COMPARATIVE STUDY OF THE OPTICAL PROPERTIES EFFECT OF THE FACADE EXTERIOR COATING ON THE BUILDING ENERGY DEMAND

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ABSTRACT:
With the aim of improving the building energy efficiency, different technologies have been developed that optimize the use of solar energy in building envelope and avoid warming of urban areas. Chromogenic devices based on materials whose optical properties can be reversibly modified by an external stimulus have become relevant among these technologies.
The façade coating can have different types of texture or color that determine specific optical properties, including absorptance, which defines the amount of solar radiation absorbed by the material with respect to the incident radiation.
In the present work , the influence of the optical properties of two types of exterior façade coatings on the building energy demand is analysed: a belitic cement synthesized in the laboratory through a low energy and low CO2 emissions process and a brick representative of a typical building masonry, presenting the former a more polished surface and lighter color than the latter.
This study has focused on determining the parameters that optimize the use of the optical properties of the studied coatings in the building energy efficiency. The results show that the N-S orientation and the uninsulated wall suppose greater impacts on the energy demand by the coating change. In turn, the effect of coating change is remarkable in the climates studied, but it is in the temperate A3 climate where lower demands are achieved, approaching those established for passive buildings.
These parameters will be used for future studies with a new thermochromic mortar coating developed from belitic cement, analyzing its influence on the building energy demand.

Keywords: ***→ Energy efficiency, facade coating, optical properties, buildings, solar absorptance***

RESUMEN:
Con el objetivo de mejorar la eficiencia energética de la edificación se han desarrollado tecnologías que optimizan el aprovechamiento de la energía solar en los sistemas constructivos evitando a su vez calentamiento de las zonas urbanas. Entre estas tecnologías han cobrado relevancia los dispositivos cromogénicos basados en materiales cuyas propiedades ópticas pueden modificarse de manera reversible mediante algún estímulo externo.
El revestimiento en fachada puede presentar diferentes tipos de textura o color, que determinan unas propiedades ópticas específicas, entre ellas la absortancia, que determina la cantidad de radiación solar absorbida por el material respecto a la radiación incidente.
En el trabajo que se presenta se analiza la influencia de las propiedades ópticas de dos tipos de revestimiento exterior en fachada sobre la demanda energética del edificio un cemento belítico sintetizado en laboratorio mediante un proceso de baja energía y bajas emisiones de CO2 y un ladrillo representativo de una fábrica caravista, presentando el primero un acabado más pulido y color más claro que el segundo.
Este estudio se ha centrado en determinar los parámetros que optimizan el aprovechamiento de las propiedades ópticas de los revestimientos estudiados en la eficiencia energética del edificio. Los resultados obtenidos muestran que la orientación N-S y el muro sin aislamiento suponen mayores impactos en la demanda energética por el cambio de revestimiento. A su vez, el efecto del cambio de revestimiento es notable en los climas estudiados, pero es en el clima templado A3 donde se llega a alcanzar demandas más bajas, acercándose a las establecidas para los edificios pasivos.
Estos parámetros servirán para próximos estudios con un nuevo revestimiento de mortero termocrómico desarrollado a partir de cemento belítico, analizando su influencia sobre la demanda energética del edificio.

Palabras clave: eficiencia energética, revestimiento fachada, propiedades ópticas, edificios, absortancia solar

1.- INTRODUCTION

The effect of global warming is leading to more extreme weather conditions, with a gradual desertification of warmer areas. The appreciable increase in temperatures reached in recent years requires bioclimatic strategies in buildings capable of adapting to these increasingly severe external conditions [1].

Moreover, the effect of global warming joins the urban heat island effect, which translates into an increase in the temperature of the urban environment in large cities, compared to rural or more open surrounding environments. This effect is enhanced by the materials used in the construction of both, buildings and urban elements. [2]

The Spanish climate is very varied, and unlike many European countries where their main interest is to protect themselves from a cold outside environment, in Spain there is a combination of cold winters with hot summers and even areas where warm weather predominates with a shorter winter season [3] [4]. The periodic revisions and updates of the Spanish building regulations in their energy efficiency requirements contribute to make the buildings increasingly airtight, inheriting models of cold climates, when the Mediterranean climate lends itself to the use of outdoor conditions to favour bioclimatic performance of the building. The exterior building coating materials can have a significant contribution to this effect. In this sense, it is important to know their optical response to solar radiation, in order to quantify their performance and optimize their effects through the study and possible development of new construction materials. [5]

According to Directive 2012/27 / EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency [6], buildings represent 40% of the final energy consumption of the Union and consequently their Article 4 requires Member States to design a long-term strategy, which reaches beyond 2020.

The long-term strategy for energy refurbishment in the Spanish building sector [7] analyses the existing building range and defines the strategic scenarios to which apply refurbishment measures for the reduction of energy consumption in buildings. Among these measures actions are framed to improve the energy performance of the façade wall as part of the envelope of the building delimiting from the outside. [8]

The improvement of building energy efficiency includes, among other technologies, those that optimize the use of solar energy in the building elements and reduce the warming of urban areas. This use depends directly on the optical properties of the exterior surface of the facade, which include not only its colour, but also its reflectance and absorbance over the entire wavelength range of solar radiation. [9] [10]

Among the optical building technologies, chromogenic devices based on materials whose optical properties can be reversibly modified by some external stimulus have recently become relevant.

In the case of opaque materials, which do not transmit solar radiation, the property of interest is the absorptivity, which determines the amount of solar radiation absorbed by the material with respect to the incident radiation. The absorptivity of the outer coating material varies with its composition, colour and texture, and determines the exterior surface temperature of the wall. The study presented aims to move towards the proposal of a new material capable of adapting its optical properties to the conditions of the external environment, a thermochromic mortar for facade coating. This material should have a clear colour, with low solar absorption when the climate is warm, to mitigate wall surface warming, and should have a darker colour, with high solar absorption when the weather is cold to favour a higher surface temperature. In this context, we present the analysis of the façade performance as a function of the optical properties of two types of exterior coatings that represent the two states of the thermochromic mortar. On the one hand, to represent the material at high temperatures a belitic cement synthesized in the laboratory is considered, which has a clear colour and is a more innovative and eco-efficient alternative to the current cements of the market. On the other hand, to represent the material at low temperatures a brick-masonry exterior surface is considered.

In addition to the optical properties of the exterior coating material, there are other parameters that influence the building energy demand, such as the climatic zone, orientation and insulating capacity of the wall.

The main objective of this study is to determine the values of these parameters that provide a greater effect of the optical properties of the facade coatings in the energy efficiency of a building model (new or existing) and quantify its effect. The conditions for which a greater effect is observed, will be those that provide a greater potential for the use of the variable optical properties of a thermochromic mortar.

2.- METHODOLOGY AND CASE STUDIES

2.1.- FACADE COATINGS CONSIDERED

Two different materials have been considered as facade coatings: belitic cement and brick.

Belitic cement is an eco-efficient cement synthesized in the laboratory by hydrothermal treatment and calcination at low temperature, using as raw material a fly ash from a thermal power plant and commercial calcium oxide. This cement has as its main component the Belite or dicalcium silicate, instead of the tricalcium silicate predominant in conventional Portland cement [11].

The brick represents a typical building masonry. A brick without surface treatment has been used to avoid the possible influence of its optical properties on the energy performance results.
Belitic cement paste samples have been prepared with a polished finish similar to the brick coating (see Fig.1).

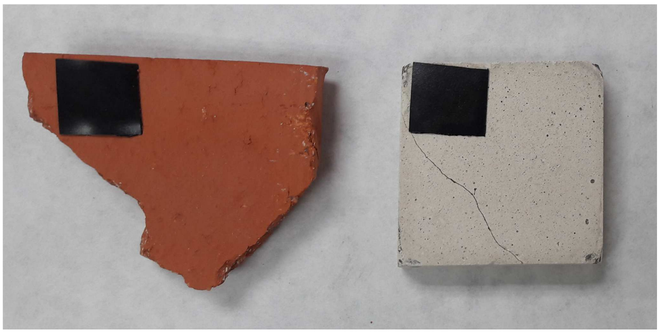

Fig.1. Samples of façade coating materials: brick (left) and belitic cement (right)

The samples of coating materials have been characterized to determine the optical properties of interest for their study in façade coatings. These properties, defined in Design Builder simulation tool, are, for opaque materials, visible absorptance, solar absorptance and thermal absorptance (emissivity) [12]. Visible and solar absorptances of the samples were determined from the reflectance spectra obtained with a double-beam dispersive spectrophotometer, as described in standard UNE-EN 410: 1998 [13]. The emissivity values have been taken from the Design Builder database.
The experimental optical properties of the materials considered to represent both types of facade exterior coating are shown in Table 1:

	Absorptance		
	Thermal	**Solar**	**Visible**
Brick	0,9	0,52	0,69
Belitic Cement	0,9	0,35	0,37

Table I. Materials optical properties

2.2.- BUILDING MODEL

In order to carry out this study, a single-family semi-detached house has been chosen as a building model, which is considered a common Spanish building type[14] [15].
The house has two floors, with a total living area of 82 m^2. It has an envelope area of 211 m^2 with a 15% window percentage area in the facade, enclosing a living volume of 222 m^3. The resulting compactness of the building is 1.05 m, as the result of dividing the living volume by the envelope area.

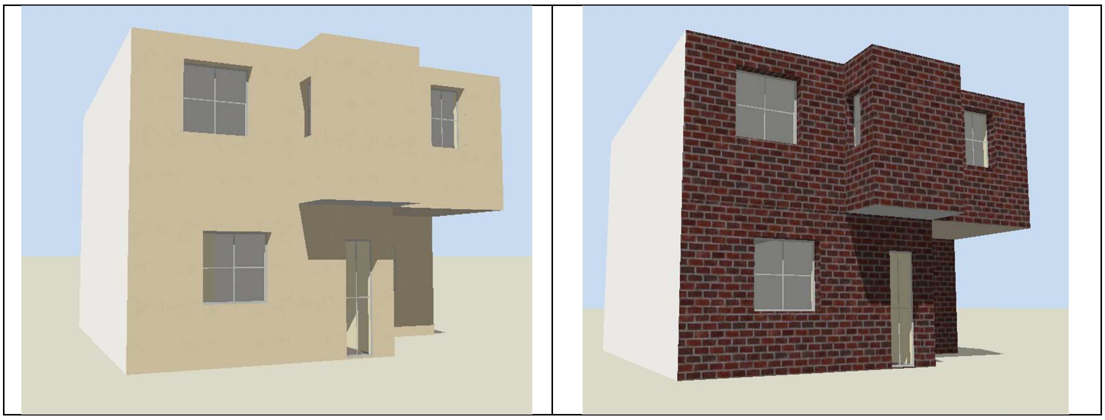

Fig. 2. Building model with two types of coatings: Belitic cement and brick masonry

As a façade type, a double-masonry wall was used with a non-ventilated intermediate air chamber in the uninsulated cases. In the insulated façade study cases, the thermal transmitances of the envelope are the guide values included in Spanish standards at Appendix E of DB HE1 of the CTE [16].

The analysis of the energy demand of the study case is based on simulations using the Design Builder software tool (version 4.7.0) [17], which integrates the Energy Plus calculation engine. Design Builder is a specialized software in environmental and energy simulation of buildings that allows assessing the building energy consumption among other aspects [9].

The building usage profile used in the simulation was the one that incorporates the Design Builder tool in its database as "Residential Spaces", assigning the corresponding specific usage profile to each room.

2.3.- STUDY CASES

To satisfy the described objectives of the study, a series of cases have been proposed, varying the parameters of interest (climatic zone, wall insulation, orientation) with the facade coating types described above.

To analyse the influence of the façade optical properties, depending on the climate, the building has been studied in two of the climatic zones in which the Spanish climatology is classified for the fulfilment of building energy demand requirements according to appendix B of the Basic Document of Energy Saving of the CTE [16]. The chosen areas are D3 (climate of Madrid), and A3 (climate of Almeria). The climatic zone D3 represents a severe climate in winter due to its low temperatures, and severe summer due to its high temperatures. The climatic zone A3 represents the same summer climate severity as D3 combined with a mild winter climate. These two climatic zones with very different performance in winter are proposed, to see the impact of the façade's optical properties on the building energy demand.

In order to observe the influence of the façade optical properties on the building energy demand depending on the insulating capacity of the wall, two types of wall construction systems have been studied in the same building, one insulated and the other uninsulated. To observe this parameter, only the insulating layer has been removed from the wall. The rest of envelope elements remain the same, keeping the same thermal transmittance value in both cases (the guide values of Appendix E of DB HE1). Having evaluated two types of façade coatings for the different cases, the thermal transmittance value varies slightly for walls, depending on the coating in question.

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Table 2 shows the thermal properties of envelope elements for each case, being:
Um: Wall Thermal transmittance
Uc: Roof Thermal transmittance
Us: Ground Thermal transmittance
Uh: Window Thermal transmittance
gv: Window solar factor

	Um ($W/m^2·K$)	**Uc** ($W/m^2·K$)	**Us** ($W/m^2·K$)	**Uh** ($W/m^2·K$)	**gv** (-)
D3 - INSULATED	0,27	0,22	0,34	2,25	0,57
D3 – UNINSULATED	1,29-1,32	0,22	0,34	2,25	0,57
A3 - INSULATED	0,49	0,46	0,53	2,25	0,57
A3 – UNINSULATED	1,29-1,32	0,46	0,53	2,25	0,57

Table II. Thermal properties of envelope elements

On the other hand, the effect of the façade optical properties on the building energy demand may be more noticeable in some orientations than in others. To assess this effect, the building model has been simulated by orienting the facades to north-south and east-west.

3.- RESULTS

3.1.- ORIENTATION

The results for N-S oriented building are more favourable than the corresponding E-O oriented building for all cases studied. Both heating and cooling energy demand are lower in N-S orientation, with greater difference in cooling, as shown in Fig.3.

Also, the relative increase in heating demand due to the change in coating material is greater for N-S orientation, around 10%, than for E-O orientation, around 8%.

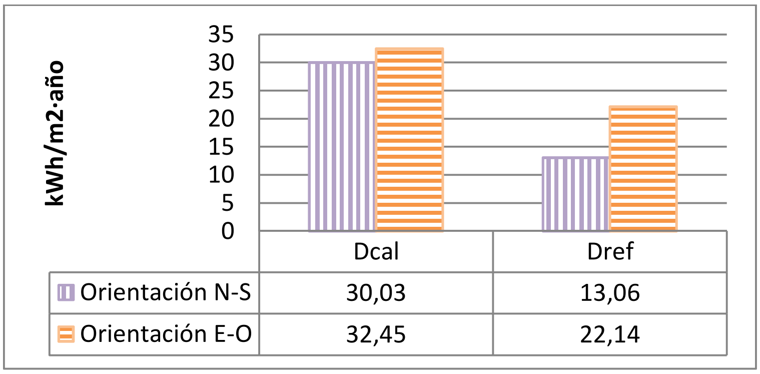

Fig. 3. Energy Demand ($kWh/m^2·year$)
D3 Climatic Zone. Uninsulated. Belitic Cement coating

3.2.- CLIMATIC ZONE

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In D3 climatic zone, heating demands are higher than in A3 climatic zone, which contributes to the fact that demand variation due to coating change is more noticeable in D3 climatic zone. As shown in Fig. 4, the effect of belitic cement coating on heating demand causes a more than 3 kWh/m^2·year increase with respect to heating demand of the same building with a brick masonry exterior coating. In the case of A3 climatic zone, heating demand is slightly modified with coating change a difference slightly lower than 1 kWh/m^2·year.

Regarding cooling demand, the difference in both climatic zones is similar in absolute values, around 2.14-2.55 kWh/m^2·year. In the case of A3 climatic zone, which only cooling demand stands out, the reduction achieved by moving from a brick coating to a belitic cement one approaches 15 kWh/m^2·year , which is the value established for Passive House buildings. This makes interesting to consider in these climates the possibility of optimizing the envelope energy performance in order to approach a "passive" building without the need for air conditioning systems.

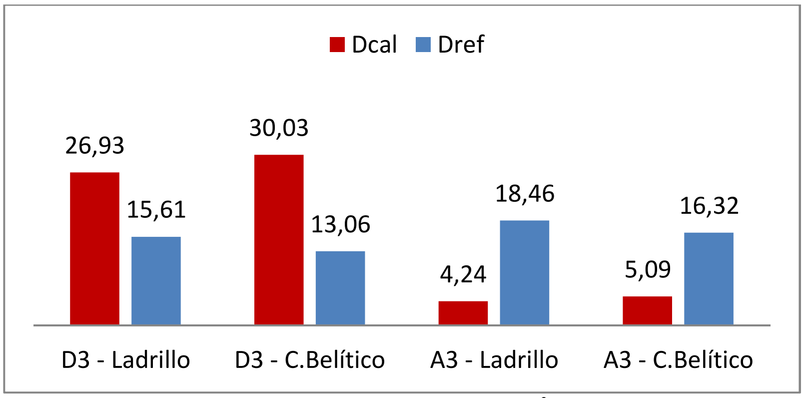

Fig. 4. Energy Demand (kWh/m^2·year)
N-S Orientation. Uninsulated

3.3.- INSULATING CAPACITY OF THE WALL

The demand results obtained for A3 climatic zone in N-S orientation, are described below. In cooling demand values represented in Fig. 5 it can be seen that when the wall is uninsulated, the difference is higher than 2 kWh/m^2·year. When the wall is insulated, this difference does not reach 1 kWh/m^2·year. This same trend can be observed, although to a lesser extent, for heating demand, with a difference between both types of coating around 0.20 kWh/m^2·year for an insulated wall and 0.85 kWh/m^2·year for an uninsulated wall.

Results show that the effect of changing façade coating on the building energy demand is more significant when the wall is uninsulated. This conclusion was expected, but it is interesting to have a quantification of this difference.
Regarding the building total energy demand, it is reduced in both cases when changing from brick to belitic cement coating, being this effect slightly greater in the uninsulated wall case.

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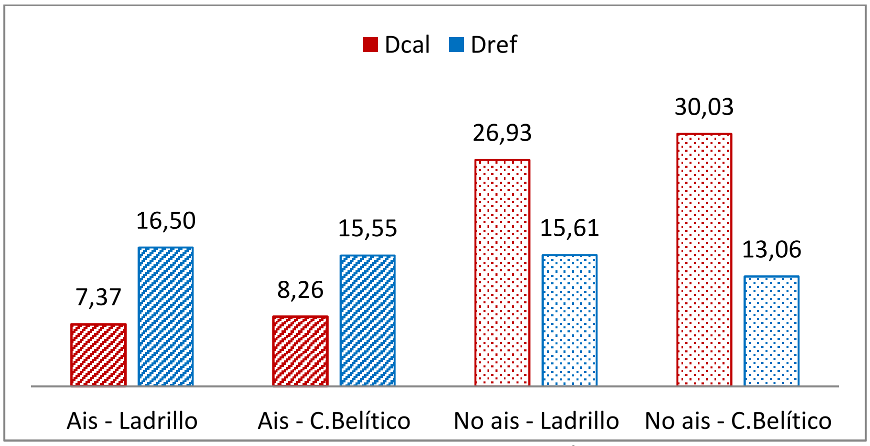

Fig. 5. Energy demand (kWh/m^2·year)
A3 Climatic Zone. N-S Orientation

3.4.- COATING MATERIAL EFFECT IN THE MOST FAVORABLE CONDITIONS

From the previous data the most favorable conditions can be deduced to optimize the building model performance analyzed with respect to the influence of the façade exterior coating on the energy demand. These conditions are: the north-south orientation, a climate zone characterized by a non severe winter, such as the A3 studied, and an uninsulated façade wall.

In Fig.6, which represents heating and cooling demands of the building model for the above conditions, it can be seen that the coating with better cooling demand performance is the belitic cement one, with a value close to 15 kWh/m^2·year. On the contrary, the heating demand performance is slightly better in the brick case.

Therefore, under these conditions, it would be especially advantageous to have a thermochromic material with the optical properties of belitic cement in warmer weather and brick properties in cold weather.

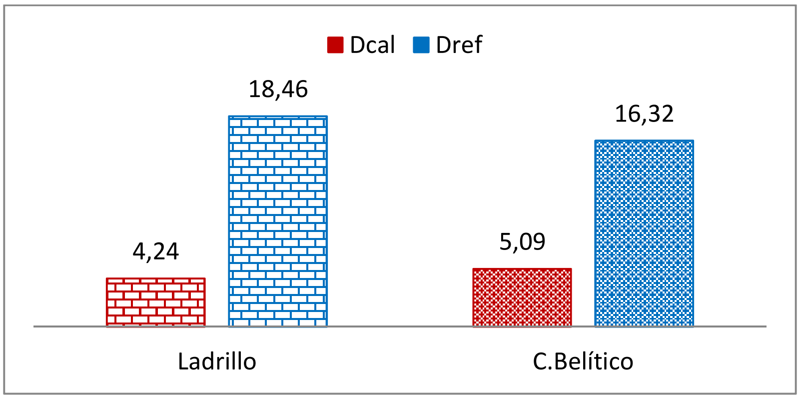

Fig. 6. Energy demand (kWh/m^2·year)
A3 Climatic Zone. N-S Orientation. Uninsulated

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4.- CONCLUSIONS

Based on the chosen building model, the reached results show that N-S orientation is more favourable than E-O orientation due to its lower demand values, for both heating and cooling. This aspect is independent of the type of façade coating, but it is a determining factor to be taken into account in order to design the building with optimum usage of the optical parameters of façade coating materials. In addition, the effect of changing the facade coating on the building heating demand is more noticeable in N-S orientation compared to E-O orientation.

Regarding the climatic zones studied, D3 (severe weather in winter and summer), and A3 (severe weather in winter but mild in summer), the results show the following conclusions. In D3 climatic zone, heating demand values are considerably higher than in the A3 and cooling demand values slightly lower than in A3. This is independent of the façade exterior coating, as the difference in cooling demand for the two coatings is similar in both climates, and more significant in D3 climatic zone for heating demand, since the climate is colder. Thus, the effect of coating change is remarkable in both climates, being the A3 climate where lower demands can be reached, approaching those established for passive buildings, with a value of 15 $kWh/m^2 \cdot year$.

Through the analysis of the building model with two types of façade walls, insulated and uninsulated, it is observed that the demand differences when changing the facade coating are more notable in the uninsulated wall case. This aspect was foreseeable, so the object of considering it in this analysis was to quantify the demand difference in the building model studied. As the results show, cooling demand reduction in A3 climatic zone when changing from brick to belitic cement coating is 11.6% in the uninsulated wall building model, and 5.2% when the wall is insulated.

The optical properties of the two coatings studied make each more suitable for a different part of the year. The brick is better for the cold months, when heating demand predominates, while belitic cement has a better performance in warm months, when the building demands cooling. It would be, therefore, interesting a thermochromic coating material, which encompasses the desired properties at each time of year, those of brick in winter (high absorptance) and those of the belitic cement in summer (low absorptance).

This material would adapt to the outside temperature, changing its colour so that its absorptance would vary, and with it, its response to the external solar radiation. This is intended to take advantage of solar radiation when needed for heating demand, and to reflect it when cooling demand is required.

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