THERMAL ANALISYS BEHAVIOR OF PORCELAINIZED STONEWARE VENTILATED FACADE WITHOUT THERMAL INSULATION IN SUBTROPICAL CLIMATE - BRAZIL

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ABSTRACT

In Brazil, the ventilated facade tiling system in buildings is still little used. The main objective of this study is to analyse comparatively the thermal behaviour of a ventilated facade without thermal insulation material and a conventional facade, in the summer and winter conditions of southern Brazil (sub-tropical climate) and under conditions of an air chamber with ventilation. Thermal measurements were made (24 h) in both facade panels (ventilated and conventional) during three months of summer and winter, using temperature sensors and heat flux transducers, whose signals were acquired with a system composed of 10 bits A/D converter, 11 channels, communicating with a microcomputer. With regard to the thermal behaviour of the ventilated facade with an air chamber open at its upper and lower ends, it was evidenced that energy gains in the interior ambient, in 24 h, were around 1.8 times lower than those verified in the conventional facade, on characteristic summer days with sunny weather. The highest values of the relation q_2/q_1 *(conventional facade heat flux / ventilated facade heat flux) were approximately 5.0 at 12:30 h on the two days, occurring in periods of increased solar radiation. On characteristic winter days with sunny weather, the ventilated facade practically did not present heat gain. This ventilated facade thermal behaviour is harmful in relation to thermal efficiency, when compared with the conventional facade. An alternative, in order to increase heat gains in the ventilated facade on sunny winter days, would be to close the air chamber upper and lower ends, so as not to have ventilation.*

1. INTRODUCTION

The building external covering system known as a ventilated facade is characterized by ventilation in an air chamber, as shown in the system scheme in Figure 1. Ventilation is the current of temperature differences between the chamber interior air and exterior ambient air. In this way, an ascending airflow originates with heating of this air in the chamber interior. Moreover, pressure differences in the ventilated air chamber interior, due to wind action, also contribute to ventilation (Schweizer Ingenieur und Architekt, 1985). In Brazil, modular panels for buildings facades are sometimes used, however the ventilated facade tiling system is still little used. Technical norms such as DIN 18516: Part 1 (1999), DIN 18516: Part 3 (1990) and DIN 18516: Part 5 (1999), as well as authors as Fliesen und Platten (1988), Karl (1997) and IEMB (1998), describe the constructive aspects of the ventilated facade system.

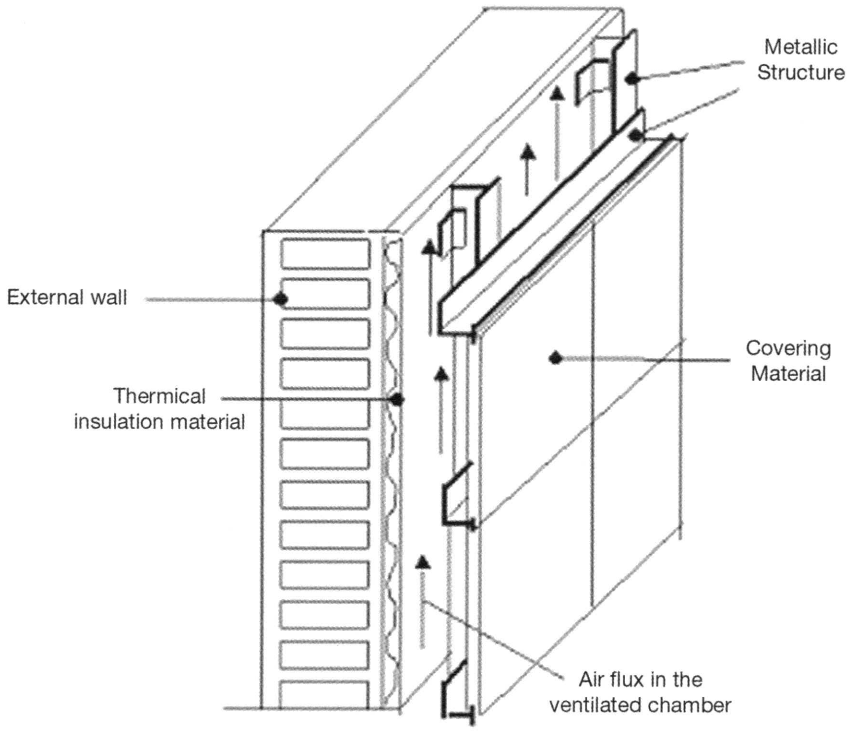

Figure 1. Scheme of ventilated facade covering system.

In summer, a significant part of the heat that is transferred from the covering material to the air chamber is eliminated from the ventilated facade system due to ascending warm airflow. In this way, only a reduced fraction of heat that is transferred by the covering material reaches the building interior (Schweizer Ingenieur und Architekt (1985)). Thus, there is an improvement of facade thermal insulation and, consequently, thermal comfort in building internal environments. In winter, heating systems of building internal environments are normally used in cold climate countries. Using the ventilated facade system in these countries evidences adequate heat retention in interior environments, due to thermal insulation material used on the exterior surface of external wall.

In Italy, Meroni et al. (1991) had analysed the hygrothermal behaviour of a building developed for studies with a ventilated facade with thermal insulation material. To adequately simulate the conditions of an inhabited building, a temperature around 20° C was maintained in the internal environments of the three floors, using a heating system. A superficial temperature gradient in ventilated facade was evidenced between the building floors, in day periods with insolation, in virtue of the ascending heat flux in a continuous executed air chamber, which increased the temperature in the higher floors.

Lorente (2002) studied heat transfer in a wall ventilated with glass as covering material. The results obtained in summer conditions demonstrate that in the ventilated wall internal lower surface temperatures were verified to those found in a conventional wall during all 24 hours. However, the difference between these internal superficial temperatures in the ventilated wall and in the conventional wall became more significant as solar radiation increased.

The ventilated facade tiling system without the use of thermal insulation material, is presumably the most suitable solution in the subtropical climate conditions of southern Brazil; therefore in winter it is desirable to achieve heat gains in internal building ambients due to insolation. Normally heating systems do not exist in country buildings. The aim of this work is to analyse comparatively the thermal behaviour of a ventilated facade without the use of thermal insulation material and a conventional facade, both with porcelainized stoneware tiles, in the summer and winter conditions of southern Brazil (subtropical climate).

2. MATERIALS AND METHODS

A procedure for no-pass cylindrical holes executed in tiles corners was developed, where expander screws for fixing were inserted. Metallic bars were also developed to constitute the supporting structure of the ventilated facade prototype. A building was executed with an air-conditioned ambient in Tijucas, SC, city (near Florianópolis – latitude 27°03'S, longitude 48°45'W), measuring 600.0x200.0x300.0 cm (Figure 2). The building is made up of a pillars and beams structure of reinforced concrete with in-fills of solid ceramic bricks and having only one opening, which is the access door in the south facade. A form-moulded slab for building covering was executed and on its top a roof with asbestos roofing tiles.

Figure 2. General view of the building with the panels of the ventilated facade prototype and conventional facade.

A ventilated facade panel (269.5x269.5 cm) was executed with porcelainized stoneware tiles in 44.85x44.85 cm nominal dimensions, in grey colour. This colour presents an intermediate absorptivity between the low absorptivity of white colour and the high one of black colour. The sides of the ventilated facade panel had been closed with isopor. The air chamber width in the ventilated facade panel was 17.25 cm. The ventilated facade presents geometric relations that characterize a very ventilated air chamber, as defined by Brazilian draft norm CE:02:135.07-003: Part 2.

No problems were verified related to the union between screws and tiles, nor problems related to the bending strength of tiles with holes and fixed with the screws, during approximately two years of observation.

In the panel adjacent to the ventilated facade, porcelainized stoneware tiles were fixed with mortar, which presented the same characteristics as those used in the ventilated facade panel. The normal to building external wall with the conventional facade and the ventilated facade panels presents an orientation of approximately 20° in relation to magnetic north and 2°30′ in relation to true north, so that it practically receives insolation during all daylight.

Measurements were made in summer and winter as well as of the conditions of the ventilated facade air chamber with open upper/lower ends (with ventilation). In summer, the conditioning air (10,000 BTUs) was adjusted to operate in a cooling way. In winter it was adjusted to operate in a heating way. The aim of the use of conditioning air was to keep a steady internal temperature in the building interior and also to have a significant temperature difference between interior and exterior ambients. In the conditioning air exit, a wooden deflector plate was placed in order to reduce the air circulation intensity in the building interior; and keep the equipment measurements thus from being affected.

We used integrated temperature sensors LM35 - National Semiconductors, T092 encapsulating (diameter 5.0 mm; height 5.0 mm), which supply a voltage in function of temperature (10 mV/°C). A sensor is shown in Figure 3(a). The measurement uncertainty of these sensors is estimated at 0.3°C. The sensors for superficial temperature measurement had been glued with silicon and their connection handle fixed with aluminized ribbon of a grey colour. The connection handle was also fixed on the surface to reduce the thermal bridge effect. The sensors for air temperature measurement (T_2, T_5 and T_8 in Figure 4) was hung. The sensor for external temperature measurement (T_5 in Figure 4) was protected with a recipient wrapped in aluminized paper.

To measure heat flux we used fluximeters of the "tangential gradient" type with 10.0x10.0 cm dimensions, which had been constructed in the LMPT laboratory of UFSC (Figure 3(b)). This is a sensor with great sensitivity (70 mV/(W/m^2)) and small thickness (300 mm), allowing the heat flux measurement in walls with a minimum of disturbance (Güths, 1995). The fluximeters had been glued with silicon and painted with white ink.

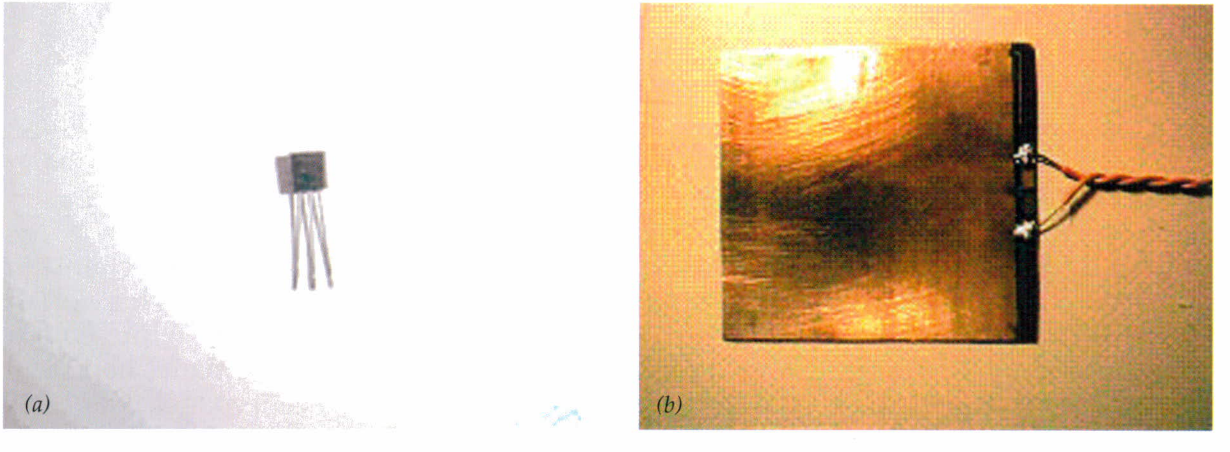

Figure 3. Integrated temperature sensors LM35 - National Semiconductos (a) and "tangential gradient" fluximeter (b).

Figure 4 shows, in building vertical cuts, the temperature sensors and fluximeter positions in the ventilated facade panel and the conventional facade panel, respectively. Temperature sensors T_1, T_2, T_3 and T_6 and fluximeter 1 had been located approximately in the middle of the ventilated facade panel length. Temperature sensors T_4 and T_7 and fluximeter 2 had been located approximately in the middle of the conventional facade panel length. The T_8 sensor (internal temperature) was located approximately in the middle of the building length, while the temperature sensor T_5 (external temperature) was located in the south wall next to the corner with the building west wall, protected from solar radiation incidence.

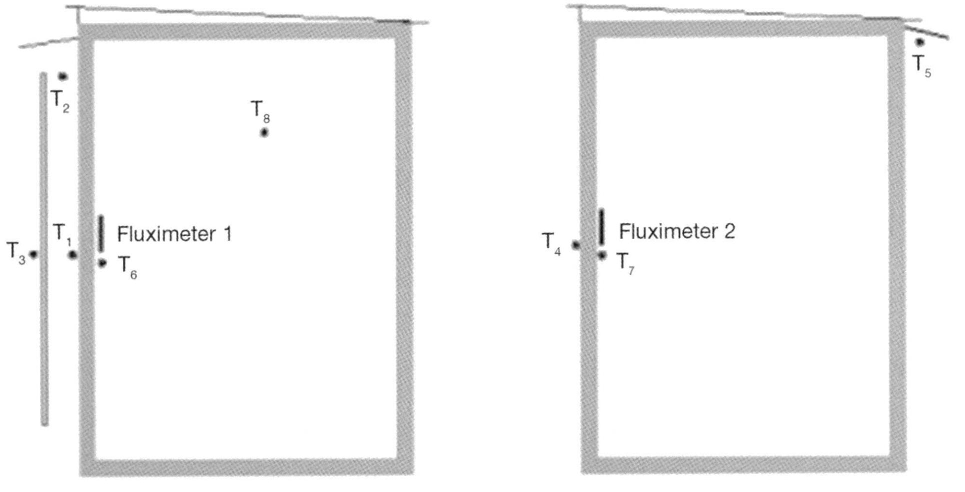

Figure 4. Temperature sensors and fluximeter position in the ventilated facade and the conventional facade, respectively.

Signals were acquired by a system equally developed in LMPT laboratory, consisting of an Analog/Digital converter (A/D) of 10 bits, 11 channels, which communicated with a microcomputer through the parallel port. The channels were swept each second and average values stored in disk each 10 minutes. The data acquisition was made during three summer and winter months in 2002 year. We processed the heat flux and temperature data obtained on every day of measurement. To condense the results, we have extracted the two last days of a consecutive three days series that were representative of summer and winter conditions on days with sunny weather and on days with cloudy weather.

3. RESULTS

Figures 5 and 6 show the relation between the facade incident solar radiation values and differences between the facade external superficial temperatures and external ambient temperatures, for characteristic days with sunny and cloudy weather. On sunny days, it can be observed that the differences between the superficial and external temperatures are greater than on the cloudy days. The solar radiation data was obtained in the Solar Energy laboratory solarimetric station of the UFSC, which lies at a distance of approximately 30 km in a straight-line from Tijucas, SC, city. Facade incident solar radiation values were calculated from the radiation data obtained in the solarimetric station. Equations were used for the calculation of incident solar radiation in inclined planes given by Iqbal (1983), from data of incident radiation in the horizontal plane.

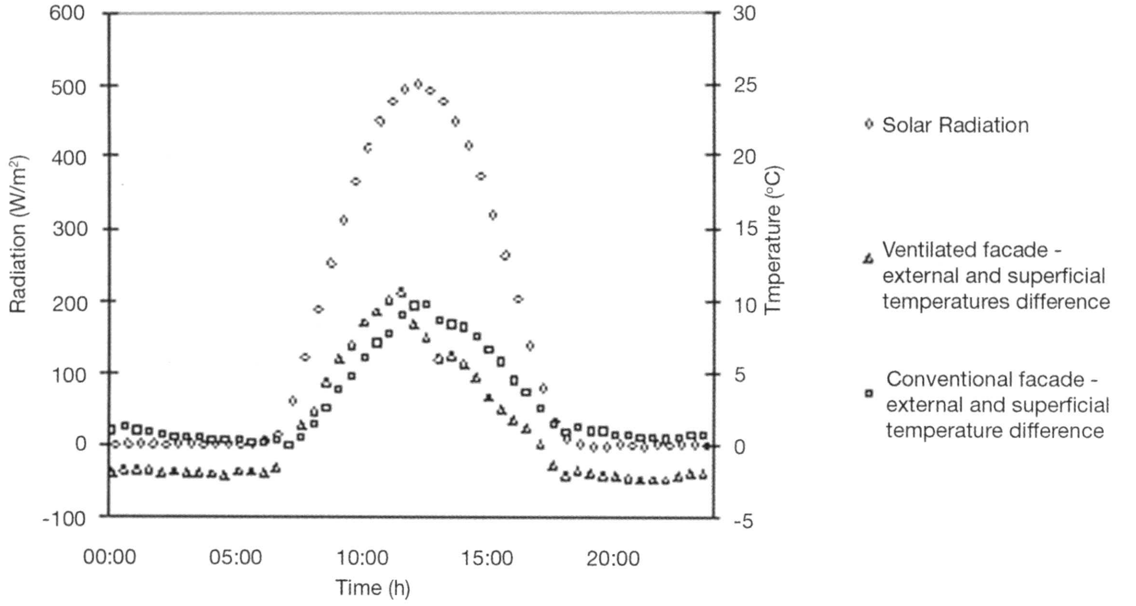

Figure 5. Relation between incident solar radiation values and differences between superficial and external temperatures on a characteristic day with sunny weather for ventilated and conventional facades.

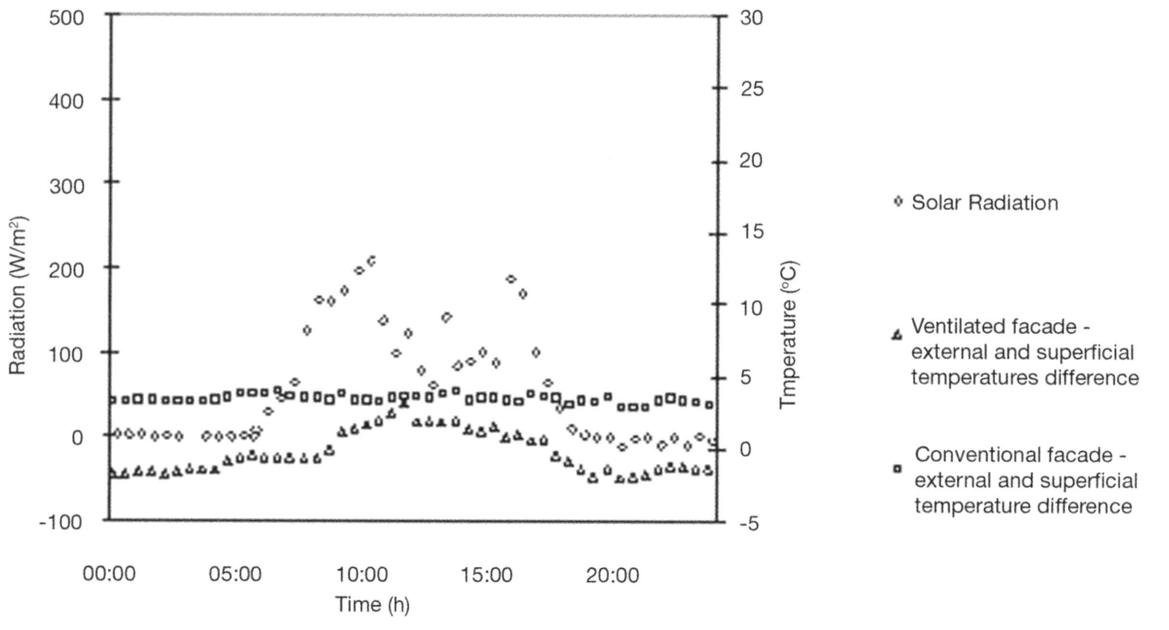

Figure 6. Relation between incident solar radiation values and differences between superficial and external temperatures in characteristic day with cloudy weather.

3.1. SUMMER CONDITIONS

On characteristic summer days with sunny weather, i.e., with greater differences between external superficial temperatures in the facade panels (sensors T_3 and T_4 in Figure 4) and external ambient temperatures (sensory T_5), we determined the external ambient temperatures and the building internal temperatures (sensor T_8) shown in Figure 7. It can be observed that the air conditioning system was not powerful enough to keep the building internal temperature constant. However, the air conditioning system kept internal temperatures below external temperatures, reaching difference maximums of approximately 11°C around midday, on the two days. The minimum values of the difference between internal and external temperatures were around 2°C during the night, on the two days. A thermal delay of approximately 4:00 h between internal and external temperatures can still be noted.

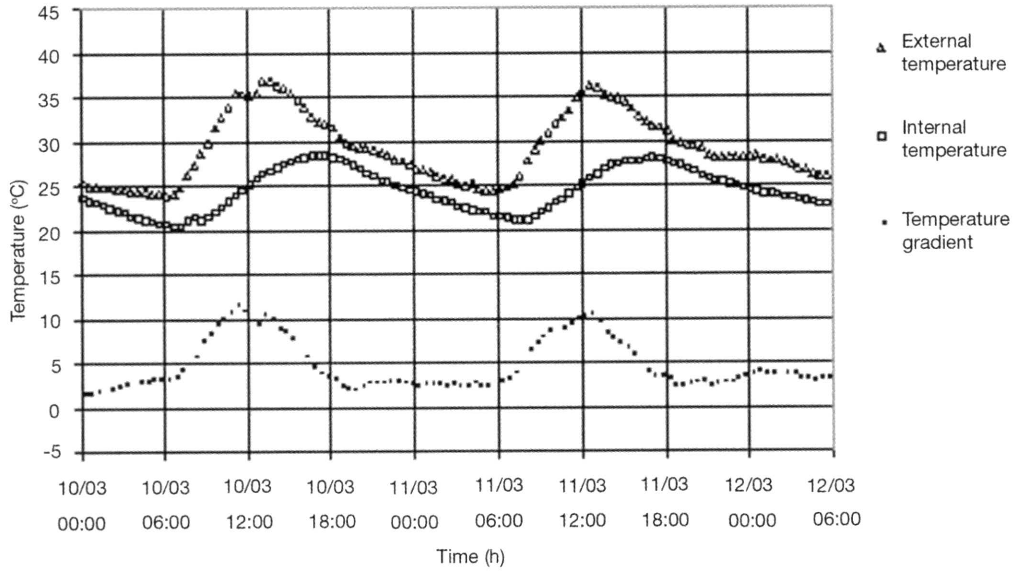

Figure 7. External and internal temperatures in the condition of summer with sunny weather (with ventilation in the air chamber).

Figure 8 presents the differences between external superficial temperatures in facades and temperatures in the external ambient, with maximum values in the ventilated facade tiling system around 10°C around midday, on the two characteristic days. In the conventional facade tiling system, maximum values of difference between superficial and external temperatures around 9°C had been verified around midday, on the two days.

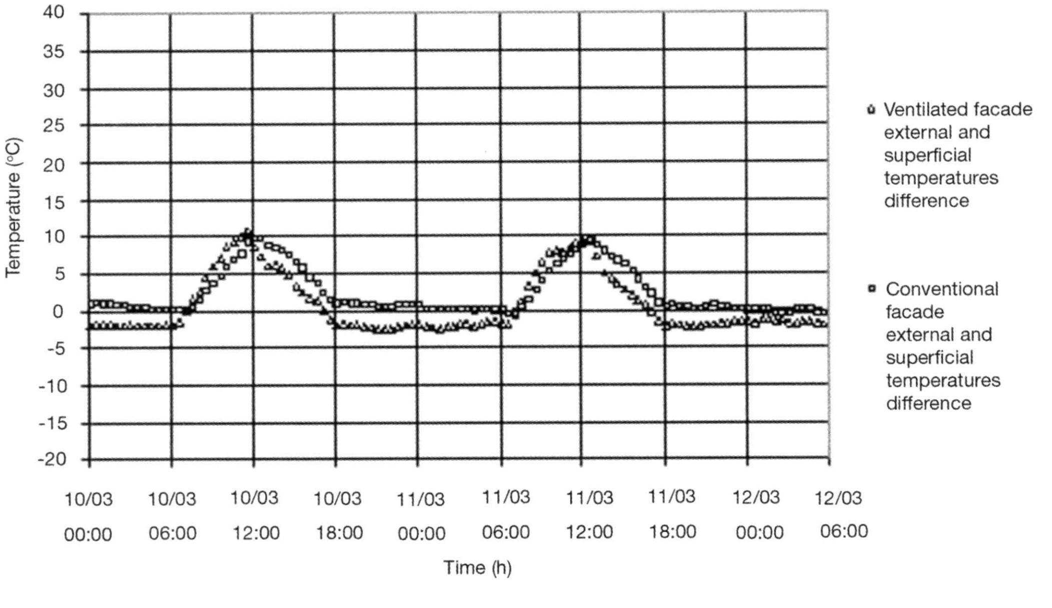

Figure 8. Differences between external superficial temperatures and external ambient temperatures on the analysed days.

Figure 9 shows the heat flux values in the facade tiling systems, verifying maximum values of heat gain of approximately 33 W/m^2 in the conventional facade tiling system, at 15:30 h, on the two consecutive days. In the panel of the ventilated facade tiling system, without thermal insulation material, significantly lower maximum values were evidenced, around 14 W/m^2 during the nocturnal period, on the two days.

In this manner, differences around 58% between the maximum heat gains in the two facade tiling systems are verified. In the present study, the heat gains of the internal ambient are considered positive values, i.e., the heat flux from the exterior to the building interior, while the heat losses of the internal environment are considered negative values.

Integrating the heat flux curves in a 24-hour period, we obtained an energy gain around 1,7 x 10^6 J/m^2 for the conventional facade (E_2) and around 9,2 x 10^5 J/m^2 for the ventilated facade (E_1). The relation between energy gains in the facades tiling systems (E_2/E_1) is 1,8. There is a time difference of approximately 6:00 h, on the two days, between the heat gains peaks in the two facade tiling systems.

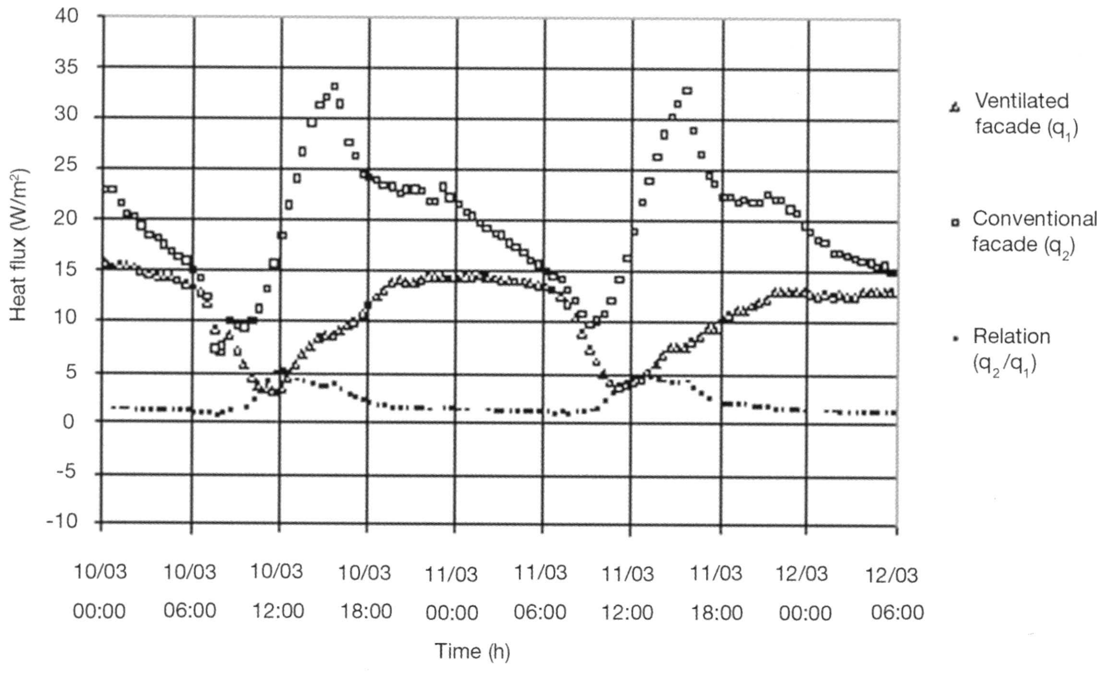

Figure 9. Heat fluxes in the facades (with ventilation in the air chamber) and relation q_2/q_1 in the condition of summer with sunny time.

The relation (q_2/q_1) between the heat fluxes in the conventional facade (q_2/q_1) and in the ventilated facade (q_2/q_1) can be considered the efficiency of the tiling system with a ventilated air chamber in relation to thermal insulation. The q_2/q_1 relation in the set analysis condition presents a gradual increase from approximately 8:00 h, reaching maximum values around 5,0 at 12:30 h, on the two consecutive days. From this time it is noted that there is a gradual reduction of the q_2/q_1 relation values, reaching values of about 1.1 around 6:30 h of the following day. In function of the experimental uncertainties, the ratio q_2/q_1 presents an uncertainty of ± 0,1.

Thus, the ventilated facade system without thermal insulation material, with the air chamber with open upper/lower ends, presented significantly lower heat gains and greater efficiency in relation to thermal insulation on summer days with sunny weather, when compared with a conventional facade system. Only, on the first day, some relation q_2/q_1 values lower than 1.1 occurred between 6:30 h and 8:00 h.

The highest values of the q_2/q_1 relation occurred in periods in which solar radiation increased and raised the differences between facade external superficial temperatures and external ambient temperatures, so that the conventional facade system presented proportionally greater heat fluxes. This is due to the fact that in the conventional facade system, mechanisms of conduction heat transfer between the different materials layers mainly occur. In the ventilated facade system, the increased solar radiation and the differences between the superficial and external temperatures are less significant in virtue of convection mechanisms that occur in heat transfer of the ceramic sheets to the air in the ventilated chamber and from this to the external wall, which allows part of the heat part to be eliminated from the system.

3.2. WINTER CONDITIONS

On characteristic winter days with sunny weather, the building internal temperature remained above the external temperature. The difference between internal and external temperatures presented a minimum of 3°C around midday on the second day, and maximums of approximately 17°C around midnight on the two days (Figure 10).

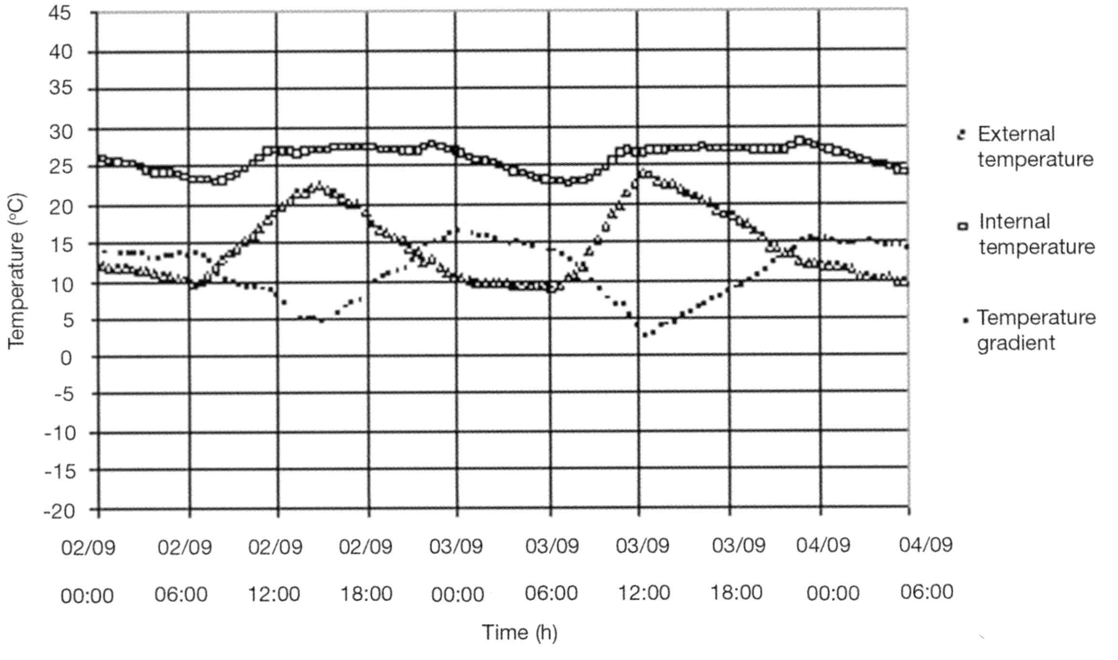

Figure 10. External and internal temperatures in the condition of winter with sunny weather (with ventilation in the air chamber).

The differences between facades external superficial temperatures and external ambient temperatures on the two days are presented in Figure 11. It shows that in the ventilated facade tiling system and in the conventional facade tiling system maximum values of these differences occurred of about 16°C around midday, on the second day.

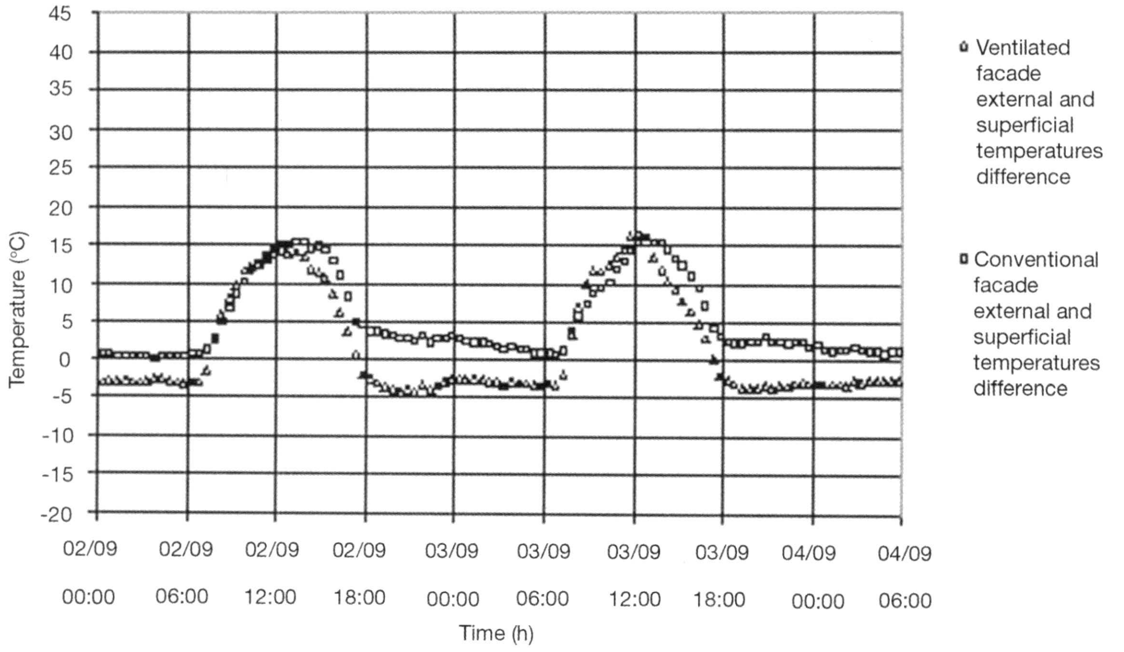

Figure 11. Diferences between external superficial temperatures and external ambient temperatures on the analysed days.

The conventional facade tiling system presented maximum heat gains around 22 W/m^2, around 16:30 h, on the two consecutive days (Figure 12). During dawn and morning, heat loss occurs reaching a peak of approximately 13 W/m^2 at 9:00 h, on the two days. Integrating the heat flux curve, a energy gain was found of 5,8 x 10^5 J/m^2, during the afternoon and night until around midnight, on first day, whose value was a little higher than that verified on the second day. The maximum energy loss is 3,6 x 10^5 J/m^2, during the dawn and morning, on the first day, resulting in a net balance of 10^5 x J/m^2 during the 24 h period.

The ventilated facade tiling system with open upper/lower ends of the air chamber practically did not present heat gain. Heat loss of up to 17 W/m^2 was verified, at 11:00 h, on the second day (difference of 24% between the facade tiling systems). The energy net balance during the period of 24 h results in a loss of 5,9 x 10^5 J/m^2 for the ventilated facade, on the first day. The ventilated facade thermal delay is still noted. This thermal behaviour verified in the ventilated facade with open upper/lower ends of the air chamber is harmful in relation to thermal efficiency, when compared with the conventional facade, considering that heat gains in building internal ambients are desirable in winter. The conventional facade system mainly presents heat conduction mechanisms between the constituent materials, which allow a greater heat gain due to insolation in winter.

The relation q_2/q_1 does not adequately represent the efficiency of the ventilated facade system in certain periods in the present condition. During daylight an inversion occurs in the heat flux direction in the conventional facade system, i.e., around 12:00 h heat loss reverses to heat gain, while the ventilated facade system continues losing heat.

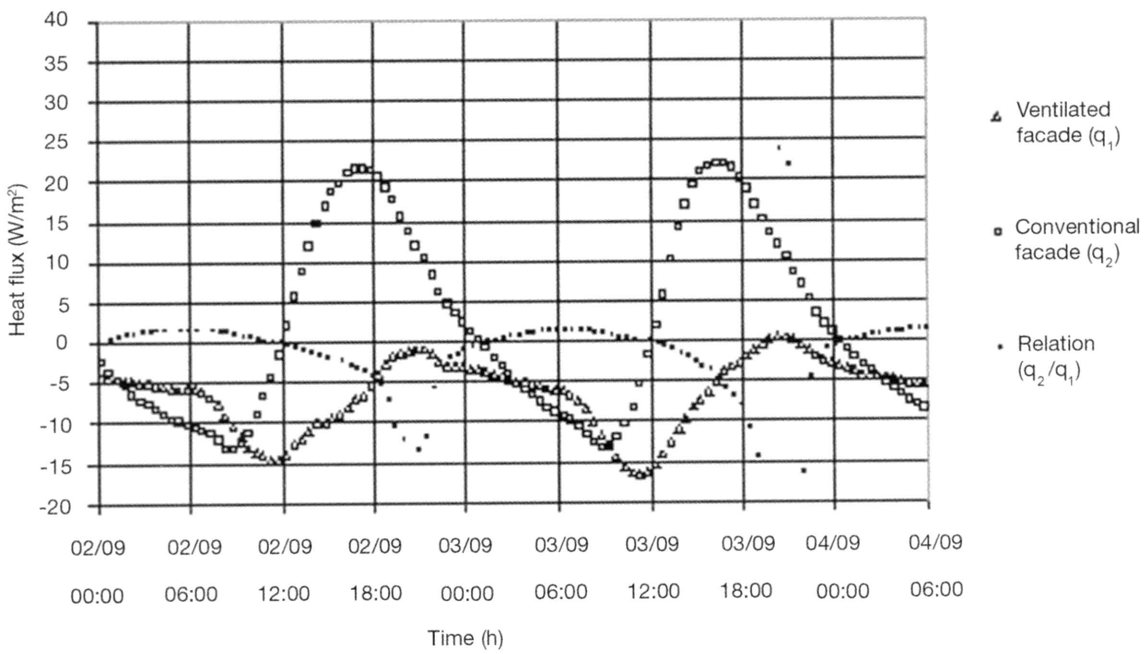

Figure 12. Heat fluxes in the facades (with ventilation in the air chamber) and relation q_2/q_1 in the condition of winter with sunny weather.

Between 00:00 h and 12:00 h approximately, both systems lose heat and the relation q_2/q_1 allows verifying ventilated facade system efficiency. Relation q_2/q_1 values superior to 1.1 are verified between 2:00 h and 8:30 h, on the first day, and 4:00 h and 8:30 h, on the second day. The maximum value of the relation in these periods is 1,8, at 7:00 h, on the first day. Therefore, the conventional facade system lost more significant heat amounts than the ventilated facade system in these periods. Relation q_2/q_1 values superior to 0 and inferior to 0,9 are verified between 10:00 h and 11:30 h, on the two days, as well as approximately between 1:30 h and 2:30 h, on the second day and the following day. These values of the relation q_2/q_1 demonstrate that there are more significant heat losses in the ventilated facade system in these periods.

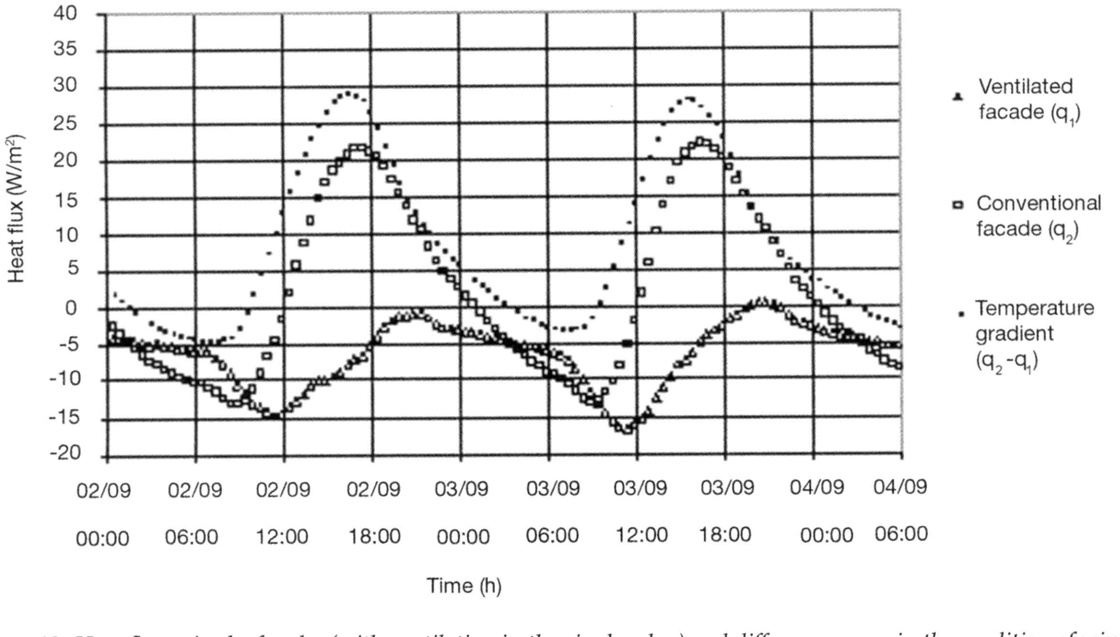

Figure 13. Heat fluxes in the facades (with ventilation in the air chamber) and difference $q_2 - q_1$ in the condition of winter with sunny weather.

The difference between the heat fluxes in the conventional facade (q_2) and in the ventilated facade (q_1) can also be adopted as a comparative parameter between the thermal behaviour of the two facade tiling systems, allowing thermal behaviour to be analysed in the time periods where heat gains are verified in the conventional facade and heat losses in the ventilated facade. Figure 13 shows that between approximately 12:00 h and 24:00 h, the conventional facade presents significantly greater heat gain values than the ventilated facade, which during this period loses heat on the first day and only presents some schedules with heat gain on the second day. It is evidenced that maximum differences occur between the facade heat fluxes of approximately 29 W/m^2, around 16:00 h, on the two days, for heat flux values in the conventional facade of 21 W/m^2 in the respective schedules of the two days.

The results obtained for the ventilated facade in the condition of winter, with ventilation in the air chamber, show that on sunny days, this tiling system does not present significant heat gains, when compared to the conventional facade system. In the search for a way to increase heat gains in the ventilated facade, an alternative on sunny winter days might be to close the upper/lower ends of the air chamber, so that it is not ventilated.

4. CONCLUSIONS

On characteristic summer days with sunny weather energy gain was verified, in 24 h, around 1,8 times lower in the ventilated facade without thermal insulation material, with an air chamber with upper/lower ends open (approximately 9,2 x 10^5 J/m^2, on the two days), in relation to the conventional facade, which presented energy gain, in 24 h, of approximately 1,7 x 10^6 J/m^2, on the two days. The heat gain peaks in the conventional facade occurs approximately 6:00 h before (15:30 h on the two days) the maximums verified in the ventilated facade, demonstrating the largest thermal delay of the ventilated facade. The ventilated facade without thermal insulation material presented a significant reduction in heat gains and greater efficiency in thermal isolation. The highest values of the relation q_2/q_1 are approximately 5,0 at 12:30 h on the two days, occurring in periods in which solar radiation increased.

On characteristic winter days with sunny weather, the ventilated facade without thermal insulation material, with open air chamber upper/lower ends, practically did not present heat gain. Energy gain in the conventional facade is 5,8 x 10^5 J/m^2, on the first day, whose value is a little greater to that verified on the second day. This ventilated facade thermal behaviour is harmful in relation to thermal efficiency, when compared with the conventional facade. In certain periods of the two days, the relation q_2/q_1 does not represent ventilated facade efficiency adequately. Between 2:00 h and 8:30 h, on the first day, and 4:00 h and 8:30 h, on the second day, the ventilated facade presented significantly lower heat losses. The differences between heat fluxes in the facades show that the conventional facade presents significantly greater heat gains than the ventilated facade, between approximately 12:00 h and 24:00 h.

REFERENCES

[1] DEUTSCHES INSTITUT FÜR NORMUNG. DIN 18516, Teil 1: Außenwandbekleidungen, hinterlüftet: Anforderungen, Prüfgrundsätze. Berlin, 1999.

[2] ___________ DIN 18516, Teil 3: Außenwandbekleidungen, hinterlüftet: Naturwerkstein. Anforderungen, Bemessung. Berlin, 1990.

[3] _________ DIN 18516, Teil 5: Außenwandbekleidungen, hinterlüftet: Betonwerkstein; Anforderungen, Bemessung. Berlin, 1999.

[4] FLIESEN UND PLATTEN[1]. Konstruktionen mit fliesenbelägen. Außenwandkonstruktionen - vorgehängte hinterlüftete fassaden. Tl.II. Fliesen und platten, v. 38, n.2, p. 48-63, 1988.

[5] IEMB – INSTITUT FÜR ERHALTUNG UND MODERNISIERUNG VON BAUWERKEN. Hinweise zum standardleistungsbuch für das bauwesen. Bauen im bestand (BiB) block- und plattenbau. Leistungsbereich 502: vorgehängte hinterlüftete fassaden. Berlin: Beuth, 1998.

[6] IQBAL, M. An introduction to solar radiation. Toronto: Academic Press, 1983.

[7] KARL, A. Keramische Fassaden. Keramik-Grobplatten für vorgehängte, hinterlüftete Aubenwandbekleidungen. Deutsches architektenblatt, v. 29, n. 11, p. 1699-1702, 1997.

[8] LORENTE, S. Heat losses through building walls with closed, open and deformable cavities. International journal of energy research, v. 26, n. 7, p. 611-632, 2002.

[9] MERONI, I.; ESPOSTINI, W.; TIRLONI, P.; POLLASTRO, C. Facciate ventilate: il comportamento igrometrico. L'Edilizia, n. 4, p. 203-208, 1991.

[10] SCHWEIZER INGENIEUR UND ARCHITEKT. Bauphysik der hinterlüfteten fassade. Schweizer ingenieur und architekt, v. 103, n. 44, p. 1107-1110, 1985.