Performance analysis of a double skin façade

Application to a case study

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Extended Abstract

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1. Introduction

Climate change and environmental problems associated with human actions have raised the general public's awareness about the sustainable development of society. In recent years, there has been a growing effort to promote the reduction of greenhouse gas emissions with the aim of mitigating health impacts and minimizing energy use (Chan, 2014). To report and prevent problems such as over consumption of nonrenewable energy, buildings need the application of new technologies with sustainable characteristics (Musa, 2016). One of the requirements of a more sustainable construction is minor use of nonrenewable resources, compatible with the characteristics that the building disposes to be the most independent of this type of energy (Butera, 2005). Another objective is to achieve a maximum functional performance that implies providing thermal comfort in different zones with different climatic conditions (Musa, 2016). That worry must be greater in buildings with large areas of glazing, because of heat exchanged with the surrounding have a significant weight in the energy balance of the building.

The application of a double skin façade (DSF) system benefits from its aesthetic appearance and modern concept, which makes it grow considerably in recent years (Shen, 2016). A double skin façade system is essentially a set of two "skins" mostly of glass separated by an air space (Butera, 2005). This system has the potential to save energy cost in the long term (Musa, 2016). The application of DSF comes as an alternative to a simple glazed curtain façade in order to improve resident comfort, energy consumption and the hygrothermal behavior of buildings.

In the present work, thermal performance of double skin façade is assessed in a post-occupancy building. The objectives of this work are: to understand the concept and classify DSF, identifying their configurations and the way of functioning and pointing out the different advantages and disadvantages of this system; characterize the thermal performance of double skin façade;; to analyze the application to a study case, define the monitoring campaigns, select days of particular interest and examine some parameters such as incident radiation, wind speed and direction in order to assess the thermal behavior of DSF under real operation conditions.

2. Case study

In this study Building H, from the Office Park Expo, Parque das Nações, Lisbon, Portugal was selected as a case study. This building has a plant that forms a double rectangle, with continuous facades, creating two large areas oriented to SE and NW. The building vertical envelope is all glazed, with a double skin façade, Figure 1. This building was been developed to optimize the energy consumption related to the air conditioning.

Figure 1– Photography of the building H.

Four monitoring campaigns were carried out jointly by the National Civil Engineering Laboratory (LNEC) and the Instituto Superior Técnico (IST), whose objective was to increase the knowledge about the double skin façade system, particularly the thermal performance, in the Portuguese climate. Several variables were studied, during different periods of the year, on floors 15 and 16 of the building.

2.1 Building characterization

The building is a naturally ventilated multi-storey double skin façade. The air inlet and exhaust grilles are made up of four inclined blades arranged along the façade alternately, preventing the exhausted air on a given floor from being admitted to the next upper floor. The façade consists of an outer glass, an air gap with the respective shading device and an inner glazing unit, Figure 2.

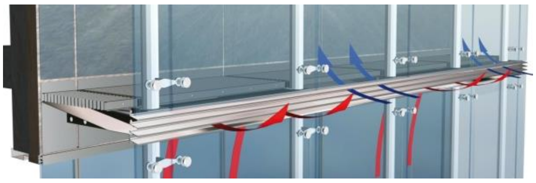

Figure 2 - Ventilation air inlet / exhaust scheme of the DSF (FACAL, n.d.).

This inner pane is not completely glazed because there is an opaque wall with thermal insulation. The shading device was placed between the two skins and is a light-colored rollerblind. The air conditioning system was regulated to maintain an indoor temperature of 25ºC, from Monday to Friday, between 8 am and 6 pm.

2.2 Experimental procedure

The DSF was monitored with 28 thermocouples, thermohygrometers (1 in each of two office and another one abroad) and pyranometers (1 in each façade and another one abroad). For the measurement of the indoor temperature and relative humidity a thermohygrometer was placed in the proximity of the window without being directly exposed to the solar radiation. It is important to note that the indoor temperature was regulated by the HAVAC system. The temperatures of the airgap and surfaces of the FDP panes were measured with thermocouples whose operation is based on the joining of two metals which generates an electrical voltage that is a function of temperature. The thermocouples were placed on the inner and outer face of the inner pane, on the inner face of the shading device, and in the cavity in front and behind the shading device.

Measurement equipment was installed in the Northwest, Southwest and Southeast façades, with weekly data collection, during the monitoring periods. Figure 3 schematizes the location of the sensors.

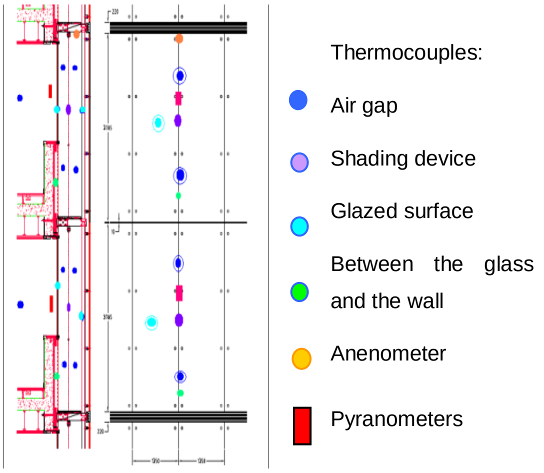

Figure 3 - Planned placement of the monitoring devices in the campaign carried out (FACAL, n.d.).

The installation zone of these equipments was made in the facades NW, SE and NE.

2.3 Characterization of monitoring campaigns

As mentioned, four monitoring campaigns were carried out. The monitoring periods adopted, in order to obtain the data of the different climatic conditions, were divided in the dates presented in Table 1.

Table 1- Campaign time intervals.

Campaign	Start	End
1	2009. 08. 27	2009.10.07
2	2009.12.02	2010.02.10
3	2010.04.26	2010.06.08
4	2010.07.09	2010.08.31

In order to evaluate the performance of the façade, the following variables are represented by:

Indoor temperature (Tint); Outdoor temperature (Text); Temperature of the outer glass (Tve); Shading temperature (Ts); Temperature of the inner glass (Tvi); Air gap temperature, behind the shading (Tai); Air gap temperature, between the shading and the outer pane (Tae); Air gap temperature (Tg); Solar radiation incident on the plane of the facades (RadV).

3. Analysis and discussion of results

3.1 Solar radiation effect

i) Working days under clear sky conditions

On sunny days it is important to draw attention to the solar radiation fluxes incident on the façade. Figure 4 shows the incident solar radiation on SW. Higher values of incident solar radiation were reached in experimental campaign 2, winter season, which can be explained by the lower solar altitude in this season.

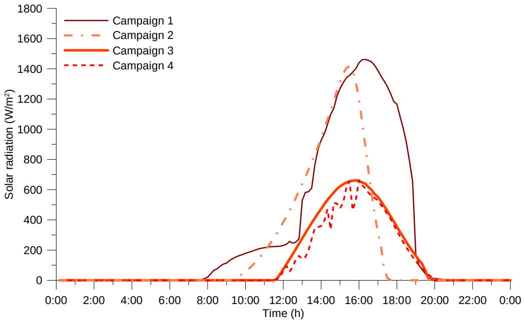

Figure 4 - Radiation in the vertical plane verified in each of the campaigns, working days under clear sky conditions, on the SW facade.

Still on Figure 4, the campaign 4, summer season, presents a profile with some irregularities, in the interval between 12am and 4pm, due to the passage of clouds in that period of time.

By analyzing the temperature difference between the air of the facade channel and the indoor space, in the façades SW and NW, Figures 5 and 6 respectively, it is verified that the campaign 4, summer season, in both façades, presents an always positive differential, which means that the air in the channel is warmer than the indoor environment, which is expected due to the strong incident radiation associated with the high outdoor temperature. This difference is variable throughout the day, with maximum coincident with the heat accumulated in the façade, due to the thermal inertia of the constituent materials, caused by the incidence vertical plane radiation.

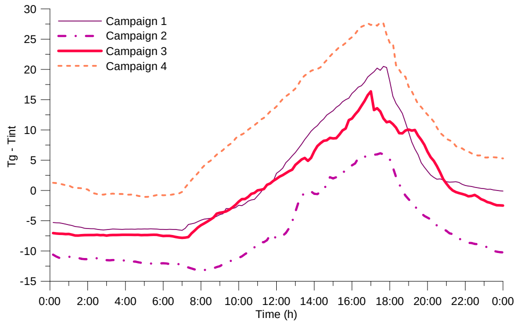

Figure 5 - Temperature difference between airgap and indoors in each of the campaigns, working days under clear sky conditions, on the SW facade.

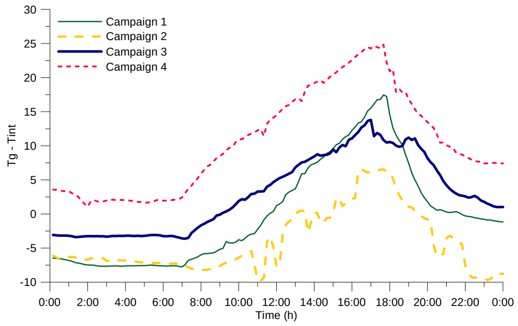

Figure 6 - Temperature difference between airgap and indoors in each of the campaigns, working days under clear sky conditions, on the NW facade.

In the SW facades, Figure 7, the highest temperature is usually that of the outer glass, followed generally by that of the inner pane on the side of the channel. Therefore, in most cases, the temperature of the air is lower among the constituent elements of the facade.

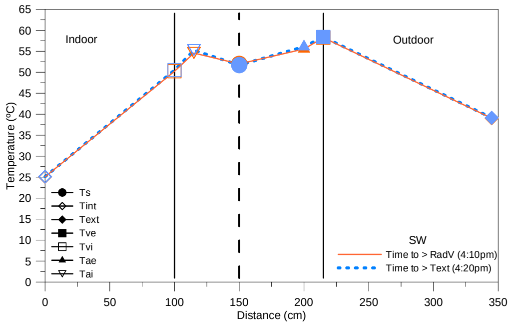

Figure 7 - Horizontal profile of temperature, working days under clear sky conditions, campaign 4 (SW).

In the SE façade, Figure 8, provided there is incident solar radiation, the temperature of the shading device is always higher than the air in the channel, that is, greater than the temperature in front of and behind the shading device, Tae and Tai, respectively. It should be noted that in this façade the shading device reached the highest temperature of all constituent elements at the time the highest value of radiation in the vertical plane was recorded.

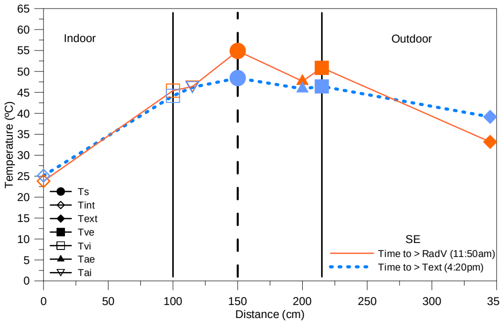

Figure 8- Horizontal profile of temperature, Working days under clear sky conditions, campaign 4 (SE).

In the NW façade, this behavior is less evident and only occurs at the time of day when there is a higher solar incidence, as shown in the horizontal profile referring to the time at which the maximum solar radiation was reached. Outside this period, the gradient of temperature is practically zero, with all the constituent elements of the façade having very similar temperatures.

ii) Working days under overcast sky conditions

Figures 9 and 10 present the solar radiation on the vertical plane, on cloudy days, on the SW and SE facades, respectively. In all façades, lower intensities of solar radiation were observed, when compared to days under clear sky conditions. Moreover, a higher variability of incident solar radiation, throughout the day was observed, corresponding to the phenomenon of cloudiness. Campaign 3, spring season, carried out in May, is the one that reaches the highest radiation values in the SE façade, Figure 9. In the SW facade, the campaign 2, winter season, is the one that stands out with higher values of vertical radiation, because in winter season the height of the sun is smaller and a vertical surface facing south receives the solar radiation for longer than one with any other orientation, Figure 10.

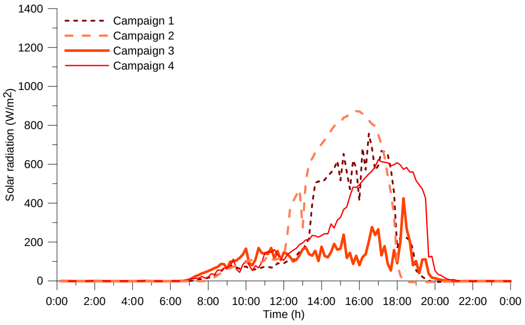

Figure 9 - Radiation in the vertical plane verified in each of the campaigns, Working days under overcast sky conditions, on the SW facade.

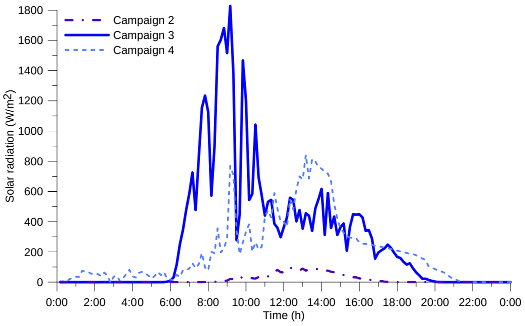

Figure 10 - Radiation in the vertical plane verified in each of the campaigns, Working days under overcast sky conditions, on the SE facade.

As on sunny days, on the NW façade, campaign 2, winter season, there were low values of incident radiation.

The values of the temperature difference between the air of the channel and the interior, present a similar behavior in the façades SW and NW, Figures 11 and 12, respectively. Campaigns 1, end of summer season, and 4, summer season, recorded positive differences between 10 am and 8 pm, that is, airgap is warmer than indoors, period of time when there was solar radiation.

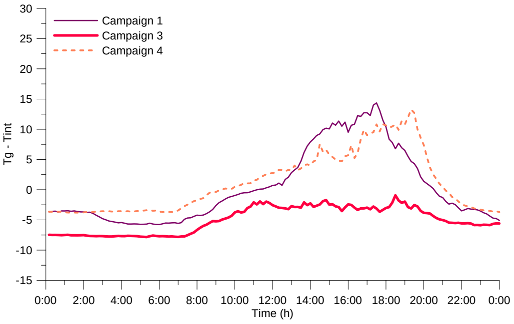

Figure 11 - Temperature difference between channel air and interior space in each of the campaigns, Working days under overcast sky conditions, on the SW facade

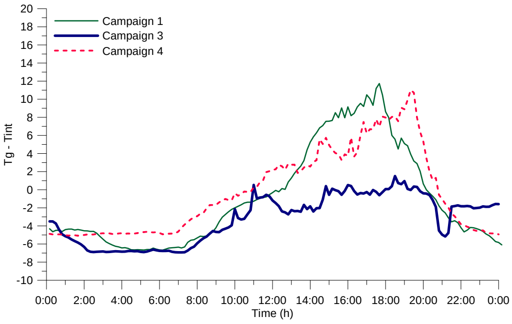

Figure 12 - Temperature difference between channel air and interior space in each of the campaigns working days under overcast sky conditions, on the NW facade.

Due to the cloudiness, the temperatures of the shading device remain close to the temperatures of the glazed cloths, Figure 13.

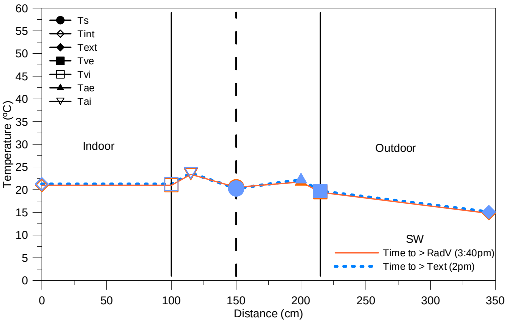

Figure 13 - Horizontal profile of temperature, working days under overcast skies conditions, campaign 2 (SW).

Except for campaign 4, summer season, SW façade, at the time when the maximum value of solar radiation was reached, the highest temperature in the outer glass was highlighted, Figure 14.

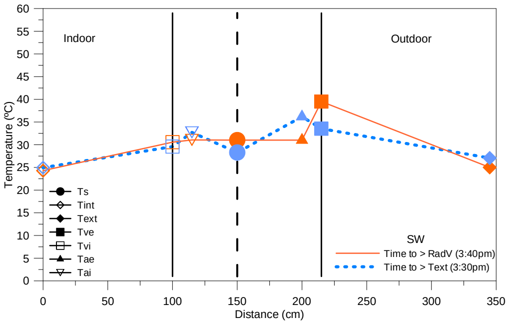

Figure 14 - Horizontal profile of temperature, Working days under overcast sky conditions, campaign 4 (SW).

iii) Weekend days under clear sky conditions

On weekend days under clear sky conditions, the horizontal temperature profiles show that the inner glass generally has the lowest temperature. The Campaign 4, summer season, shows that on the façade SW, Figure 15, the air temperature in the cavity reaches higher values than any other constituent element of the façade, such behavior is the same as in campaign 3, spring season, and 4, summer season, on the SW façade, on working days under clear sky conditions.

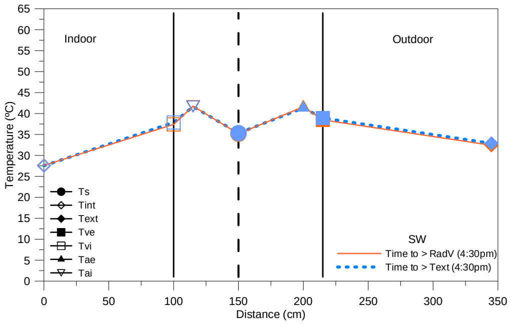

Figure 15 - Horizontal profile of temperature, weekend days under overcast skies conditions, campaign 4 (SW).

Campaign 1, end of summer season, reaches higher temperature values than campaign 4, summer season, because the vertical incident solar radiation was more intense in the first campaign, as shown in Figure 16.

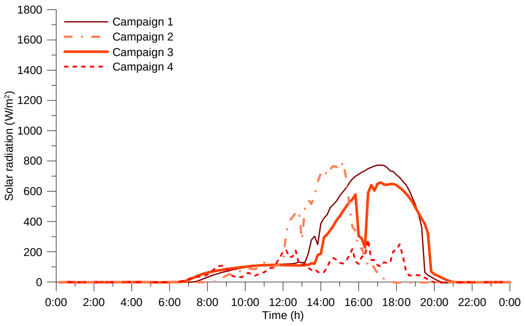

Figure 16 - Radiation in the vertical plane verified in each of the campaigns, weekend days under clear sky conditions on the SW facade.

iv) Weekend days under overcast sky conditions

The behavior of horizontal temperature profiles on weekend days under overcast sky conditions is generally the same as cloudy working days. The possible variations are due only to the variability dependence of cloudiness.

Campaign 3, spring season, Figure 17, presents a very uniform temperature profile indicating a stronger and permanent cloudiness.

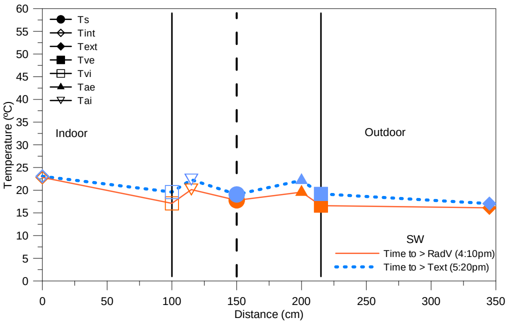

Figure 17 - Horizontal profile of temperature, weekend days under overcast skies conditions, campaign 3 (SW).

3.2 Wind effect

i) Working days under clear sky conditions

During the night, the positive differential observed in campaign 4, summer season, on the SE façade, Figure 18, refers to the fact that the wind affects NO-NE, Figure 19. It was concluded that on the NE façade, the pressure coefficients are positive up to 5pm and it is possible that the air flow has circulated through the SE façade until to the façade facing SW. The SW façade shows lower pressure coefficients, so most of the air will leave this façade, because the air flow always follows the direction of the lowest pressure coefficient, and the larger the amount of air in circulation, the lower the difference between the airgap and the indoor.

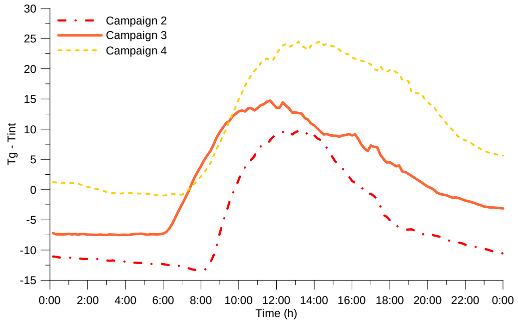

Figure 18 - Temperature difference between channel air and interior space in each of the campaigns, on working days under clear sky conditions, on the SE facade.

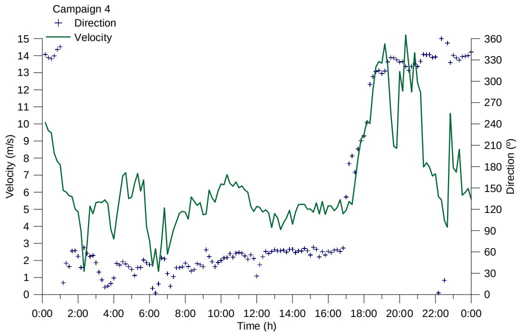

Figure 19 - Wind speed and direction working days under clear sky conditions, campaign 4.

ii) Working days under overcast sky conditions

On cloudy days, the effect of solar radiation is less significant than on sunny days, and the contribution of the wind pressure variation in the air circulation in the façade is more significant. In campaign 2, winter season, the night stratification is evident in the NW façade, Figure 20. This may be due to the wind action which maintained a constant North incidence and velocity values approximately between 0 ms^{-1} and 6 ms^{-1}, Figure 21.

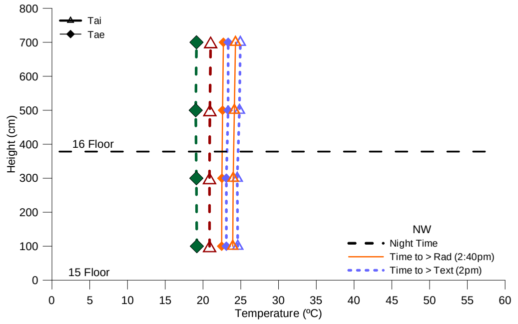

Figure 20 – Vertical profile of temperature, working days under overcast sky conditions, campaign 2 (NW).

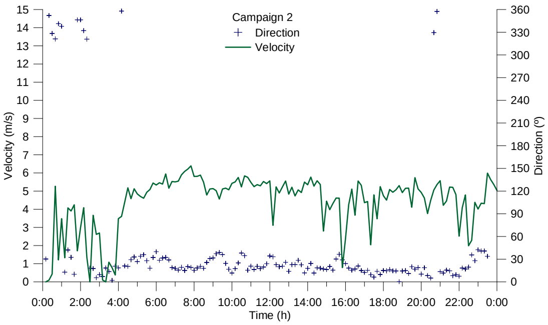

Figure 21 - Wind speed and direction on working days under overcast sky conditions, campaign 2.

iii) Weekend days under clear sky conditions

In the winter, the wind speed reached values close to zero, during the night, consequently, almost zero pressure differentials. Nevertheless, the temperature difference between the air of the canal and the inner space in this period of time is positive, Figure 22. This is due to the phenomenon of heat release on the façade due to thermal inertia.

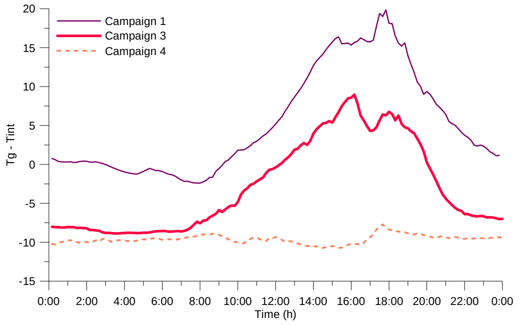

Figure 22 - Temperature difference between channel air and interior space in each of the campaigns, on weekend days under clear sky conditions, on the SW facade.

iv) Weekend days under overcast sky conditions

In campaign 3, it is verified a reversal in the vertical profiles of temperature, Figure 23. Through the contribution of both radiation and wind, the air in the channel heats up, the temperature is increased, and the air flow is upward.

Therefore, a decrease of temperatures near the upper openings indicates a possible air recirculation near the top of the air cavity. In fact, outdoor air may enter on the upper opening which could cool the top of the channel, i.e. the thermal effect causes the air to remain at the top of the channel and, as a sufficient wind pressure differential is not reached, the airflow does not go down.

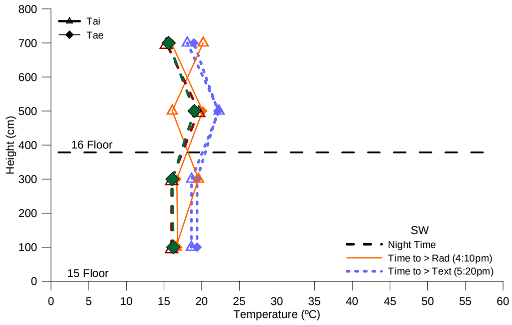

Figure 23 - Vertical profile of temperature, weekend days under overcast sky conditions, campaign 3 (SW).

4. Conclusions

The temperature variation on the façade is very dependent on incident solar radiation.

During the day, horizontal and vertical temperature profiles are mostly influenced by incident solar radiation, generally reaching higher temperature values in the outer glazing pane. It is concluded that the application of shading devices between glazed panes provides lower values of temperature in the innermost channel, compared to the outermost channel. It is observed that the shading device inside the cavity between the glazed panels contributes significantly to the thermal performance of the double skin facade and therefore a careful choice of either the material or the position is of upmost importance. Also, the fact that the inner glass is characterized by having a low coefficient of thermal transmittance implies a reduction in the passage of heat from the airgap to the interior of the building.

Glazed façades facing south will have a higher incidence of solar radiation. Even with the reduction of solar gain through the application of a shading device, on a DSF airgap spaces with that orientation continue to require a greater amount of energy to cool the interior spaces throughout the day. Against the south-facing façades, the north-facing façades indicate a lower incidence of solar radiation and this will allow savings in annual energy consumption to cool the indoor environment.

It is also important to refer that it was very useful to acquire data on weekend days, because in these days the air conditioning system was not activated and this allowed gathering conditions necessary to evaluate the performance of the façade without the support of the air conditioning system. It was verified that in cases of weekend days under overcast sky conditions the north-facing building rooms will reach the lowest values of indoor temperature both in winter and summer.

In campaign 2, corresponding to winter, temperatures inside the façade were higher than the outdoor air temperature, both during the day and the night. The temperature gradient is directly related to the incident solar radiation, or, during the night, to the thermal inertia of the components of the facade. The thermal inertia of the building materials of the DSF allows that even at night the airgap temperature values of the façade remain higher than those registered abroad, even at low flow rates.

It was found that, at night, the temperature values recorded on the façade are similar to the outside air temperature and, during the day, the temperature values were correlated with the incident solar radiation on the façade.

It was concluded that the difference between the indoor and outdoor temperatures was highest during the winter season because the highest values of solar radiation in the vertical plane and the lowest values of the outdoor temperature were recorded at that season.

In addition to the incident radiation, in double skin facade systems with natural ventilation, the wind also has an influence on the performance of this system of facades. It should be noted that when the natural ventilation is not efficient the temperatures inside the gap rises.

Sometimes, it is observed in the vertical profile of the airgap temperatures that there is lower temperature values next to the upper exhaust openings when it was expected that, the temperature of the air increases in height, from the floor to the top. It is important to evaluate the building as a whole and to understand the displacement of the air flow. For that, the values of the wind pressure coefficients on each façade openings which are also dependent on the direction the wind, were analyzed. It was concluded that, the air flow behavior has a significant contribution with respect to the air temperature variation in the gap.

During the night, when there is no variation of pressures due to thermal effect because the air temperature in the air channel is almost equal to the outdoor temperature, the ventilation flow continues to exist, due to the influence that the wind exerts, causing a difference of pressures between the upper and lower opennings. It is concluded that, when air flow rates are insignificant, due to natural ventilation on the façade, there is a trend towards considerably higher temperature values.

Finally, the system of double skin façades are very promising constructive elements with respect to improving the thermal behavior of buildings with high glazing areas. At the same time they have the ability to save energy spent on air conditioning equipment. However, the high complexity, rigor and requirements for a typology that could not compromise the overall performance of the system, and the initial investment can prevent further integration of this solution in the construction market. The development of a DSF should take into account the type of use of the building, so that data on the internal gains are available and the heat exchanges and the area where it is located are conveniently studied.

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