Experimental study of the thermal and light performance of glazing with solar control films

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Abstract

The growing concern about climate changes and the consequent need to reduce greenhouse gases, leads to the control of the energy consumption, both associated to recent buildings and older buildings. In this context, glazed areas are an element of great interest in the building surroundings, not only because of the greater ease of the heat exchanges between the environments that they separate, but also because of the inherent ability to take advantage of natural light, and an essential element in the energy consumption and in the thermal and visual comfort systems. In order to improve the performance of the glazing systems, some solar control films have been developed, on which this work is based. In a first phase, a study was carried out regarding the implications of these films on the properties of glazing, with a significant improvement in the efficiency of the glazing system in some situations. An experimental campaign was then divided into two phases (winter and summer), which included the analysis of three office rooms, one without any installed film (considered as reference), a second office room with a PDLC film installed and a third and last office room with a reflective film. After the analysis of the obtained results, some conclusions were drawn. During the winter campaign, the PDLC film presented the lowest values of indoor illuminance and global radiation on vertical plane, and there were no significant differences for the room with the reflective film. In relation to the results obtained during the summer campaign, these presented to be inconclusive, which would not be expected, and could be the result of an incorrect application of the films. It was also concluded that the application of this type of films should be subjected to a careful preliminary study, taking into account the orientation of the façades in which it is intended to be installed.

Keywords

Solar control films, smart films, polymeric adhesive films, energy efficiency, thermal and optical performance.

1. Introduction

The current energy landscape, which is still strongly characterized by the use of fossil fuels and the known environmental impacts (global warming, climate change), makes it important to adopt measures to reduce energy consumption in all economic sectors. construction sector. Given the lack of fossil energy sources in Portugal, the country's high energy dependence has always been a reality. However, in recent years, through the focus on renewable energies and the promotion of energy efficiency, this dependence has been decreasing. Depending on the renewable energies of sources freely present in nature, it is important that the bet on the type of source (sun, wind, water) and the technology of its use brings the least degree of uncertainty possible, under penalty of the investments made do not obtain the return expected. In Portugal, hydroelectric energy being one of the main components of the renewable energy sector, its production can be considerably affected in years of drought, with negative consequences for energy dependence. This makes it important to diversify sources of renewable energy (sun and wind, for example) and energy-saving products (in the case of buildings, thermal insulation of the surroundings and adequate sun exposure are important characteristics). (in the case of equipment, the performance, the management of its operation and the periodicity and quality of its maintenance are important) [1].

In addition to the problem of energy dependence mentioned above, there is also a concern with climate change which, according to the fifth report of the Intergovernmental Panel Climate Change (IPCC), has a strong link with human activity, of greenhouse gases (GHG), with high costs associated with the reduction of these emissions [2]. The construction sector has a high significance in terms of energy consumption and emissions, accounting for 36% of final energy consumption and 39% of carbon dioxide (CO2) emissions. Although progress in sustainable construction is a reality and continues to advance, this progress has not accompanied the development of the building sector and the requirements of energy services. This incompatibility resulted in a 1.2% increase in final energy requirements in buildings from 2010 to 2016, as efforts towards energy efficiency did not follow the increase in floor space. Hence there is a need to improve energy intensity per square meter (m2) in the global building sector by an average of 30% by 2030 (compared to 2015) in order to meet the climate targets, set out in the Paris Agreement [3]. According to the United Nations Environment Program - Sustainable Building and Climate Change (UNEP - SBCI), the potential for reducing energy consumption in this sector over the lifetime of the building is a positive aspect when compared to other sectors, 30 to 80% through low cost measures [4].

In Portugal, energy consumption in the domestic sector accounts for about 22% of the energy consumed in buildings, much of which is devoted to air conditioning in order to improve comfort conditions [5].

In recent years there has been a significant increase in the use of glazing on the facades of non-residential buildings associated with architectural issues, based on aesthetic concerns and the entrance of natural light into the building. However, this use of large-scale glazing has had some implications for energy consumption, due to the need to use air conditioning systems to ensure the requirements of thermal comfort [6].

The façades of buildings play a fundamental role in their thermal performance, since they act as a barrier between the external environment and the interior environment, whose main function is the control of external environmental factors in order to guarantee the necessary comfort conditions when of its use [7]. The windows and glazed surfaces are the elements of the building envelope that require more attention, and the control of thermal losses in the heating season and the thermal gains in the cooling station is essential for the optimization of the thermal behavior of the building [8].

The regularization of the dimensions of glazed areas is a complex task in order to balance the energy consumption of heating, ventilation and air conditioning systems and the use of natural light in order to minimize the need for artificial light, while ensuring a high comfort visual [9]. This difficulty in achieving a balance between the various systems mentioned above, as well as the minimization of energy consumption, has led to the study and development of new technologies to control energy gains and losses in buildings, among them the application of solar control films in which include polymeric adhesive films and PDLC (polymer dispersed liquid crystal) type intelligent films, the latter being the focus of this dissertation.

The main objective of solar control films is to change the properties of glazing, significantly reducing the energy absorbed into the interior space, minimizing the energy consumption associated with air conditioning systems, but without significantly affecting the visible transmittance values in order to minimize consumption related to artificial lighting systems. Intelligent films, unlike adhesive polymeric films, also provide the possibility of regulating visible transmittance in a convenient and advantageous way regarding energy consumption. The use of solar control films is recommended mainly for buildings that exhibit excessive heating problems.

2. Case Study

The experimental campaign was developed at the IST (Instituto Superior Técnico) campus in Taguspark, located in the metropolitan area of Lisbon, Oeiras municipality. (Figure 1). Three offices were selected in the building, built in 2009, with characteristics, dimensions, type of use and similar orientations (Southwest). Since regular data collection would be necessary, the fact that there is easy access to these offices has also proved particularly important. Two of the office rooms already had two types of films installed (a PDLC-type intelligent film applied by the interior and a reflective film also applied by the interior) and a third office room with no film installed was selected, which served as reference for comparation.

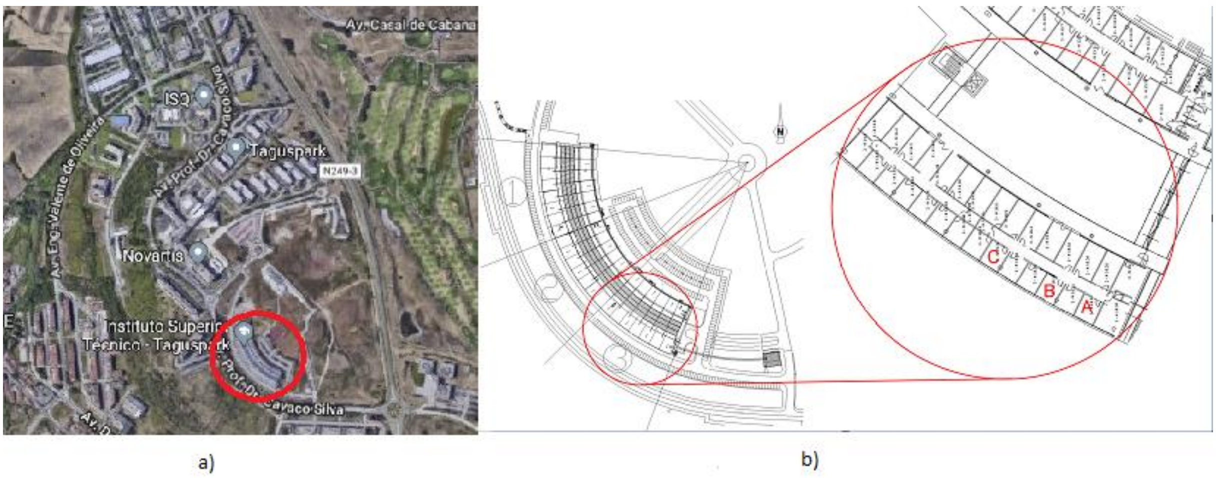


Figure 1 Location of the case study: a) location of IST Taguspark; b) blueprint of the building and location of the office rooms.

For that study, the three office rooms (individual office rooms) shown in Figure 1 with similar geometry and solar orientation were then defined. The office room A was then analyzed without solar control film and in the B and C office rooms the existing films were maintained: in the case of office room B, a Smart Cling Self Adhesive Smart Tint (Low Tension); and in the office room C a reflective film also applied by the interior (Home-Safe Auto-Adhesive UV Protection). All the office rooms are located on the 2nd floor, which corresponds to the last floor of the building.

3. Experimental setup

The experimental monitoring campaign was carried out in-situ in the three offices (A, B and C). As discussed above, office room A was used as a reference case in the present study, whereas office room B has a PDLC type intelligent film applied from the inside and the office room C a solar control film is also applied from the inside. It should be noted at this stage that the study of the PDLC-type intelligent film focused on the use of the film in opaque mode (off mode).

In order to determine the thermal and visual performance of the glazing in the different cases, the following quantities were monitored simultaneously and continuously in the three office rooms:

- indoor and outdoor temperature;
- indoor and outdoor surface temperature of the glazing;
- heat flow in the glazing;
- normal interior radiance to the facade and exterior in a vertical plane normal to the facade (measured on the roof and exterior facade of the office rooms) and horizontal (measured on the roof);
- interior illuminance in vertical and external plane in vertical plane normal to the facade (measured in the exterior facade of the office rooms);

For each office room, 9 T-type thermocouples with 0.2 mm thickness were used for the following purposes: 2 thermocouples for measuring the ambient temperature (exterior and interior); 4 thermocouples for measuring the surface temperature of the glazing (2 exterior and 2 interior); 2 thermocouples for measuring the surface temperature of the façade (interior and exterior) and 1 thermocouple for measuring the surface temperature of the inner blind (these were not used because they were not feasible). In order to measure the heat flux in the glazing, a Hukseflux flowmeter was placed on the inside surface of the glazing of each office room. For the measurement of indoor solar radiation, pyranometers LI-COR LI200 were used in chambers A and B and Kipp&Zonen CMP6 in office room C and for the measurement of interior illuminance were used in LI-COR 210R luximeter in all enclosures. A schematic of the position of the measuring devices (apart from thermocouples and flowmeters) can be seen in Figure.

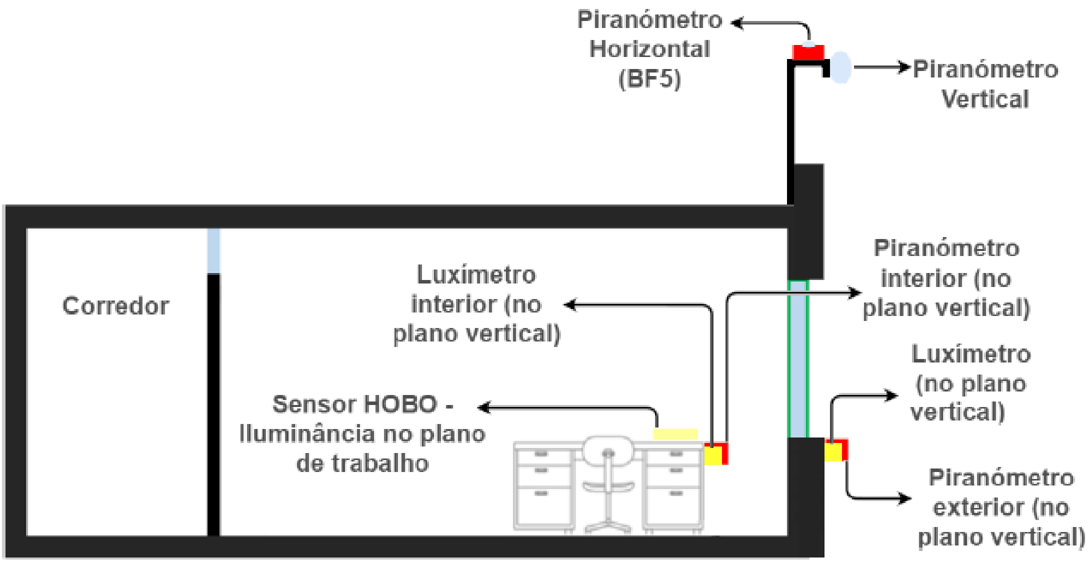


Figure 2 Schematic of the position of pyranometers, luximeters and HOBO sensor (adapted).

4. Results and discussion

The experimental campaign was presented in two distinct phases: a first in which the offices were monitored during a winter season and a second in which the offices were monitored during a summer season. It should be noted that both the summer campaign and a campaign of winter remained a kind of PDLC film in opaque mode (off mode).

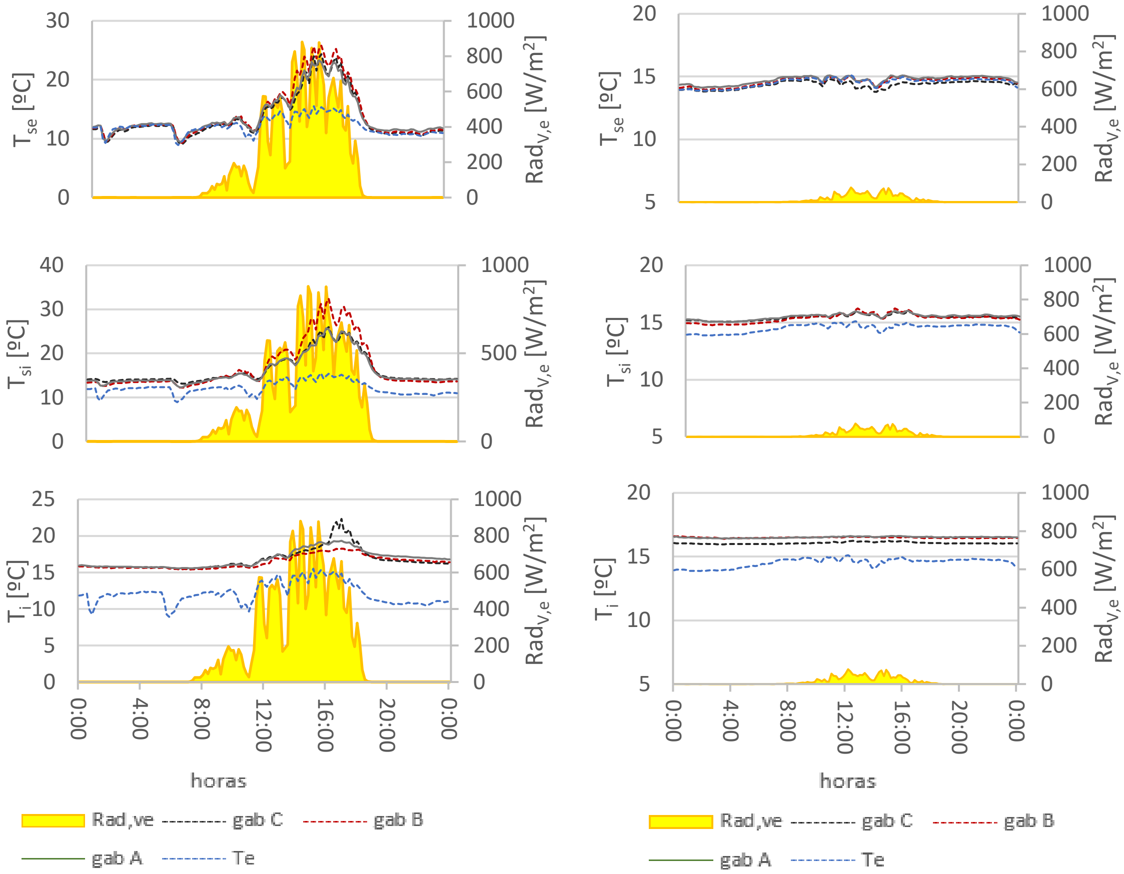
4.1. Winter campaign

The values recorded refer to the final period of the cold season and the beginning of the spring half-season. Considering the extensive volume of measurements taken during this experimental campaign, we opted to analyze only two days considered as representative days of the entire winter experimental campaign:

- day when there was a lower average outdoor temperature - Frigid Day (DMF);
- day in which the lowest mean solar radiation (calculated based on the sunshine period) was observed - Day of least radiation (DmR).

4.1.1 Temperature

By analyzing the DMF graphs (Figure 3 a) there is a constant influence of solar radiation on increasing surface temperatures and indoor environment, which is justified by the fact that the DMF is a clear sky day with a level of high incident solar radiation. Such as Chaiyapinunt et al. [10] also indicates that the differences between the office room temperatures for DMF and the differences between office room temperatures for the DmR show that the efficiency of the films is higher for the days with the highest level of solar radiation. When analyzing the external surface temperature (T_{se}) graphs (Figure 3), it is generally shown slightly higher values for case B (case with PDLC film) and values very close to the case A (reference office room / without film) and C (reflective film office room), which suggests an abstraction of the upper outer surface for the glazing system of the office room B and as such a lower reflecting capacity.

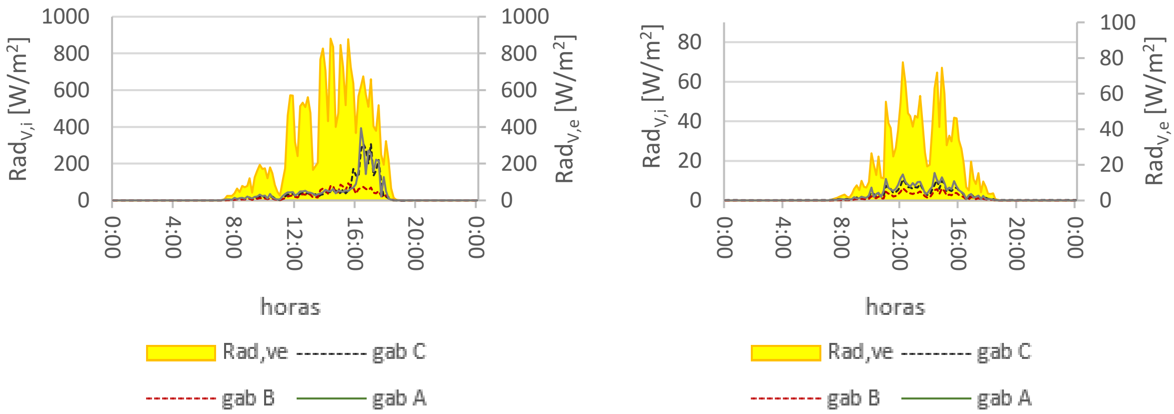


a) b)

Figure 3 Exterior surface temperature (T_{se}), interior surface temperature (T_{si}), exterior temperature (T_e), interior temperature (T_i) and external vertical global radiation ($Rad_{V,e}$) in DMF (a) and DmR (b).

4.1.2 Irradiation

When analyzing the graph of Figure 4 a) it is possible to identify a marked difference between the values recorded for the B office room (with PDLC type intelligent film) and the other office rooms between 4:00 p.m. and 6:00 p.m. office room B considerably lower for the same time interval in which there is a peak radiation for the remaining office rooms for the DMF. For the DmR (Figure 4 b), the values of radiation arriving inside the office rooms vary little, but it is also possible to verify slightly lower values for the office room B, which suggests a lower solar transmittance value for the system PDLC type intelligent film glazing in off mode of this case.



a) b)

Figure 4 Exterior vertical global radiation (Rad_{Ve}) and interior vertical global radiation (Rad_{Vi}) in DMF (a) and DmR (b).

4.1.3 Illuminance

With regard to illuminance, it can be concluded, based on the graphs relating to DMF and DmR (Figure 5 a) and b), respectively) and bearing in mind that the amount of vertical radiation transmitted inland is the main PDLC type intelligent films, that opaque mode is not the best option of use in the cold season due to the difficulty of maintaining the desirable levels of visual comfort, promoting the use of artificial lighting on days of lower radiation. As can be seen from the graphs of Figure 5, the lowest recorded luminance values refer to enclosure B with implemented PDLC smart films. Careful management of this type of films is required based on the standard of visual comfort in order to minimize the need for artificial lighting.

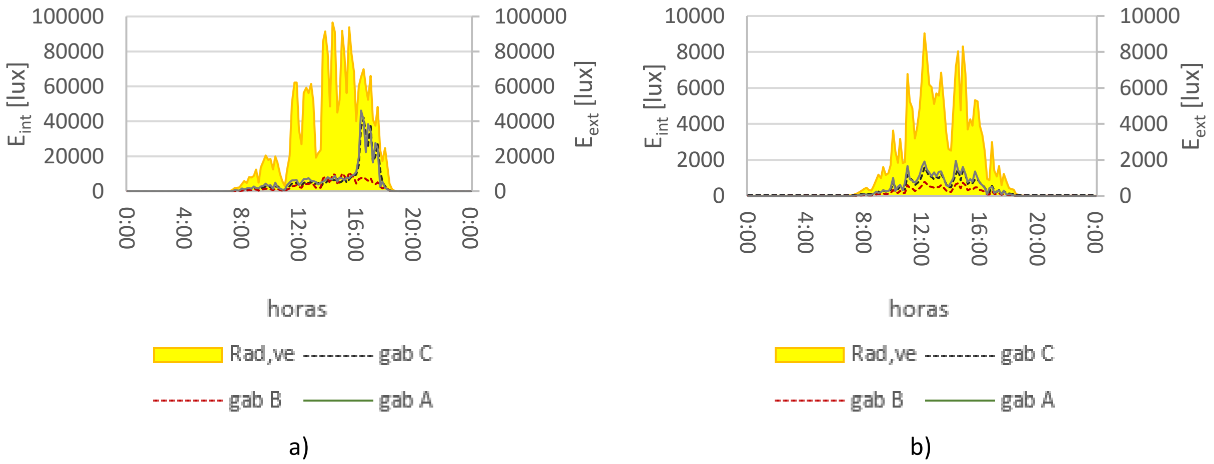


Figure 5 External vertical illuminance (E_{ext}) and interior vertical illuminance (E_{int}) in DMF (a) and DmR (b).

4.2. Summer campaign

As in the winter campaign, the summer campaign also took two days as representative days of the whole experimental campaign due to the large volume of measurements that were made, so we opted to analyse only:

- the day on which there was a higher average outdoor temperature - Hottest Day (DMQ);
- the day in which the highest average solar radiation (average calculated based on the sunshine period) was observed - Day of Higher Radiation (DMR).

4.2.1 Temperature

Analyzing the graphs concerning the interior surface temperature (T_{si}) in the DMQ and the DMR (Figure 6 a) and b) respectively) it will be seen that the interior surface temperature is generally higher for the B office room. This difference is bigger for the DMR, in which the outside temperature is lower. For DMQ this difference from office room B to office room A and C is not as noticeable. As in the winter campaign, these higher values of indoor surface temperature for office room B suggest a greater absorption for this film (PDLC film). It should be noted that once again the differences in temperature recorded for the different offices are of little relevance.

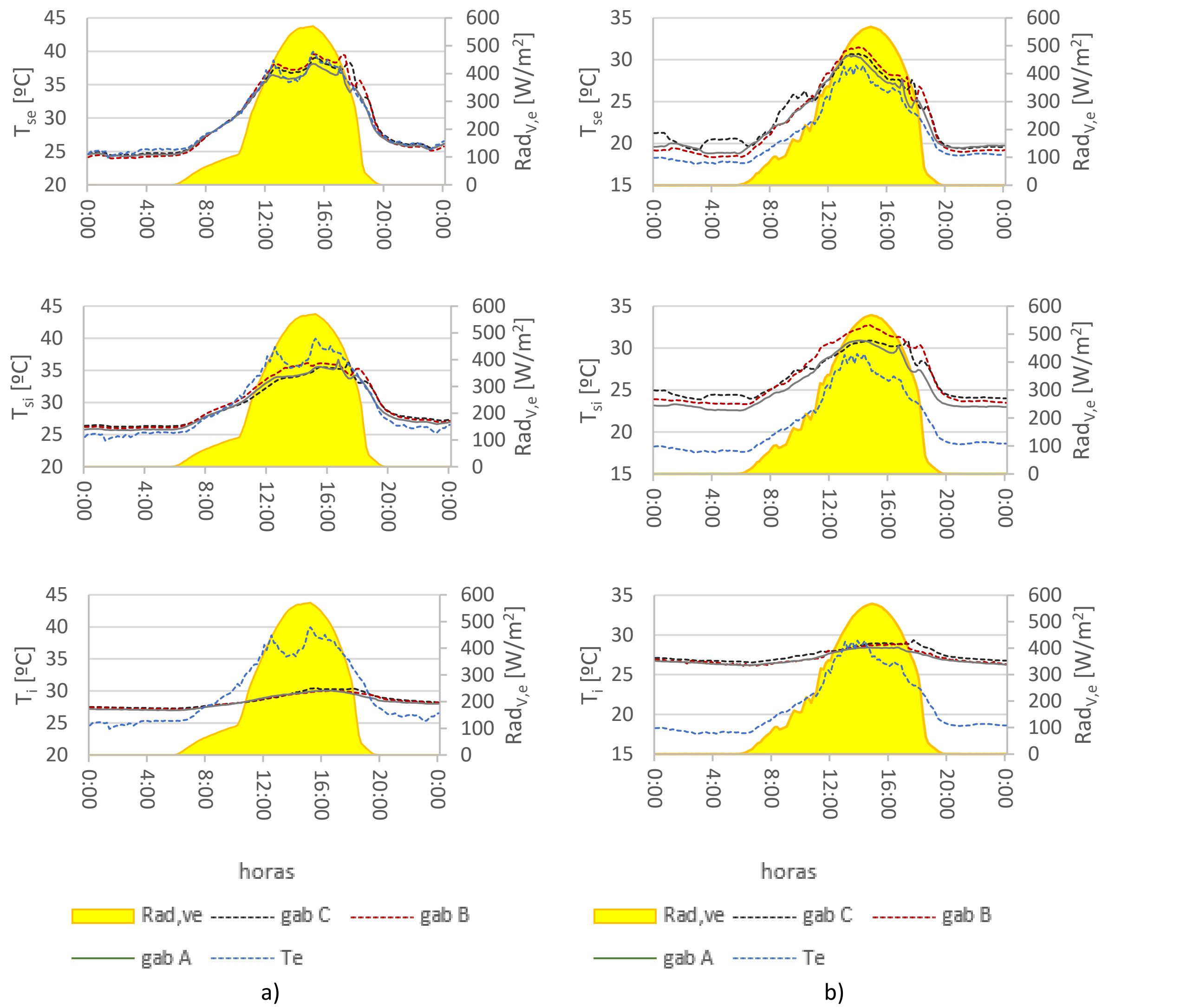
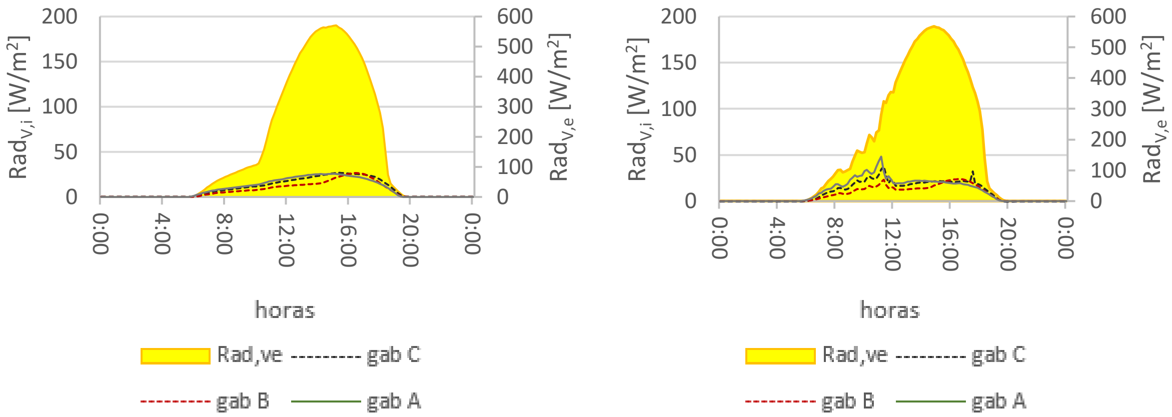


Figure 6 Exterior surface temperature (T_{se}), interior surface temperature (T_{si}), exterior temperature (T_e), interior temperature (T_i) and external vertical global radiation (Rad_{Ve}) in DMQ (a) and DMR (b).

4.2.2 Irradiation

When analyzing the graphs in Figure 7 (a) and (b) it is possible to identify a slight difference between the values recorded for office room B and the other offices between 7 am and 4 pm, with the values recorded for office room B being slightly lower both for DMQ as for DMR, which, as in the winter campaign, suggests a lower solar transmittance value for the glazing system of this case.

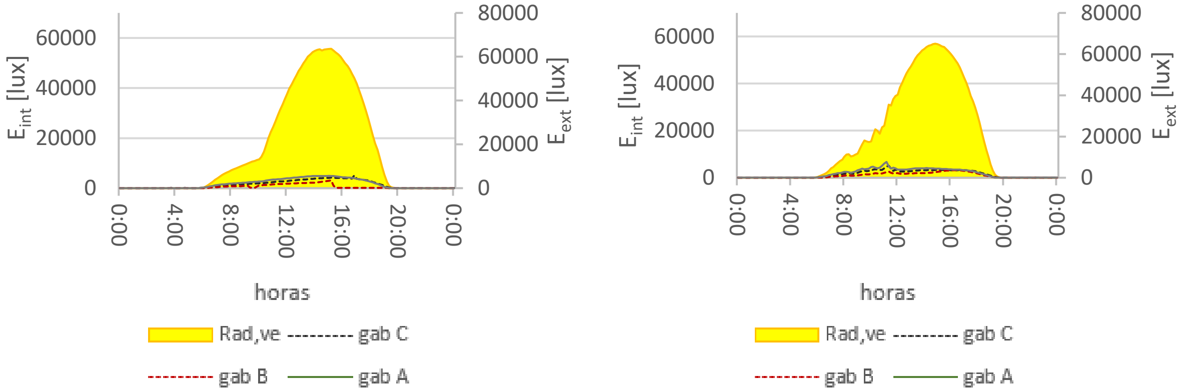


a) b)

Figure 7 Exterior vertical global radiation (Rad_{Ve}) and interior vertical global radiation (Rad_{Vi}) in DMQ (a) and DMR (b).

4.2.3 Illuminance

As noted for the winter campaign, the lowest recorded luminance values refer to enclosure B with PDLC intelligent films installed. Which, when well managed between on-mode and off-mode, can bring advantages from the point of view of visual comfort, more properly in the reduction of the glare by excess of natural light. However, the order of magnitude of the solar radiation records and the expected illuminance for this phase of the experimental campaign was higher than that verified. Based on the values obtained in the winter campaign was expected higher values of illuminance in the summer campaign, which raises some questions.



a) b)

Figure 8 External vertical illuminance (E_{ext}) and interior vertical illuminance (E_{int}) in DMQ (a) and DMR (b).

5. Conclusions

Currently the energy consumed to maintain conditions of thermal and optical comfort inside the buildings represents a large part of the total energy consumed. In this context, intervention in the energetic rehabilitation of the building envelope is crucial, as there is a growing focus on improving the energy efficiency of glazed spans (responsible for most of the solar gains and consequent increase in air conditioning needs).

On the other hand, although there is a tendency to increase glazed areas, there is an inefficient use of natural light, sometimes resulting in situations of visual discomfort due to dazzling.

An example of this investment in the energetic rehabilitation of buildings, through the improvement of the energetic efficiency of the glazed spans, are the solar and intelligent control films that act on the alteration of some of the properties of the glazing, such as solar and visible transmittance and the solar factor.

In this sense, it was decided to study the behavior of a PDLC-type intelligent film (presented by the manufacturer as a privacy control film in its primary purpose) and the behavior of a reflective solar control film. Although the films under study were not applied in the entire glazed area, it was possible to verify differences in the behavior of the glazed systems in the different offices, with better results for the winter campaign than for the summer campaign.

As regards internal temperatures, it has been found that both office rooms with films in the glazing system have generally allowed a small reduction of the same in relation to the office room without film, and it is therefore advisable to develop studies with the application of these films in the whole of the glazing in order to ascertain the true potential of these films in the reduction of the interior temperature.

Regarding irradiance and illuminance, lower values were found for the PDLC-type intelligent film in opaque mode (change in transmittance), which suggests the potential of this film to improve visual comfort in the hot season through the use off mode, in addition to the potential advertised by the manufacturer regarding privacy control. It is important to highlight the disadvantage of using this mode in the cold season which may lead to an increase in the need for artificial lighting, especially on more overcast days.

The fact that the films were not applied to the entire glazing, coupled with the orientation of the glazed facades which, according to the bibliography consulted, is not the most advisable for the application of solar control films in Mediterranean climates, could have been an attenuation of the differences that would be expected for the values recorded in each office room. Thus, in addition to the future developments advised in the following subchapter, it is considered useful to alert that the orientation and area of glazing are key aspects to be considered in the choice of case study in studies of a nature similar to this dissertation, advising the application of the films to study in the entire glass of the case study.

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