THERMAL BEHAVIOR OF MEDICAL OFFICES IN HOSPITAL UNITS: CURRENT CONDITIONS AND POTENTIAL FOR ENERGY EFFICIENCY IMPROVEMENT

Francisco António Cabaço Belo Sanches da Natividade

Instituto Superior Técnico, Universidade de Lisboa, Portugal, May 2019

Abstract: *Hospitals are buildings that by the nature of their function - providing health care with maximum comfort, hygiene and safety, in an intensive way - are a priori high energy consumers. This fact also makes them buildings where the potential of energy saving is high. Hospitals built prior to the implemented European directive on energy efficiency of buildings make up cases in which compliance with the currently recommended efficiency standards is more difficult to achieve. This work intends to carry out an experimental study to assess the thermal behavior characteristics of medical offices of a hospital building with construction prior to these mentioned directives. As a case study, the building of first nursing school Francisco Gentil of Instituto Português de Oncologia (IPO) of Lisbon was chosen, which by its characteristics, size and potential of energy rehabilitation represents a relevant case study, whether to evaluate the current thermal behavior or to identify potential rehabilitation solutions and opportunities to improve its thermal performance. For this purpose, the monitoring of the environment and building envelope of two representative medical offices, with specific solar orientations, was carried out through the use of appropriate measurement and recording equipment that allows monitoring temperatures spatially and temporally, heat flows, irradiances and illuminances, in particular. In this work, only the thermal behavior in the heating and cooling seasons will be analyzed. The obtained results allowed inferring about the actual thermal performance, at both the constructive and environmental level, which constitutes important supporting information for any strategy to improve energy efficiency. Along with the experimental campaign, a simulation study of the offices was carried through an EnergyPlus calibrated model aiming to obtain a set of possible solutions that enhance the energy performance of the building.*

Key words: hospitals, thermal behavior, monitoring, simulation

---

1. INTRODUCTION

The sustainability of construction is currently a priority, for both environmental and economic reasons, and this is well found within the European directives related to the energy performance of buildings [1] through lines of action directed either to new buildings or to existing buildings needing rehabilitation.

The large urban centers are characterized by very aged buildings and, therefore, have a necessity for intervention. Not disregarding other buildings, hospitals are buildings whose functionality, energy performance and adaptation to technological evolution are paramount and must be ensured. They are also buildings where the need for control of environmental parameters is of greater relevance compared to current buildings, given that their main users require a variety of health care and, for this reason, ensuring the conditions required for indoor environment is an issue of fundamental importance.

Numerous evaluation studies have been carried out in hospitals involving indoor parameters that simultaneously affect patients' health and comfort conditions, such as: humidity and the need for its control, to prevent the development of bacteria and respiratory system irritations [2,3]; temperature, for its importance for the patients in both the operative phase, in operating rooms, or in the recovery phase in patient rooms [4,5]; and ventilation, for its impact on air quality and prevention in the dissemination of infections [6].

The present study is in line with the aforementioned studies, but limiting the analysis of the environmental parameters to its influence on comfort and relationship with the thermal performance of the building. More specifically, the thermal performance of the first nursing school building *Escola Superior de Enfermagem Francisco Gentil*, of *Instituto Português de Oncologia* (IPO) of Lisbon was assessed, as a case study, through an in-field experimental campaign monitoring. Moreover, building energy simulations were performed to analyze the impact of the implementation of potential rehabilitation solutions on the energy efficiency improvement of the building. The building, dating back to the 40s of the 20th century [7], is endowed with characteristics that make it a potential case of energy rehabilitation, thus representing a relevant case study, whether to assess the current thermal behavior or to identify potential rehabilitation solutions and opportunities to improve its energy performance. For this purpose, measurements of surface and ambient temperatures, of heat fluxes generated on walls and glazing, and of irradiances and illuminances were carried out simultaneously in two medical offices with different solar orientations (East and West). Afterwards, a simulation model was built and several simulations were carried out in order to obtain a set of possible solutions that could potentiate a better energy performance for the building. In this work, the results and respective discussion of the measurements relative to the thermal behavior of these medical offices are presented in light of the time of their construction as well as the results referring to the energy saving potential of each of the intervention measures analyzed.

2. CASE STUDY

The main goal of this work is the assessment of the thermal performance of medical offices of a hospital unit. As a case study, the building of the first nursing school *Francisco Gentil*, *of Instituto Português de Oncologia (IPO)* of Lisbon (Figure 1a) was selected to be monitored and modelled. The building under study, designed by Raul Lino and Ernst Kopp [7], with 4 floors above ground and a basement, was built in 1938, so it has constructive solutions characteristic of the time, where the mixed structure of concrete and masonry were beginning to appear. In the present case, the structure is column-beam framed made by reinforced concrete and is provided with facade walls with two different constructive solutions, respectively in glazing areas and opaque areas, these ones with two different thicknesses. In fact, and evidencing the era that marked the beginning of the use of new materials in civil engineering construction, the facades of the building combine two types of masonry. They consist of a zone of massive brick and a zone of stone masonry, where the structural elements of concrete of the building were inserted.

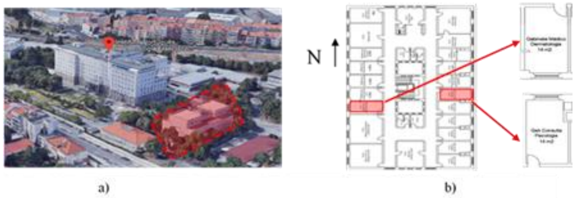

Figure 1. Location of case study: a) location of the building in the enclosure of IPO; b) plan of the 2nd floor, with the location of the monitored offices

Exteriorly, the building presents a stony coating at the level of the first floor, throughout its perimeter. The remaining floors are lined with simple traditional plaster of cementitious mortar. Naturally, and in light of the date of its construction, the building does not have thermal insulation materials.

For the present study, two medical offices with similar geometry and occupation were monitored - the Psychology office and the Dermatology office (Figure 1b). They are situated on opposite wings of the 2nd Floor and have an area of 14 square meters, a height of 3 meters, but different solar orientations. The outer wall of the Psychology office is oriented to East (E), so it receives direct solar radiation in the morning. On the other hand, in the Dermatology office, whose facade is orientated to the West (W), the solar radiation affects mainly in the afternoon. Both offices are equipped with a wall-mounted radiator for ambient heating and a window (1.70x1.45 square meters) equipped with a single clear glazing unit of 3mm, box of shutters and wooden frame. The opaque surrounding of both facades consists of a thicker area of stone masonry - designated as "Thick Wall" (Pe) -, with a considerable thickness (0.60 m) when compared to the rest of the area of massive brick masonry (of 0.25 m of thickness) and where the window is installed - designated as "Thin Wall" (Pf). In both offices, the floor is lined with wooden studs and the finishes are simple, with a traditional plaster and wooden baseboards. It should also be noted that the offices are under some shading from trees in the area surrounding the perimeter of the building.

3. EXPERIMENTAL CAMPAIGN

The in-field experimental campaign monitoring was carried out in the heating and cooling periods from the 23rd of February to the 23rd of September of 2018, simultaneously in the Dermatology and Psychology offices represented on plan in Figure 1b.

In order to assess the thermal and luminous performance, the following variables were monitored and measured: i) indoor and outdoor temperature (Ti, T_e); ii) internal and external surface temperature of glazing and walls (T_{si}, T_{se}); iii) external solar radiation in the vertical plane of the facade ($R_{adv,e}$); (iv) heat flux in glazing and walls (q); v) external illuminance in the vertical plane of the facade ($I_{v,e}$); vi) surface temperature of the air-conditioning apparatus (Ts_{AQ}) and indoor ambient temperature close to it (Tar_{AQ}). For that purpose, with regard to the measurement of ambient and surface temperatures, Type T thermocouples with 0.2mm of thickness were used. The heat flux was measured in glazing and walls using Hukseflux fluxmeters, assuming as positive the flow direction from the interior to the exterior. For the measurement of radiation and illuminance, a LI-COR LI200 pyranometer and LI-COR LI210R luxmeter were used, respectively. These sensors were connected to the data acquisition systems: Campbell CR10X in the Psychology office and Delta-T DL2e in the Dermatology office. The installation of an HOBO appliance in each office also allowed the measurement of indoor ambient temperature, relative humidity and internal illuminance in the horizontal working plane (at a height of 0.90 m).

In the Psychology office, the following sensors were used: 8 thermocouples - 2 were used to measure the indoor and outdoor ambient temperatures, 2 for the measurement of the inner and outer surface temperatures of the thinner wall, 2 for the measurement of the inner and outer surface temperatures of the thicker wall, 2 for the measurement of the surface temperature of the air-conditioning apparatus and the ambient temperature close to it - 3 fluxmeters, associated with the glazing and the two walls under analysis, a pyranometer, a luxmeter and a HOBO.

In the Dermatology office, although the same measurement protocol with similar sensor arrangement has been followed, two thermocouples and one fluxmeter less were used, and because of this the thicker wall could not be analyzed. Figure 2 shows the arrangement of these sensors as well as the detail of the constructive solutions of the walls of an adjacent building of IPO, whose construction dates back to the same period, and which are analogous to the walls of the building under study.

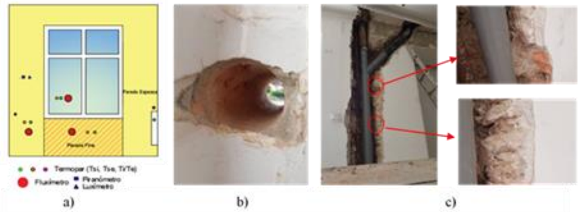

Figure 2. a) Schematic representation of sensors' placement in the Psychology office; b) Transverse bore in the thin massive brick wall; c) Detail of thick stone masonry wall.

4. ANALYSIS AND DISCUSSION OF RESULTS

Although the experimental campaign was carried out continuously between the 23rd of February and the 23rd of September, two distinct periods, referring only to heating (winter) and cooling (summer) seasons, are considered for analysis purposes. It should also be noted that, in the present work, only the results regarding the thermal behavior of the offices are analyzed.

4.1 Winter Campaign

From a relatively extensive sample, referring to the period between the 23rd of February and the 23rd of March of 2018, 3 representative days of the thermal performance of the medical offices during the winter period were selected for a detailed analysis: the coldest day (DMF); the day of least radiation (DmR); and the day in which both offices were air-conditioned (DAQ).

4.1.1 Temperatures and radiation

Figure 3 shows, for the 3 days under analysis, the external (T_e), interior (T_i) and surface (Tsi and Tse) temperatures measured on the walls of each of the offices, as well as the incident global external radiation measured in the vertical plane of the facades of the respective offices ($R_{adv,e}$).

It is observed that in the three days under analysis, in both cases: (i) solar radiation directly influences all the recorded temperatures, i.e. if, on the one hand, the increase in solar radiation leads to the increase of all temperatures, on the other hand, sudden breaks in radiation - due to transient cloudiness and shading caused by trees - also causes sharp reductions in surface and indoor air temperatures; (ii) the indoor air temperature is always higher than the outdoor temperature; (iii) in the daytime periods without radiation, the outer surface temperature of the walls adjusts to the outside temperature; iv) the inner surface temperature of the thin wall varies in a similar way in the two offices, depending on the weather conditions of the day; v) with the exception of the periods of higher solar radiation, the internal surface temperature is considerably higher than the outer surface temperature in the walls under analysis.

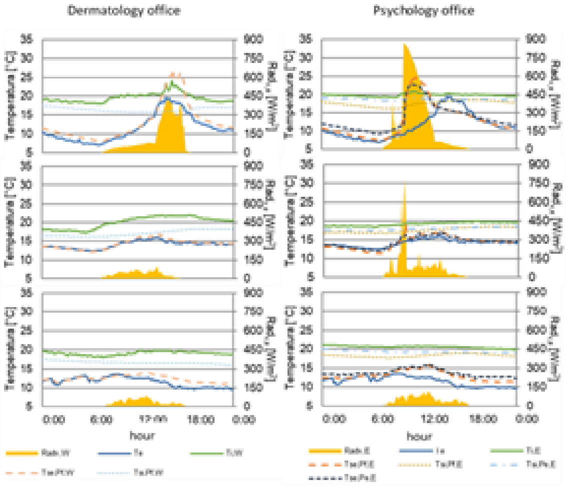

Figure 3. Temperatures: a) The coldest day (DMF); b) Day with air conditioning (DAQ); c) Day of least solar radiation (DmR).

Regarding DMF (the coldest day, Figure 3a), the strong influence of solar radiation on external surface temperatures is noteworthy. At the moments of higher solar radiation it is observed that: i) the exterior surface temperatures measured on the walls of both offices increased significantly; ii) in all the walls under analysis the external surface temperature is both higher than its internal surface temperature and higher than the indoor temperature of the medical office; iii) the external surface temperature of the thin wall is greater than the external surface temperature of the thick wall and the inverse occurs relative to the inner surface temperatures; (iv) it is also noticed that both thin-wall surface temperatures respond more rapidly to variations in external weather conditions (outdoor temperature and solar radiation) than those in the thick wall, which may be related to the lower thermal mass of the thin wall .

In the DAQ (day with air conditioning, Figure 3b), both offices were under the influence of the heat generated by the air conditioner, which was turned on from 6h00 to 19h00. Although not shown graphically, the temperature recorded on the surface of the wall radiator over the period of operation ranged from 45 to 50 °C in the Psychology office and between 55 and 60 °C in the Dermatology office. Although the influence of the heat generated by the apparatus on the thermal environment of the offices is not evident, it is noticed that the indoor temperature tends to increase progressively throughout the day from the time it is switched on (6h). This is most noticeable in the Dermatology office because of the higher range of values within which the radiator temperature has oscillated. Although with less expression, the internal surface temperature recorded on the thin wall of the Dermatology office, and the internal surface temperature recorded on the thin and thick walls of the Psychology office also increased.

With regard to the DmR (day of least solar radiation, Figure 3c) it is observed that both indoor temperature and internal surface temperatures measured in the thin and thick walls of the Psychology office are slightly higher when compared to the indoor temperature of the Dermatology office and the inner surface temperature measured in the thin wall. The fact that in the previous day (16th of March) the solar radiation on the vertical plane of the façade was, on average, about 40 W/m^2 higher in the Psychology office than in the Dermatology one, which led to the increase of all the internal temperatures in this office, may justify such difference. By analyzing the internal surface temperatures measured on the walls of the Psychology office, it is noted that the temperature in the thin wall is lower than the temperature measured in the thick wall in the early hours of the day. This can be explained by the fact that the thin wall, with lower thermal mass and therefore with less heat storage capacity, tends to have, for a same period of time, a heat loss higher than the thick wall. On the other hand, the thin wall heats up faster, so that, when solar radiation ceases to have effect at late afternoon, its internal surface temperature tends to adjust to that of the thick wall in the remaining hours of the day.

It is also important to refer to that the external and internal surface temperatures measured in the glazing, although not represented, show the state of degradation and reduced energy efficiency thereof. On every day of the campaign the internal surface temperature of the glass has adjusted almost perfectly to its external surface temperature. The highest variation recorded between the two surfaces was 0.5ºC.

4.1.2 Heat flux and thermal transmittance

Next, the heat fluxes measured in the glazing and walls of each office, corresponding to the three representative days under analysis (DMF, DAQ and DmR), and the thermal transmittance (U-value) of both walls are analyzed. With respect to the heat fluxes, as the heat flux meter was placed on the internal surface of each element, the recorded heat flux is actually the one between the internal surface of each element and the indoor environment and assuming as positive the direction of the heat flux from indoors to outdoors. Thus, the higher the difference between the internal surface temperature of the element and the indoor temperature of the medical office, the higher the heat flux at the interface. It should also be noted that the flux measured in the glazing by this experimental procedure is more accurate during the night period [8] so that, for the present analysis, only the results for this period are presented. With respect to the thermal transmittance (U), this parameter was determined from the internal (T_{si}) and external (T_{se}) surface temperature values and the corresponding heat fluxes (q) measured over a period of 13 days (with measuring intervals of 10 minutes) according to the progressive average method recommended in EN ISO 9869: 1994 [9] and represented by equation (1), where n is the total number of records and R_{si} and R_{se} are the conventional (internal and external) surface thermal resistances:

$$U = \frac{1}{\frac{\sum_{j=1}^{n} T_{si_j} - \sum_{j=1}^{n} T_{se_j}}{\sum_{j=1}^{n} q_j} + R_{si} + R_{se}} \quad [W/m^2 °C] \tag{1}$$

In Figures 4a, 4b and 4c, there are shown: i) the heat flux measured in the glazing (Env) and the thin wall (Pf) of the Dermatology office; ii) the heat flux measured in the glazing and in the thin (Pf) and thick (Pe) walls of the Psychology office; iii) the incident global solar radiation on the vertical plan of the façade measured on the days selected for analysis, in each office. Figure 4d shows the values of the thermal transmittance of thin and thick walls under analysis.

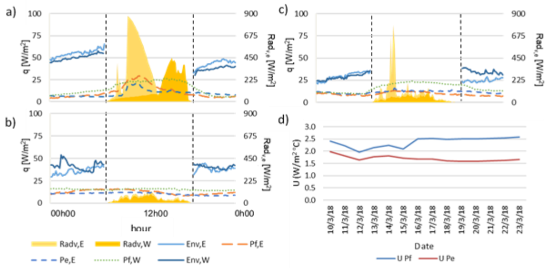

Figure 4. Heat Flux: a) The coldest day (DMF); b) Day with lower solar radiation (DmR); c) Day with air conditioning (DAQ); d) thermal transmittance (U) of the thin (Pf) and thick (Pe) wall.

On the days under analysis (DMF, DAQ and DmR, Figure 4), it can be observed that: i) heat flux measured in each element of the two offices was always positive, as it was always from the interior to the exterior; ii) in the day periods without solar radiation, all heat fluxes measured on the walls of both offices tended to a similar range of values; iii) in the Psychology office, after the period of solar radiation, the measured heat flux in the thick wall tends to be slightly higher than the thin wall, due to the thermal inertia effect.

Regarding the DMF (Figure 4a), it is observed that the measured heat flux in both walls of the Psychology office increases in the period of higher solar radiation. This is due to the greater discrepancy between the internal surface temperatures of the walls and the office indoor temperature, which in the said period increases slightly. Comparing the heat fluxes in the thin walls of each medical office, it is noticed that instead of what happens in the Psychology office, where in the hours of lower solar radiation the heat flux tends to decrease, in the Dermatology office the heat flux increased. The fact that the Dermatology office is mostly occupied in the morning, together with the possible influence of the heat from the radiators of the common space of the building on the indoor temperature of the medical office, might justifies this difference.

Regarding the DAQ (Figure 4c), it can be observed the influence of the heat generated by the air conditioning unit on the indoor temperature, which is more expressive in the Dermatology office, taking into account the temperatures reached in it. Indeed, the range of values of the indoor temperature reached in this medical office during the operating period of the air-conditioning apparatus has led to a greater discrepancy between this temperature and the inner surface temperature of the thin wall. Consequently, the heat flux measured on this wall of the Dermatology office was higher when compared to the thin wall heat flux of the Psychology office, where the difference between the indoor temperature and the internal surface temperature was lower. In turn, the measured heat flux in the thick wall of the Psychology office is similar for most of the day to the heat flux measured in the thin wall. In the late hours of the day, the heat flux is slightly higher due to the effect of thermal inertia. Regarding the DmR (Figure 4b), when the offices were not occupied (weekend day), given that solar radiation did not have a major effect on the indoor temperature of both offices, due to the fact that the day was cloudy, there are no relevant observations to add. Except for a period of time, after hours of higher solar radiation, where the heat flux in the thin wall of the Dermatology office was higher than the heat flux measured in the thin wall of the Psychology medical office, the fluxes of all walls varied similarly, with values of the same order of magnitude for most of the day in both offices. In regards to glazing, the high heat flux shows the low thermal performance and state of conservation of the elements. It should be noted that on both days the heat flux is relatively high, resulting in a considerable loss of heat from indoors to outdoors.

Regarding the thermal transmittance (U-value), it can be seen from Figure 4d that, after an initial period where instability behavior is visible, the measurements stabilize. In fact, the U-value tends to 2.5 W/m^{2o}C in the case of the thin wall, and to 1.65 W/m^{2o}C in the case of the thick wall, which confirms the lower thermal resistance of the thin wall taking into account the thicknesses and materials used in the construction of both walls. These values are close to the values found in the literature for the constructive solutions in question - U = 2.4 W/m^{2o}C for massive brick (e=0.25m) [10] and 1.8 W/m^{2o}C for ordinary stone masonry (e=0.40 to 0.60m) [11]. It is also observed that for most of the time of the campaign the heat flux associated with the thin wall is higher than that of the thick wall, as the magnitude ratio of the obtained thermal transmittances allowed to foresee.

4.1.3 Frequency analysis

The records of the variables already described, both those related to external weather conditions and those that constitute the response of the offices to these conditions, are time series in which the identification or recognition of the patterns and intensities that better characterize them is done many times only by simple visual observation of the measured values. In order to deepen the study in this respect, a frequency analysis of the records of indoor and outdoor temperatures is shown in Figure 5, in this work for the Psychology office, by applying the Discrete Fourier Transform (DTF) to samples of 2048 measurements covering the period from the 9th to the 24th of March 2018. DTF allows decomposing the set of results into the overlapping of a set of harmonic functions with frequency and amplitude (in relation to the mean value) determined. Figure 5 shows the time series of these temperatures (Figure 5a) and the frequencies and amplitudes (DT) resulting from the DTF (Figure 5b).

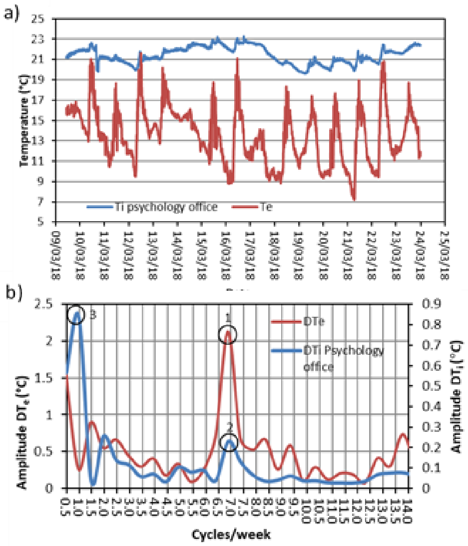

Figure 5. a) Outdoor (Te) and indoor (Ti) temperatures of the Psychology office and; b) frequencies and amplitudes (DTe and DTi) by application of TF between the 9th to the 24th of March 2018.

From the observation of Figure 5b, it can be seen that: a) the harmonic of T_e with greater weight in the recorded values (higher D_{Te}-peak 1) is that which has the period of 1 day (7 cycles/week), which corresponds to the daily cycle day/night, as would be expected; b) the harmonic of Ti naturally emphases the effect of Te, for the same frequency of T_e but with a fairly damped value (peak 2), which is indicative of the effect of thermal inertia and air conditioning of the space (which tends to stabilize the temperature); the air conditioning unit is switched off on the weekend, which is very noticeable by the harmonic with a period of one week (1 cycle/week), marked by peak 3, which corresponds to what actually occurs and is undoubtedly one of the most interesting results of this analysis.

4.2 Summer Campaign

The summer campaign ran from the 20th of June to the 23rd of September. In order to better characterize the performance of the building during this warmest season of the year, it was decided to follow the same methodology adopted in the winter campaign by selecting for analysis the representative days from the extensive collection of results: the day of least radiation (DmR); and the day of highest solar radiation (DMR).

4.2.1 Temperatures and solar radiation

Figure 6 shows the outdoor (T_e), indoor (T_i) and surface (T_{si} and T_{se}) temperatures measured on the walls of each of the offices for the two selected days (DmR and DMR, Figure 6a and 6b, respectively), as well as the incident global external radiation measured in the vertical plane of the facades of the respective offices ($R_{adv,e}$). It is observed that, although within a different range of values, some summer temperature and solar radiation recordings are similar to those observed in the winter season. Again, in the two days under review, in both offices: i) the effect of solar radiation is observed on all temperatures for which, in correspondence with the solar radiation increase, there is an increase of all temperatures whereas, with the sudden drops of solar radiation there is marked reduction of surface and indoor temperatures; ii) both the indoor and the surface temperatures of the walls under analysis vary similarly, depending on the thermal conditions of the day; iii) except for the periods with the highest solar radiation, the internal surface temperature is considerably higher than the external surface temperature of the walls under analysis; (iv) at periods of day without radiation, the external surface temperature of the walls adjusts to the outdoor temperature.

In the DmR (Day of lower solar radiation, Figure 6a), identical thermal behavior is visible in both offices. By observing the results obtained for this day, it is noticed that, in correspondence with the solar radiation, the evolution of all temperatures recorded is similar in the two offices. The indoor and internal surface temperatures of the thin wall of the Dermatology office are slightly lower than those recorded on the thin wall of the Psychology office. Regarding the surface temperatures recorded on the walls of the Psychology office, it is observed that, with the exception of the period of solar radiation in which the external surface temperatures recorded on both walls tend to adjust to each other, both the external and internal surface temperatures of the thick wall are slightly higher when compared to those of the thin wall. This is due to the higher thermal mass of the thick wall. If, on the one hand, the thick wall when striked by solar radiation heats more slowly, on the other hand, having a greater capacity of heat storage, for a same period of time, has a lower heat loss when compared with the thin wall.

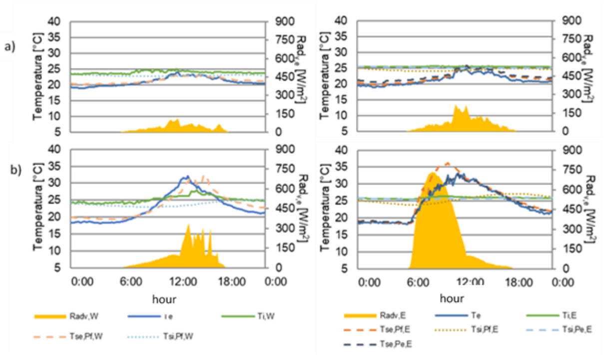

Figure 6. Temperatures: a) Day of lower solar radiation (DmR); b) Day of higher solar radiation (DMR).

With regard to DMR (Day of higher solar radiation, Figure 6b), the difference between the solar radiation recorded on the facades of the offices and the effect they have on the evolution of all recorded temperatures is remarkable. Concerning the indoor temperature of the offices, it is interesting to note that instead of what happens in the Dermatology office, the indoor temperature in the Psychology office did not have a significant increase after the highest peak of solar radiation. Although during the whole campaign it has been tried to keep the same position of the blinds, the change of position of the shading devices by the occupants, sometimes causing the total shading of the window of the Psychology office, may possibly explain what happened in this day. Regarding the internal surface temperature of the thin wall, although its variation is similar in both offices, it is observed that, in response to the higher recorded solar radiation, the internal surface temperature of the thin wall of the Psychology office is considerably higher than the same temperature of the thin wall of the Dermatology office, in the late hours of the day. Regarding the external surface temperatures of the walls under analysis, the strong influence of solar radiation is emphasized. Indeed, in the period of the day when the incidence of the sun on the facade is stronger, the external surface temperature of the thin wall of both offices is higher than all the other temperatures recorded. With respect to the thick wall records of the Psychology office, it is found that the outer surface temperature, which adjusts to the outside temperature throughout the day, is considerably lower than the outer surface temperature of the thin wall in the period of higher solar radiation. It is also worth noting that in the days under analysis, although the indoor temperature has varied, on average, between 24ºC and 25ºC in both offices, values exceeding 25ºC were obtained, which according to the literature, might be inadequate for the indoor thermal comfort conditions.

4.2.2 Heat Flux

Figure 7 shows the heat flux measured in the glazing (Env) and walls (Pf and Pe) of each office as well as the external global radiation, for both DmR (Figure 7a) and DMR (Figure 7b) representative days. It should be noted that due to a sensor failure, the heat flux through the thin wall of the Dermatology office was not assessed in the summer season.

The summer campaign is marked by some periods where the heat flux is negative, which corresponds to the period of time when the internal surface temperature of the element is higher than the indoor temperature in the office. In this case, the higher the discrepancy between those temperatures, the more negative is the heat flux in the interface. Of course, when the indoor temperature of the office is equal to the internal surface temperature of the element the heat flux will be zero.

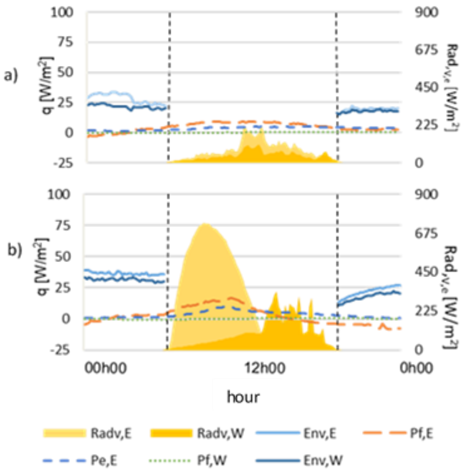

Figure 7 - Heat Flows: a) Day with lower solar radiation (DmR); b) Day with higher solar radiation (DMR)

With respect to DmR (Figure 7a), the heat fluxes of the walls under analysis varied similarly, with values of the same order of magnitude for most of the day. The lower solar radiation that characterizes the day under analysis led to a lower variation of the indoor temperature and, consequently, to lower heat fluxes throughout the day. It should be noted that only in the period of higher solar radiation the heat flux in both walls varies, in the thick wall being slightly lower than that of the thin wall. In relation to the heat flux through thin wall, it should also be noted that the fact that it is negative in the early hours of the day is due to the effect of the weather conditions of the previous day. An average outdoor temperature in the order of 23°C and an average solar radiation of about 88 W/m^2 led to the increase of the internal surface temperature of the thin wall, which was higher than the indoor temperature of the Psychology office during the late hours of the day, giving rise to a heat flux from the outside to the inside. The same does not occur in the thick wall, where the heat flux tends to be close to zero.

Regarding the DMR (Figure 7b), it is observed that in both walls the higher variation of the heat flux corresponds to the period with solar radiation. With respect to the heat flux through the thin wall, it is again confirmed that this is strongly conditioned by the solar radiation incident on the facade of the office. The effect of solar radiation on the indoor temperature in the early few hours of the day leads it to move away from the internal surface temperature to a slightly higher value range. Thus, during this period, the heat flux through the thin wall is positive and tends to increase until the internal surface temperature is influenced, on the one hand, by the solar radiation and, on the other hand, by the indoor temperature itself, also increasing by gradually restoring the thermal balance to the indoor environment. Once the difference between the said temperatures is reduced, the heat flux decreases in the remaining hours of the day, becoming negative from the moment that the internal surface temperature is higher than the indoor temperature. With respect to the heat flux through the thick wall, it is observed that this flux, being always positive, tends to increase in the early hours of solar radiation, and to decrease, tending to zero, in the remaining hours of the day.

As in the winter campaign, the results obtained for the heat flux through the glazing in both offices also show the low thermal performance and state of degradation. It should be noted that in both days the heat flux is positive and high, corresponding to considerable heat loss from the inside to the outside.

5. SIMULATION MODEL

In order to study the performance of a set of possible retrofitting measures that promote a better energy efficiency of the building, a simulation model of the offices under study was built in EnergyPlus [12].

EnergyPlus is a dynamic simulation program designed to characterize the thermal and energy performance of a building. By defining a wide variety of construction materials and building parameters, the program allows an efficient and expeditious analysis of a building in different domains, namely in terms of thermal and energy efficiency, i.e. thermal heating and cooling and the corresponding energy consumptions.

The simulation model was first calibrated with experimental results. The parameters Cv (RMSE) and MBE were calculated and values of -0.61 and 1.62 were obtained. The values obtained are in agreement with the literature proving that the model is well calibrated [13]. Once the model is calibrated, a set of possible solutions that lead to a better thermal performance for the offices were simulated: the application of an extruded polystyrene board (XPS) by the inside or outside surfaces of the external wall; the replacement of the glazing system; and the application of an extruded polystyrene board on the roof (in the last floor). The application of several insulation thicknesses and of four types of glazing was analyzed individually and, finally, the impact of the combination of these two intervention measures was assessed. Finally, due to the fact that the building consists of rooms similar to the offices under study on the last floor, an analysis and proposal of energy rehabilitation solution was also made for the building roof. In this way, the energy savings resulting from the combination of the best set of intervention measures in the exterior facade were analyzed with a proposal of intervention for the roof where the application of XPS by the exterior is also presupposed. It should also be noted that an analysis was made in terms of energy needs in the heating and cooling periods for the original situation and for the situation in which each of the intervention measures were applied. However, in this article the results are only presented in terms of total energy use as presented below.

5.1 Glazing retrofitting

For the replacement of the existing single clear glazing, four types of glazing were selected: a double clear glass; a gray double glass; a double reflective glass; and a double low emissivity glazed glass, all of them double but having different thermal properties. All glazing has a 16mm air gap and a 4mm clear glass on the interior pane. Only the 6mm glass of the outer pane whose main characteristic gives name to the solutions created - "Double Clear", "Double Gray", "Double Reflective", "Double Low emissivity" -, distinguishes them.

It was decided to simulate the replacement of the original glazing by the 4 glazing solutions mentioned above, in cases where the exterior facade of the office is oriented to the West, East, North and South. Although the object of study throughout this work was the Dermatology office, whose exterior facade is oriented to the West, and the Psychology office, whose exterior facade is orientated to East, it was also chosen to carry out simulations in cases in which the exterior facade is oriented to the South and to the North because the building *Dr. Francisco Gentil* contains similar offices with facades facing these directions.

Taking into account the 4 intervention measures for the replacement of the aforementioned glazing and in order to select the one that gives the offices under study a better thermal performance, the annual energy use was determined as function of the heating and cooling energy needs (equation 2).

$$Annual\ energy\ use = \frac{Nic}{COP} + \frac{Nvc}{EER}\ [kWh/m^2/\,year] \qquad (2)$$

where COP (the coefficient of performance) and EER (energy efficiency ratio) of a fictitious multisplit HVAC system take the values of 3.6 and 3.2 respectively, in accordance to REH [14].

As can be seen in Figure 8, in reference to the energy consumption for the existing construction: i) the application of the clear double glazing allows a reduction of the annual energy use of 7% for the West oriented office, 6% for the East oriented office, 7% for the North oriented office and 10% for the South oriented office. This glazing is the one that presents results that although positive are the least relevant compared to results of other simulated glazing solutions; (ii) the application of gray double-glazing allows energy savings of 26%, 27%, 33% and 16% for the West, East, South and North oriented offices; (iii) the application of the low-emissivity double glazing unit will enable a reduction in annual energy use slightly higher than the savings achieved with the application of the clear double-glazing unit. This energy saving is 16% for the Dermatology (West) and Psychology (East) offices and 22% and 13% for offices whose exterior façades are South and North oriented.

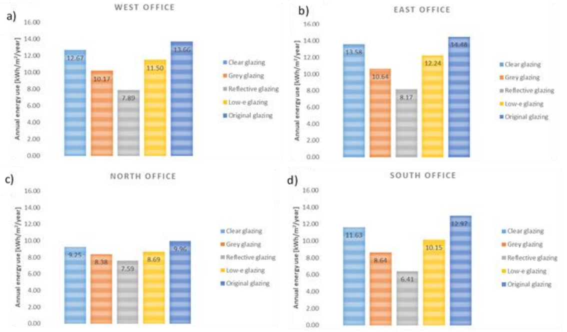

Figure 8. Annual energy use of the office when the 4 glazing under study were applied to: a) West-facing exterior facade; b) East-facing exterior facade; c) North-facing exterior facade; d) South-facing exterior facade.

It should also be pointed out that for the latter office, whose exterior facade is North oriented, the application of this glazing unit originates an energy saving similar to the energy saving resulting from the application of the double gray glazing unit (16%); iv) Double Reflective glazing unit is the solution that offers the best results for the 4 offices under study. The application of this glazing will allow a reduction of the annual energy use of the order of 42%, 44%, 51% and 24% for the offices whose exterior facades are West, East, South and North oriented, respectively.

5.2 Application of XPS thermal insulation on the external walls

Bearing in mind the age of the *Dr. Francisco Gentil* building and the fact that its entire opaque building envelope is currently devoid of any type of insulation, it was decided in this paper to study the potential of energy rehabilitation resulting from the application of thermal insulation on the exterior facade of the study offices. Among the various insulation solutions available in the current market, it was decided to study the implementation of an extruded polystyrene board (XPS) applied either internally or externally.

In order to analyze the energy saving potential of the annual energy use of the office, with regard to the application of the thermal insulation, simulations were performed for its application on the inner or outer facade surfaces, for thicknesses of 2 to 10cm. From the analysis carried out, it was possible to conclude that, in the case of the insulation applied on the outer surface, the results are slightly better and the application of a higher thickness to the detriment of a lower one, in an attempt to improve to the maximum the thermal performance of the office in study is irrelevant in this case. On the other hand, and knowing that the higher the thickness of the insulation board the higher its cost, the results allowed to conclude that it is not justified to adopt a thermal insulation thickness higher than the minimum thickness so that the opaque elements of the building envelope comply with the minimum requirements required by the REH (Regulation on the energy performance of residential buildings). In this work the implementation of 6 cm of XPS thermal insulation to be applied on the outer wall surface, as a proper energy retrofitting measure, will be in the following chapter combined with the glazing that most improved the energy performance of the offices in study.

5.3 Combination of both glazing and wall energy efficiency measures

This chapter discusses two sets of energy efficiency measures to be implemented in the offices. The first set, called set A, combines the application of an extruded polystyrene thermal insulation board (XPS) of 6 cm on the outer wall surface with a double reflective glazing on window openings, whereas the second set, called set B, combines the same extruded polystyrene (XPS) board of 6cm with double gray glazing on window openings.

The annual energy use, covering both heating and cooling seasons, is shown in Figure 9. The results in terms of annual energy use allowed quantifying, by comparison with the original situation, the energy savings promoted by the implementation of the two sets of energy retrofitting measures.

From Figure 9 it is observed that Set A is the intervention measure that yields better energy performance for all offices. The energy savings when this intervention measure is applied are 47% for the Dermatology (West) office, 51% for the Psychology (East) office, 30% and 53% for offices whose facades are North and South oriented, respectively (Figure 9a). As in the analysis of the different types of glazing (Figure 9), the application of this set of measures has a greater relevance in the offices with orientations that induce higher solar gains.

The annual energy use values resulting from the application of set B, although slightly higher than those of set A, are equally lower than those of the original construction. The energy saving resulting from the application of this set of intervention measures is 29%, 34%, 21% and 38% for offices whose exterior facades are oriented to the West, East, North and South, respectively (Figure 9b).

In this way, set A of measures was adopted in the subsequent energy retrofitting analysis towards the building roof, which is presented in the next following chapter of this paper.

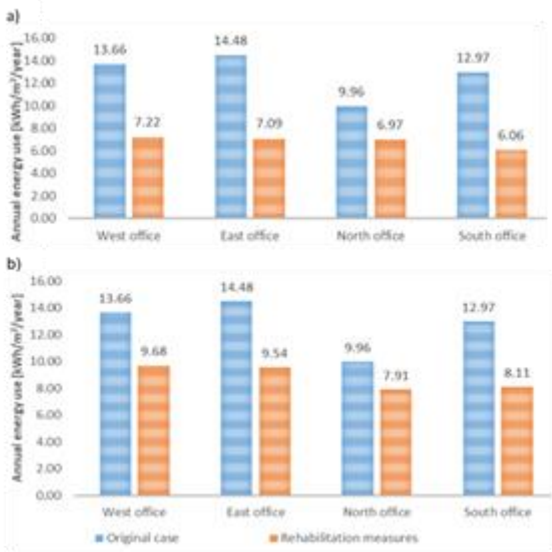

Figure 9. Annual energy use in the 4 offices under study for the original case and scenario in which it is applied: a) set A of energy retrofitting measures; (b) set B of energy retrofitting measures

5.4 Application of XPS thermal insulation on the building rooftop

Once set A of energy retrofitting measures has been selected to be applied to the exterior facade, the combination of set A and an energy retrofitting proposal for the building rooftop is analyzed in this chapter. In fact, although the main case study of this work has been the Dermatology and Psychology offices located in the 2nd floor of the *Dr. Francisco Gentil* building, due to the fact similar offices exist on the last floor, the thermal insulation of the rooftop was also analyzed. As the original constructive solution of the rooftop of the building consists of a layer of plaster (1cm), a reinforced concrete slab (12cm), a layer of light concrete and a ceramic tile (2cm), it was decided to analyze as energy efficiency measure the application of an extruded polystyrene board (XPS) from the outside on the rooftop.

The effect achieved by the implementation of energy efficiency retrofitting measures on both the exterior facade and roof provide a significant annual energy use reduction. The annual energy savings are 49% for offices whose exterior facades are oriented West and East and 37% and 53% for offices whose facades are oriented North and South, respectively. Accordingly, having regard the energy saving in each office, it is assumed that the replacement of the existing glazing by a double reflective glass, as well as the application of 6cm and 7cm extruded polystyrene board (XPS) on the exterior facade and roof, respectively, are a set of intervention measures with satisfactory results and so can be considered as a proper energy rehabilitation proposal for the *Dr. Francisco Gentil* building of IPO of Lisbon.

Figure 10. Annual energy use in the 4 offices under study for: original case and scenario combining the set A of measures on the exterior facade and a 7cm XPS layer on the rooftop.

6. CONCLUSION

Hospitals are buildings characterized by high energy consumption and whose potential for energy savings is quite high. Therefore, a good energy performance not neglecting the thermal/environmental conditions that ensure the well-being of all its occupants is currently of paramount importance. In the present work, the thermal performance of two medical offices, both in the *Dr. Francisco Gentil* building of the Lisbon Oncology Institute (IPO), with different solar exposures, was assessed in the winter and summer season - the Psychology office (East) and the Dermatology office (West) - from measurements of temperatures, solar radiation and heat fluxes on the indoor air and building walls and glazing. The results obtained showed that the indoor air temperature of the medical offices reached in summer values higher than 25ºC, which, according to the literature, are unsuitable from the thermal comfort perspective. With regard to glazing, both surface temperatures and heat fluxes have shown potential of thermal performance improvement, so replacement is recommended. The EnergyPlus program was used on a model of the medical offices, calibrated through the experimental campaign results, to simulate a set of energy efficiency retrofitting measures both on the facade and roof that enhance the thermal performance of the building. From the various intervention measures analyzed, the exterior application of an extruded polystyrene board (XPS) with 6cm on the façade and with 7cm on the roof, and the replacement of the existing glazing by a double reflective glazing revealed to be a proper proposal of energy rehabilitation. The energy savings resulting from the application of these measures in the medical offices of the intermediate and top floors are up to 50%.

REFERENCES

[1] EU, “Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)”, Off. J. Eur. Union, pp. 13-35, 2010.

[2] R. Kameel, E. Khalil, “Thermal comfort VS air quality in air-conditioned healthcare applications”, 36th AIAA thermophysics conference 2003, Orland, Florida, paper no. AIAA-2003-40199 (2003).

[3] C. A. Balaras, E. Dascalaki, A. Gaglia, “HVAC and indoor thermal comfort conditions in hospital operating rooms”, Energy and Building, 39 (2007), pp. 454-470.

[4] J. Murphy, “Temperature and humidity control in surgery rooms”, ASHRAE Journal, 48 (2006), pp. 18-25.

[5] M. Melhado, J.L.M. Hensen, M. Loomans, “Literature review of staff thermal comfort and patient thermal risks in operating rooms”, Proceedings of the 8th International healthy buildings conference, Lisbon, ISIAQ (2006).

[6] P. E. Ninomura, J. Bartley, “New ventilation guidelines for health-care facilities”, ASHRAE Journal (2001), pp. 29-33.

[7] D. Arnaut, “An Intangible Heritage in Use Portuguese Institute of Oncology”, Docomomo Journal, 55 (2016), pp.17-23.

[8] Hukseflux Thermal Sensors User Manual (HFP01 and HFP03 manual v1721), September 2015

[9] EN ISO 9869: 1994 (1994) - “Thermal insulation - Building elements - In-situ Measurement of Thermal Resistance and Thermal Transmittance”.

[10] C. Santos, J. Paiva, “Caracterização térmica de paredes de alvenaria”, LNEC-ITE 12.

[11] R. Gomes, “Condicionamentos climáticos da envolvente dos edifícios para habitação", LNEC (1962).

[12]“Getting Started with EnergyPlus, Basic Concepts Manual – Essential Information you need about running EnergyPlus”, Copyright 1996-2015

[13] IPMVP New Construction Subcommittee, “International Performance Measurement & Verification Protocol: Concepts and Options for Determining Energy Savings in New Construction - Volume III,” Washington, DC, USA, vol. III, no. April, pp. 1–249, 2003.

[14] REH- “Regulamento de Desempenho Energético dos Edifícios de Habitação”, Decreto Lei 118/2013 de 20 de agosto 2013; Diário da República, 2013; pp. 4988-5005, Portugal.