lowest heating demand values, probably because of the higher solar gain across the glazing.

Regarding electricity consumption, Fig. 8 shows that the thickest glazing type, Triple Clear 3/13mm Air, results in the lowest values in the period from April to October, where electricity demand is the highest. From November to March, on the other hand, the glazing type does not affect substantially the electricity demand of the building.

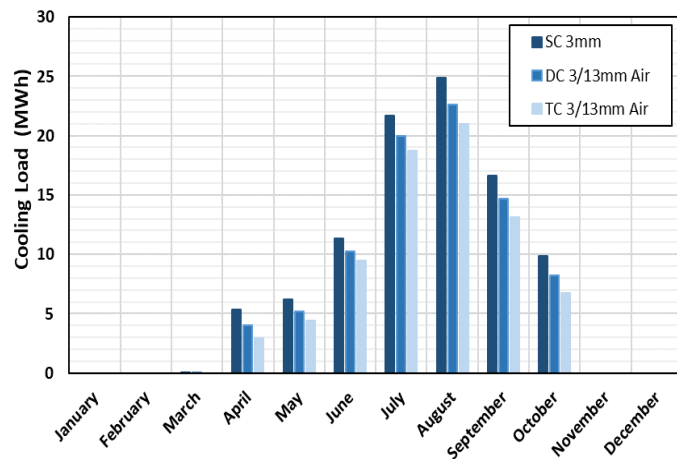


Fig. 6: Monthly cooling load of the building.

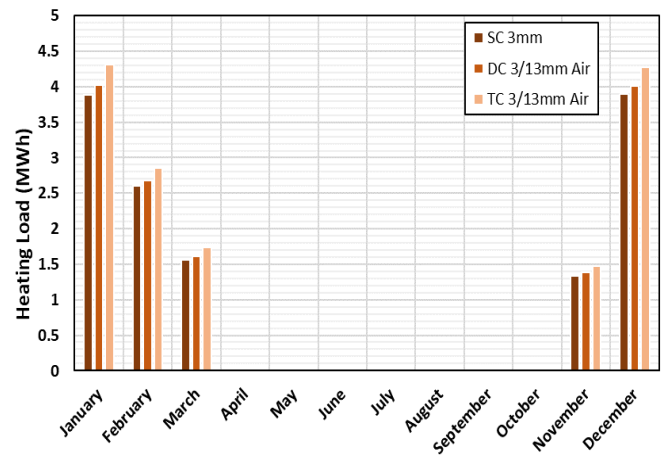


Fig. 7: Monthly heating load of the building.

Finally, Fig. 9 shows the evolution of gas consumption throughout the year, which increases with the increase in the glazing thickness. Gas is only required between November and March, the coldest months of the year. The lowest values were achieved with Single Clear 3mm, the thinnest glazing type.

The total energy consumption values for a whole year were obtained and are collected in Table 3. The minimum annual heating load, 13.28 MWh, and gas consumption, 15.62 MWh, were achieved with the thinnest glazing, Single Clear 3mm. On the other hand, minimum values for the cooling load, 76.38 MWh, and electricity consumption, 99.85 MWh, were obtained with the thickest glazing, Triple Clear 3/13 mm Air. The total energy demand values are 165.78, 155.31 and 147.62 MWh for the Single Clear 3mm, Double Clear 3/13mm Air and Triple Clear 3/13mm Air glazing types, respectively. Considering that the highest energy consumption values of the building are related to the cooling and electricity demand, the Triple Clear 3/13mm Air seems the best option in terms of the global energy performance of the building. Considering the initial energy demand of the base case, this option would reduce energy consumption in 1.5%.

B. Influence of building orientation

The results from the influence of the building orientation on building energy consumption for the three glazing types are shown in Fig. 10, 11 and 12. It should be noted that, in the base case building, glazing faces south.

For all three glazing types, the lowest cooling and total energy demand values are achieved when the glazing faces north; on the other hand, the heating load is lowest when the glazing faces south. Regarding the total energy demand, east and west orientations are the worst, mainly because of the higher cooling demand values for those orientations. Considering the glazing type, Single Clear 3mm can minimize cooling, heating and total energy demands to 77, 8.9 and 119.5 MWh when placed towards the north. Double Clear 3/13 mm Air achieves minimum values of 73.7, 9.1 and 116.9 MWh for the cooling, heating, and total energy demand. Finally, with Triple Clear 3/13 mm Air, minimum values are obtained for electricity and cooling demands when faced towards the north, leading to the lowest possible total energy demand, 115 MWh. This is a reduction of 22% with respect to the original base case.

TABLE III
ANNUAL ENERGY DEMAND FOR DIFFERENT GLAZING TYPES.

Glazing type	Heating [MWh]	Cooling [MWh]	Electricity [MWh]	Gas [MWh]	Total demand [MWh]
Single Clear 3mm	13.27	95.91	110.70	15.62	165.7
Double Clear 3/13mm Air	13.72	85	104.64	16.14	155.3
Triple Clear 3/13mm Air	14.6	76.4	99.85	17.23	147.6

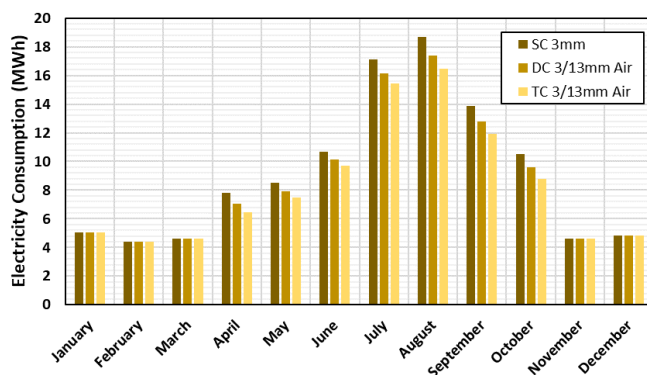


Fig. 8: Monthly electricity consumption of the building

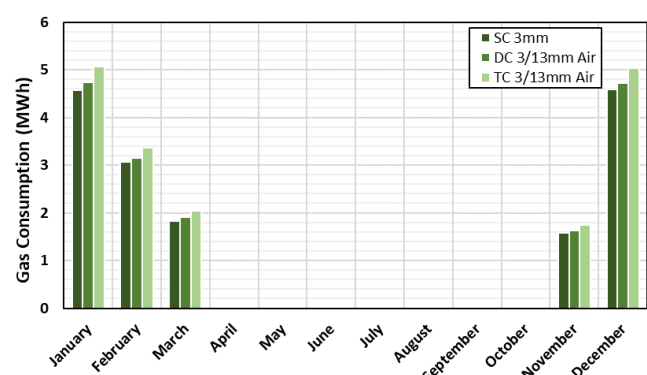


Fig. 9: Monthly gas consumption of the building.

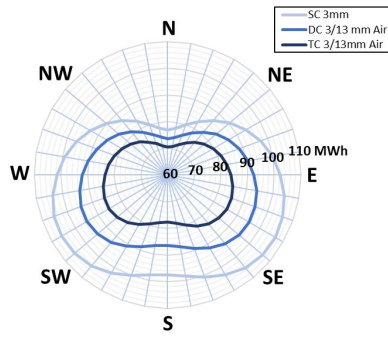


Fig. 10: Effect of building orientation on the cooling demand

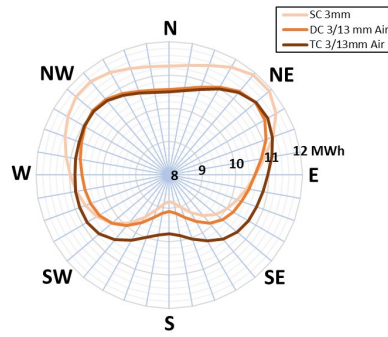


Fig. 11: Effect of building orientation on heating demand.

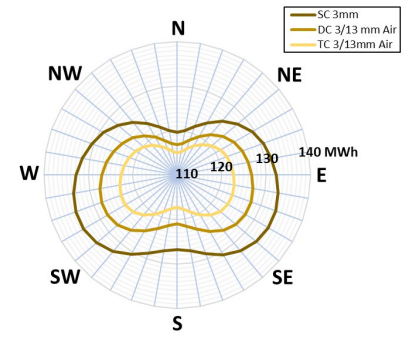


Fig. 12: Effect of building orientation on total energy demand.

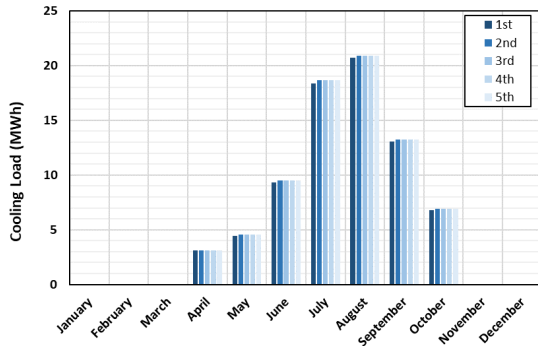


Fig. 13: Effect of PCM layer position on cooling load.

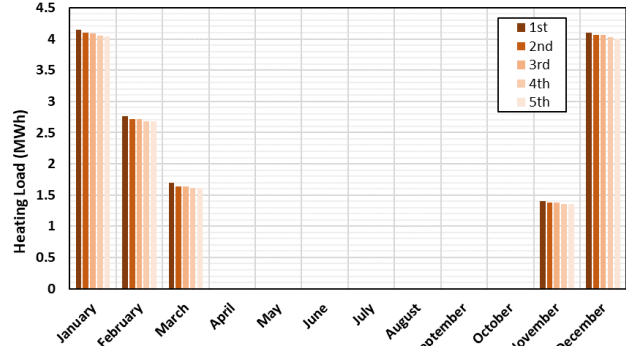


Fig. 14: Effect of PCM layer position on heating load.

Following these results, it seems sensible to place future buildings with DSF facing towards the north in Valencia, to minimize the cooling demand, the highest contributor to the total energy demand of the building.

C. Integration of PCM into the DSF

After introducing PCM into the building exterior walls at five different positions, the annual cooling, heating, electricity, and gas energy demand values were calculated and have been plotted in Fig. 13-16.

It may be appreciated that placing the PCM in the first position (outer layer of the exterior wall) results in lower cooling load and electricity demand values than for the rest of positions. Among the 2nd and 5th positions, almost no difference is observed. The effect of integrating PCM into the DSF becomes more apparent regarding heating and gas energy demand values (Fig. 14 and 16), where it may be observed that energy demand drops as the PCM is placed towards the 5th (inner layer of the exterior wall) position.

The annual energy performances of the different external wall configurations is summarized in Table 4. Regarding total energy consumption, it may be observed that the best placement positions for PCM are either the first or the fifth layer of the exterior walls, as in intermediate positions, the beneficial reduction effects in heating and cooling demands become dampened. When PCM is directly exposed to outdoor air, it preforms better.

Results collected from all the analysed configurations, shows that the option with the highest energy performance for an office building like the one studied in this work is to add a DSF facing to the north, with Triple Clear 3/13 mm Air glazing and PCM integrated in the other walls in the outer layer. This results in savings of 37.5% in heating demand and gas consumption, and a total energy consumption saving of 1.5 with respect to the base case.

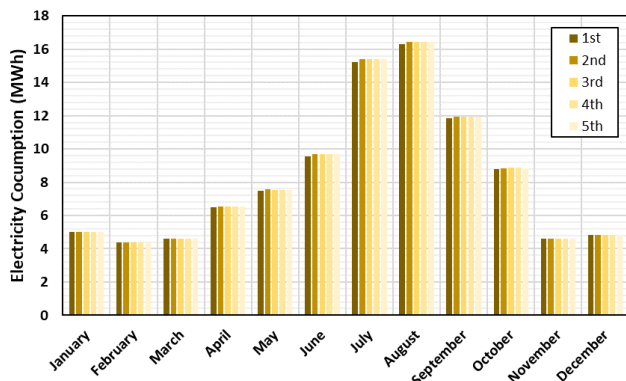


Fig. 15: Effect of PCM layer position on electricity consumption.

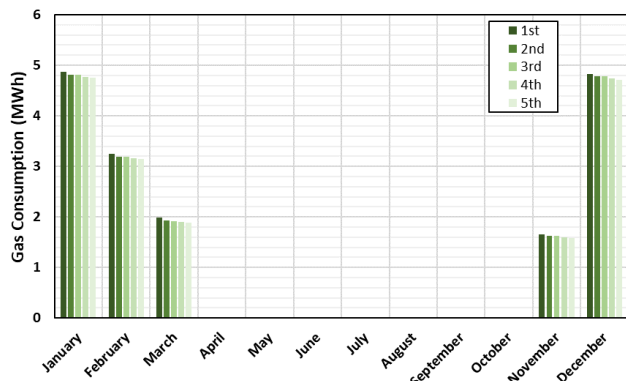


Fig. 16: Effect of PCM layer position on gas consumption.

TABLE IV
ANNUAL ENERGY DEMAND FOR DIFFERENT PCM CONFIGURATIONS

PCM Place	Cooling [MWh]	Heating [MWh]	Electricity [MWh]	Gas [MWh]	Total energy [MWh]
1 st layer	75.795	14.104	99.117	16.593	146.079
2 nd layer	76.969	13.897	99.769	16.349	147.046
3 rd layer	76.968	13.878	99.768	16.327	147.026
4 th layer	76.967	13.742	99.767	16.168	146.889
5 th layer	76.928	13.684	99.746	16.099	146.792

IV. CONCLUSIONS

The effects of placing a Double-Skin-Façade (DSF) with different glazing types and changing the building orientation on the energy performance of an office building located in Valencia (Spain) have been studied. The integration of a Phase Change Material (PCM) in the exterior walls of the building has been analyzed as well. Considering the base case with no actuations on the building envelope, it was observed that the highest energy demand corresponds to cooling demand and electricity consumption.

Regarding the glazing type employed, it was found that the thinnest glazing resulted in higher energy savings in heating and gas demands, whereas the thickest one, Triple Clear 3/13 mm Air, resulted in higher energy savings in cooling and electricity demands, as well as lower total energy consumption values.

The orientation of the building had an important role in the energy performance of the building, with minimum cooling demand values when the DSF was facing north and minimum heating demand values when it was facing south. In overall, it was found that facing the DSF towards the north resulted in the minimum total energy consumption. Maximum energy consumption values were found when the DSF was faced towards the east or west.

The integration of PCM in the external walls served to reduce the energy demand, finding that it should be either placed in the innermost layer of the walls to reduce heating demand, or in the outermost layer of the walls to reduce cooling demand. Placing it in the outermost layer minimized total energy consumption. In general, it may be concluded that the best course of action to improve the energy performance of an office building in Valencia (Spain) is to introduce a DSF facing north, as well as to integrate PCM in the outermost layer of the building exterior walls. These actions lead to a reduction of 1.5% in the total building energy consumption.

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