THERMAL PERFORMANCE IN STEEL-STRUCTURED BUILDINGS

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Abstract. *Adequate thermal performance in a building depends on the adequation of its internal and external wall, an efficient natural ventilation system, and an architectural project that makes efficient use of the local climatic conditions. In this work, unsatisfactory thermal performance in steel-structure, naturally-ventilated buildings was analyzed. To determine the thermal behavior of the building, the computational program of numerical simulation EnergyPlus was used, taking into consideration the characterization of the climatic conditions; the characterization of the building (architectural project and occupation profile); the characterization and configuration of the walls. Analyzed were some natural ventilation strategies that presented efficient thermal performance and proportioned architectural interventions with a smaller cost/benefit ratio. A study of indoor temperatures was performed, considering an overall response of the building and verifying the fulfillment of the requirements of user thermal comfort. The simulated interventions responded in an adequate manner to the thermal interactions of the building with the outside conditions. Numerical simulations presented itself to be an efficient tool, even in buildings built with problems of environmental adequation, since varios intervention proposals could be studied, which permitted a feedback on the proposition of new thermal-efficient projects.*

Keywords*: thermal performance of buildings, natural ventilation, numerical simulation.*

1. INTRODUTION

To reduce cost and execution time, along with improving performance and quality, the buildings with steel structures and complementary industrizialized systems are becoming a good option to the traditional systems, which are characterized by improvision, and waste of time, labor and capital. Among the complementary systems used in steel-structured buildings, the wall system is the most important, since it is directly related to the thermal performance of the project and the user comfort this provides.

The environmental quality of indoor areas of the buildings is also intimately related to the adequate response to the local climate conditions in which the building is located. Bio-climatic architectural concepts applied to the energy efficiency of the buildings should be in accordance with the technical availabilities, material and a construction process for steel structures (Lamberts et al., 1997).

One of the strategies of passive thermal conditioning that could be utilized in buildings is natural ventilation. This is a strategy for natural cooling by means of the air renewal in the constructed environment. In the summer, the principal purpose of ventilation is to increase the dissipation of human heat by convection and evaporation, so as to proportion a sense of comfort. The strategies of the project should be utilized when natural ventilation implies indoor comfort. Among the architectural solutions used, cross ventilation is quite efficient and it is proportioned by openings in opposite (or different) walls with pressure differences being provoked by wind action.

If, during the architectural conception phase of a steel-structured building, the principals of an efficient project were incorporated, it would permit the implantation of passive systems for thermal conditioning, minimizing undesirable climatic effects. However, when there has been no previous study done on the thermal performance in a building during the projection phase, the undesirable effects of high indoor temperatures appear after the completion of the construction. Even in this case, numerical simulation presents itself as an important tool, since it permits evaluation of the strategies which could be used to minimize the causes of the thermal discomfort (Batista et al., 2005).

2. OBJECTIVES

The objective was to evaluate the thermal performance of a steel-structured building, which doesn't present adequate thermal performance during the summer for its occupants.

To achieve this, a study of the indoor temperatures was performed, taking into consideration the overall building response and verifying the compliance of the thermal comfort requirements of its occupants. Also, some natural ventilation strategies were analyzed. These presented efficient thermal performance and proportioned architectural interventions with a smaller cost/benefit ratio.

3. METODOLOGY

3.1. Thermal performance of buildings

The evaluation of the thermal performance of a naturally ventilated building consists of verifying whether the indoor thermal responses meet the human thermal comfort requirements, proportioning air temperature and humidity inside an acceptable range. This verification can be performed by in situ measurements, or by using simulation software specifically designed for the thermal behavior of buildings.

In this work, the numerical simulation computer program *EnergyPlus* (versão: 2.1) was used to determine the thermal behavior of the model. *EnergyPlus* was developed by the Department of Energy of the United States (Crawley *et al.*, 2000). In verification by means of numerical simulation, the important phases of the evaluation process for the thermal performance of the building involve mainly the characterization of the building, characterization and configuration of the wall systems, characterization of the occupation profile, characterization of the exposure to typical weather conditions, and also, the characterization of the human thermal comfort requirements (IPT, 1998).

3.2. Caracterization of the building

The object of study for this work was the Laboratory for Control, Automation, and Production (DECAT/DEPRO) of the School of Mines at the Federal University of Ouro Preto. The building is located at the Morro do Cruzeiro Campus in the City of Ouro Preto and is part of the laboratorial complex of the School of Mines.

The complex is formed by three blocks of distinct laboratories destined to support the Civil, Metallurgical & Materials, Production, and Control & Automation Engineering Courses. They were built between July, 2004 and December, 2006 and were made possible with the support of companies and institutes such as: PETROBRÁS, USIMINAS, GERDAU AÇOMINAS, VALLOUREC MANNESMAN, BELGO ARCELOR, FINEP e FUNDAÇÃO GORCEIX.

In this study, the second floor of the Control & Automation Laboratory was chosen as the typical environment to be analyzed because of it had thermal adaptation problems for the occupants. The indoor area of the analyzed space is 675 m^2 (wall axel to wall axel), with a ceiling of 2.85 m above the floor (along the facades) and is composed of nine thermal zones, eight inside the laboratory and one in the central hall that connects the laboratories. In Figure 1, the disposition of the thermal zones is demonstrated, highlighting those whose results are presented. The ventilation openings contain horizontally pivotal frames and are situated on the southeast and northwest facades of the building, without any type of provision for solar protection (Fig. 2).

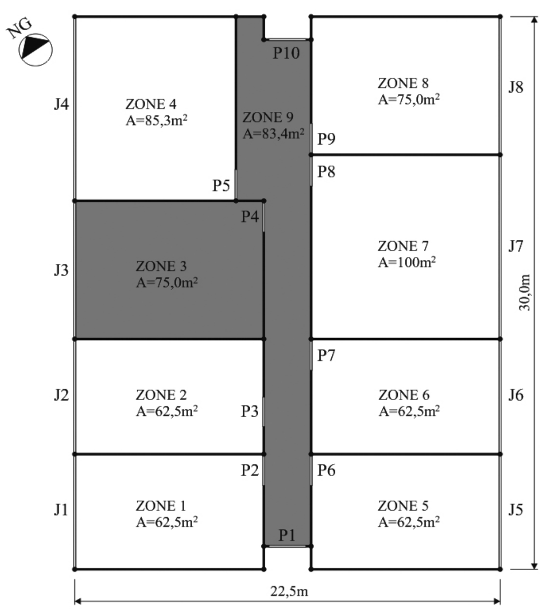


Figure 1. Plan of the second floor of the laboratory

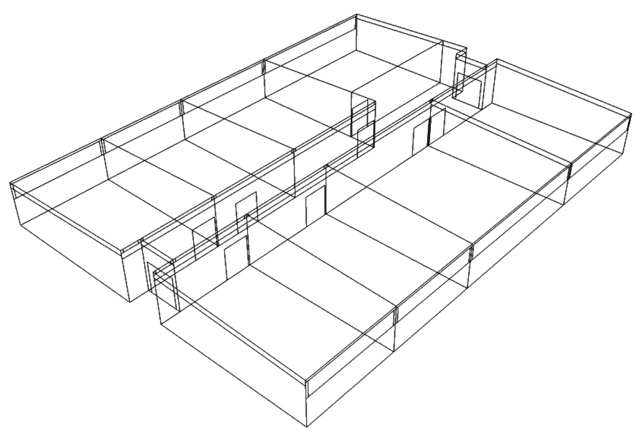


Figure 2. Perspective of the model

There is an air flow between the laboratories and the hall through a small opening, above the beams (Fig. 3). This strategy project was considered as infiltration in the simulation of the cases modeled.

Figure 3 (a). Opening detail that occurs between the beam and the roof

Figure 3 (b). View of the hall

Figure 3. Detail of the opening between the beam and sandwich-tile roof, in the hall.

3.3. Characteristics of the walls

The building is structured in steel and the external vertical wall is different according to the facade. In the southwest and northwest facades, the wall is composed of different materials and layers. Part of the wall is done with celular blocks (e = 10 cm) internally finished with plaster (e = 2.5 cm) and externally with laminated ceramic tiles (e = 0.5 cm). The other external vertical walls are: windows of common glass of 5 mm thickness, blinds (without holes) in black aluminum, and the red metallic structure (Fig. 4). For the other facades, and in the indoor vertical walls, celular blocks, plastered on both sides, were used.

The roof is composed of a steel structure covered by sandwich tiles in the rooms and polycarbonate tiles in the hall (zone 9). There is no lining under the roof and the ceiling varies with the inclination of the tiles, increasing in the direction of the hall. The floor is pre-fabricated with trussed beams and styrofoam filling.

The thermophysical properties of the wall material composition complied with Norm NBR 15220 (2005).

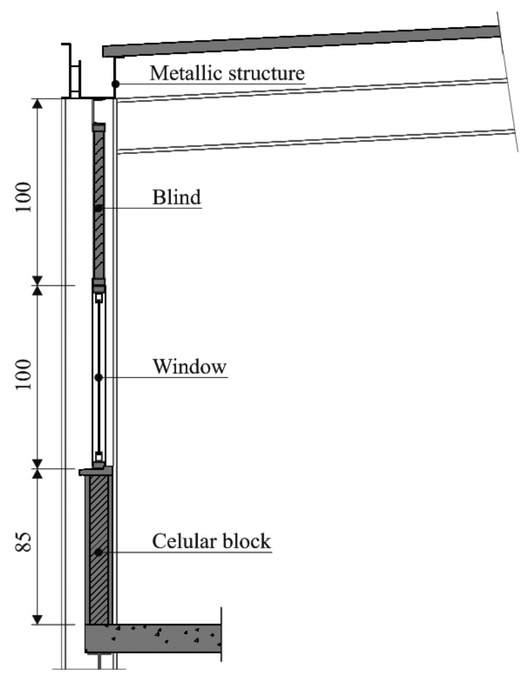


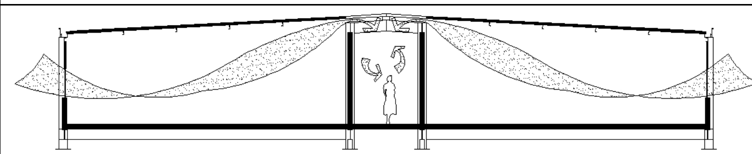
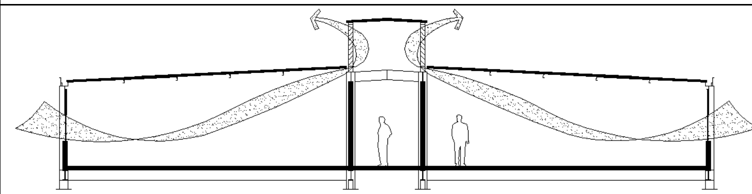
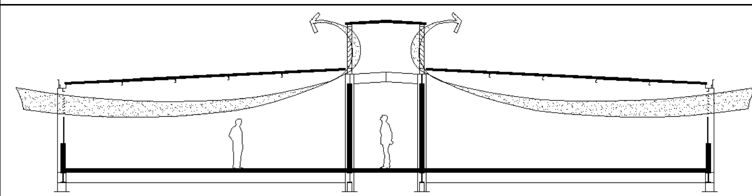
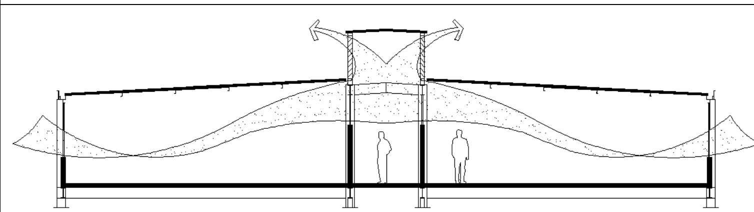
Figure 4. External vertical closing details.

3.4. Characterization of the cases and occupation routines

The simulation of the model was divided in cases according to the different strategic types of natural ventilation. Besides the reference case, which represents the actual conditions of the constructed environment, the other cases were different due to the implantation of skylights and a substitution of the polycarbonate tiles by sandwich tiles in the hall.

The height of the skylights was calculated considering the total area of the floor, of the venezian type with 7 air passages with a nominal value of 5.4 cm between fins, with openings for light of 1.43 m (Scigliano and Hollo, 2001). In Table 1 the different cases according to the routines and types of ventilation are presented.

Table 1. Simulated case types and ventilation schemes

Cases	Description	Ventilation scheme
1	Represents actual conditions of the constructed area. Period of natural ventilation: windows opened between 7:00a.m. and 6:00p.m.	
2 and 3	Passive stack ventilation. Case 2: daytime ventilation (between 7:00a.m.and 6:00p.m.), Case 3: nighttime ventilation (between 6:00 p.m. and 7:00a.m.).	
4	Permanent ventilation. In this case, there is permanent ventilation due to the openings in the venezian blinds and the skylights.	
5	In this case, the openings are larger in the hall to increase the heat exchange using the air flux between the zones, daytime ventilation.	

The laboratories are mainly used during the daytime, from 7:00 a.m. till 6:00 p.m. In Table 2, the occupation routines are presented for all the thermal zones. For the inside heat sources, electronic equipment, lighting and people were considered. The average potency of the equipment was obtained for the Eletrobrás site (PROCEL, 2008).

The occupants were considered as using light clothes with a thermal resistance of 1.0 CLO (0.155 m^2.K/W) and performing sedementary activities, liberating a heat rate of 60 W per person. Commercial fluorescent lightning turned on from 7:00 a.m. till 6:00 p.m. (100%) was also considered. Zones 1 and 2 have not yet been activated, and for this reason, their internal loads were not considered in the simulation.

Table 2. Occupation routines by thermal zones.

Thermal zones	Occupation (n° of people)	Total inside load (W)
1	0	0
2	0	0
3	1	248
4	1	368
5	2	556
6	12	3392
7	1	548
8	1	432
9	0	0

3.4. Characterization of the climatic conditions and simulated period

For the bulding simulation, climatic data from the city of Belo Horizonte was used, due to the lack of yearly climatic references for Ouro Preto. Even though there is a climatic difference between the two regions, due to the microclimate in Belo Horizonte, using data from there did not affect the analysis of the results, since the comparative analysis dealt with simulated cases.

Simulation was performed considering a typical yearly climate in the City of Belo Horizonte. Climatic data was taken for the site of the *EnergyPlus* program (DOE, 2008). For the analysis of the results, two typical days of the year were chosen: the hottest day (January 14th) and the coldest day (May 20th).

3.5. Characterization of the human requirements for thermal comfort

There does not exact temperature to define thermal comfort. An individual who feels comfortable in a determined climatic condition may not feel immediate discomfort when occurs a temperature variation. This way, the human requirements are characterized by values, or intervals of values inter-connected with temperature, relative humidity, air flow and average radiant temperature in the room. To characterize the human thermal comfort requirements, an interval of inside temperatures were set at a range from 20°C to 27°C (ASHRAE 55, 1992; ISO 7730, 1994).

4. RESULTS AND DISCUSSIONS

4.1. The air flow model

As a model for natural ventilation, in the numerical simulation process of *EnergyPlus*, the *AirflowNetwork* was used, which simulates the air flow between the thermal zones and the exterior, through openings and windows, due to forced or natural ventilation (LBNL, 2007). In this model, various conditions that influence the air flux are considered, such as, building shape, climatic parameters, characterization of the doors and windows, and infiltration through openings, windows, and doors, and interfaces of the walls with the structural system.

4.2. Results

In Figures (5) and (6), a comparison of the results obtained in all the cases (Table 1) is presented, considering zone 9 (hall) of the building for a typical day in summer and winter, respectively.

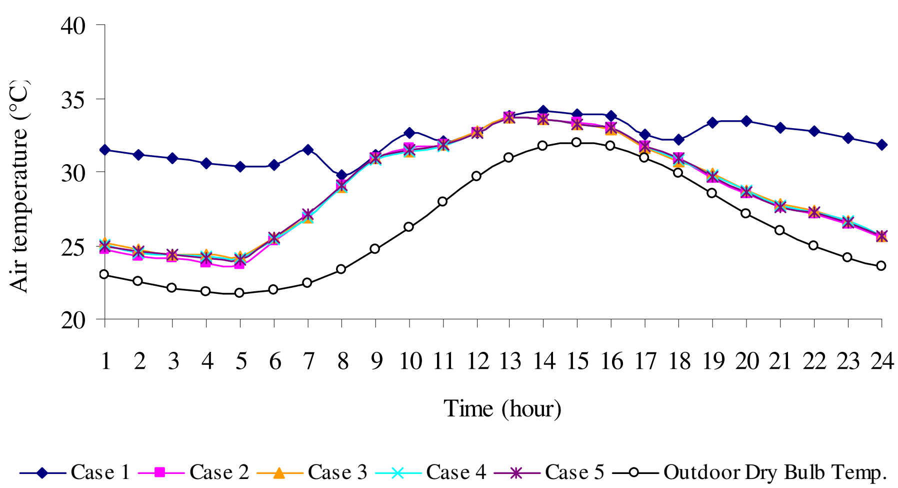


Figure 5. Temporal evolution for a typical summer day (zone 9 – hall).

In Figure (5), the great dispersion in the temperature is shown between Case 1 (reference) and the other cases. Independent of the ventilation routine and the opening size, the inclusion of skylights reduced the internal temperature of the hall, principally, at nighttime (6:00 p.m. till 7:00 a.m.).

While in Figure (6), it can be verified that the thermal performance of the reference case (Case 1), for the winter is good, when compared with the other ventilation strategies, which distances itself far from the internal comfort temperature range (between 20°C and 27°C).

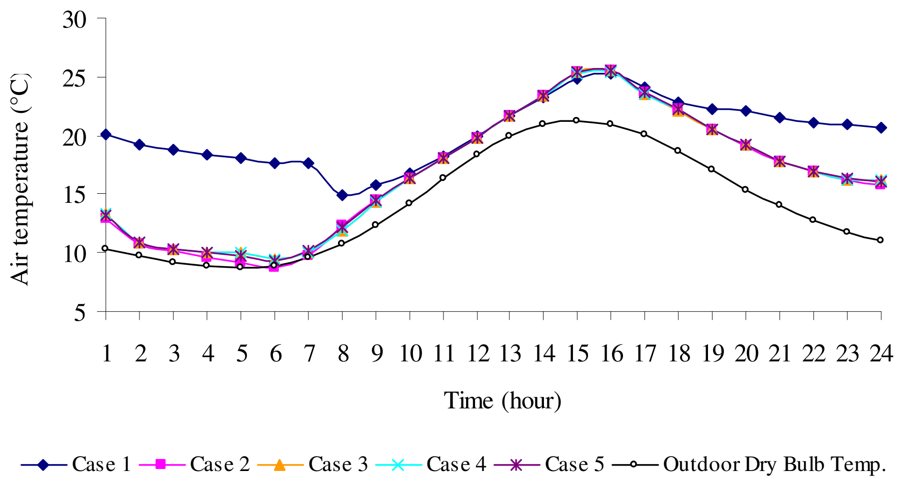


Figure 6. Temporal evolution for a typical winter day (zone 9 – hall).

In Figures (7) and (8), a comparison of the results obtained in all the cases (Table 1) is presented, considering zone 3 (laboratory room) of the building as the representative of a typical summer and winter day, respectively.

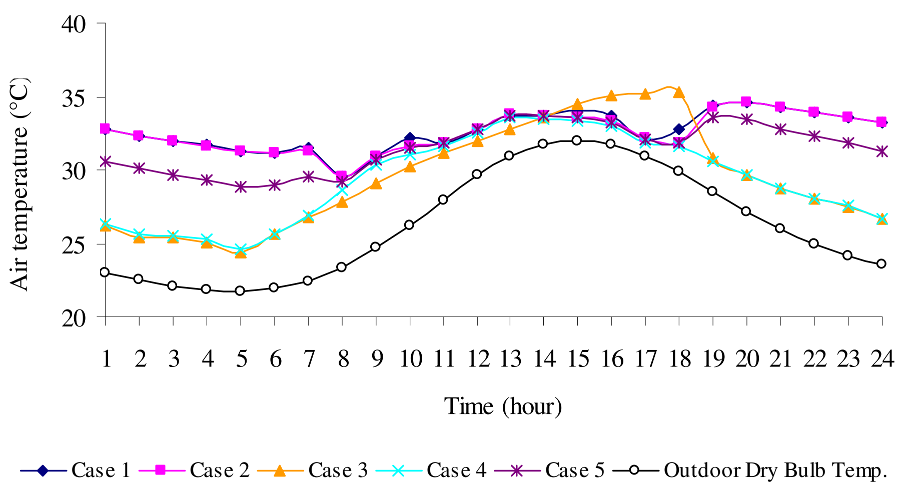


Figure 7. Temporal evolution for a typical summer day (zone 3 – laboratory room).

Considering the results shown for Zone 3, for analysis in summer, it has been verified that the inclusion of a skylight above the hall and the maintenance of the same ventilation routine, was not able to produce great dispersions between the cases 1 (reference) and 2 (with skylight). This occurs due to the low air flow which established between the hall and Zone 3, through the opening above the beams and other air infiltrations. In this case, the transfer of heat occurs mainly by conduction through walls.

As an analysis of the obtained results, for the hall (zone 9), it was observed that the Cases 3 (nighttime ventilation) and 4 (permanent ventilation) promoted a fall in the indoor temperature at nighttime; but were not capable to relieve the top temperature during the day. When only nighttime ventilation is considered, it can be observed that an accentuated elevation of temperature occurs during the later part of the day, in function of the heat that enters the environment by conduction through the facade during the day, especially through the facade containing the transparent and the metallic elements.

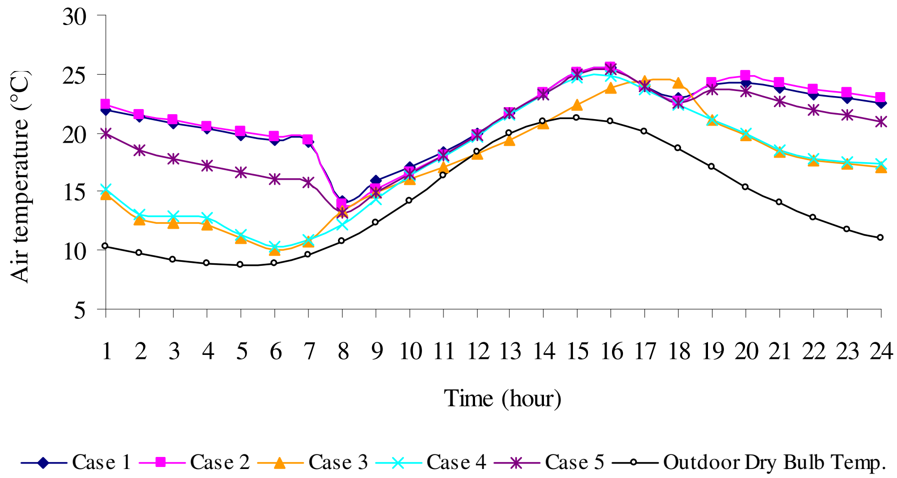


Figure 8. Temporal evolution for a typical winter day (zone 3 – laboratory room).

For the winter season, the results presented a behavior pattern of the curves that was similar to those of the summer season. In this case, the permanent and/or nighttime ventilation strategies led to discomfort caused by inside air renewal.

In Figure 9, a comparison of the results obtained for external surface temperature are presented for each plastered facade, considering a typical summer day.

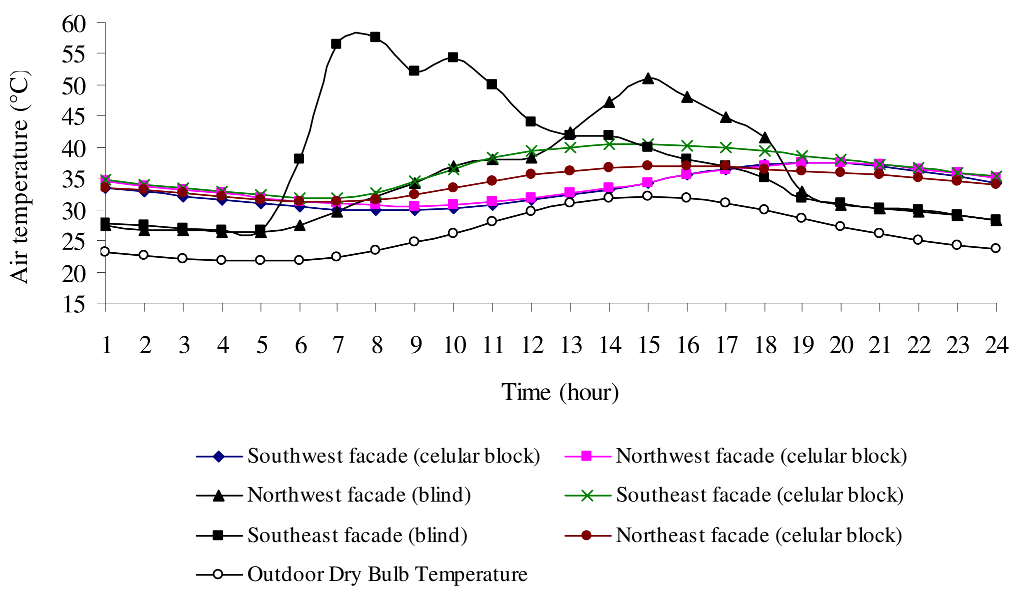


Figure 9. Temporal evolution for a typical summer day (facades).

By means of the shown results, it can be observed how the direct benefits from solar radiation interfere with the internal temperature of the building's environment. The southeast facade, which presents a large area containing windows and steel venezian blinds, received a greater amount of heat, evidenced by the profile of the temperature for the same, where a higher temperature can be observed in comparison with that of the plastered wall. The same can be observed for the northwest facade.

5. CONCLUSION

By means of the analysis of the results obtained, it has been observed that using only natural ventilation strategies is not enough to provide thermal comfort, since the influence from the facade, in steel, on the indoor temperature is very accentuated. The low thermal inertia of the vertical walls, in steel and glass, leave the indoor environment very susceptible to external temperature changes. Relief from the highest daily temperatures also depends on the use of the thermal inertia from the walls. In this case, the passive thermal conditioning strategies should be distinct for summer and winter. Natural ventilation, potentialized by the skylight, should be coupled with shade of the openings in the summer, and in the winter, the openings should permit the direct sunlight to the inside area.

In steel-structured buildings, it is common to use lighter walls systems, with less thickness. This practice, however, even being in accord with the principles of industrialized buildings, can lead to thermal adaptation problems therein, due to the lesser thermal mass of these walls.

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