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AIR CONDITIONER ENERGY EFFICIENCY ASSESSMENT IN PORTO ALEGRE AND SALVADOR AND THE INFLUENCE OF DIVERSE THERMAL INSULATION MATERIALS ON THE WEST FACADE

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Abstract. *On building construction, the west oriented facades usually causes thermal discomfort to the indoor environment, this might happen due to improper chosen materials and because of direct sun light incidence during the hottest period of the day. Looking for alternatives to reduce the electrical power used for artificial conditioning of these environments, this article assesses some thermal insulation materials used on the above-mentioned facades. The simulation model chosen was a 15 m² office with six employees working in regular business hours, the overall load of the equipment and lighting is approximately 2000 W. The simulation was carried out in two cities, Porto Alegre and Salvador, which belong to very different Bioclimatic zones. The model was built at SketchUp software and the energy simulation was run in EnergyPlus software. The analysis considered the behavior of a typical year and returned the daily average temperatures. On this research the exterior wall's materials were modified several times, demonstrating that the masonry wall consumed less energy by the environment artificially conditioned in Porto Alegre, while in Salvador the material which shown best performance was cellulose and wool insulation based.*

Keywords: *Energy efficiency, Air conditioning, Insulation, Thermal comfort, EnergyPlus.*

1. INTRODUCTION

According to Roaf (2007): "The first step to bring thermal comfort and pleasure to the buildings is to understand the relationship between climate and our need for shelter." The building can be considered the third skin of human beings, so it should provide thermal and acoustic comfort, and mainly protect them from the weather. Many buildings are designed in a wrong way by not adequately considering the local climate when defining the technical and building materials. However, it is only after occupation that users realize the need for thermal comfort and lighting for the ambients, doing it artificially and causing an annual demand growth on electricity in the country.

The first design principles sought to take advantage of the desirable characteristics of the climate and avoid unwanted ones by the use of the secular knowledge of vernacular architecture. These ancient principles are well represented in passive solar architecture applied in the ruins of Mesa Verde people which is located in Colorado Desert in United States (Bagnati, 2013), and by the architecture principles of ancient Rome with the first known artificial heating systems (Lamberts, Dutra and Pereira, 2014). However, the concepts of classical architecture are quite recent, established by the edition of the first book that we know, by Vitruvius in 1982, which introduced architecture as a living space that should balance the structural, functional and aesthetic (Lamberts, Dutra and Pereira, 2014). With the so-called "international style" of classical architecture adopted in recent decades, is observed a tendency to design buildings without adequately considering the local climate. Moreover, after the 70's energy crisis the limits of energy supply capacity become evident, causing the assimilation of energy efficiency concepts by architecture. This enabled the establishment of design criteria to ensure a greater identification with the place, considering the dwellers' thermal comfort, the visual, the acoustic and the reduction of energy consumption (Lamberts, Dutra and Pereira, 2014). The thermal performance of buildings is influenced by the different materials characteristics, for instance the inertia and thermal insulation in the building envelope, restricted to the conditions and local climate (Lamberts et al., 2010).

Through the popularization of mechanical air conditioning systems, most of the designers have stopped worrying about local climatic aspects because of the ease of artificially constraining the environments. It is known that to improve energy performance in buildings, the ideal is to deploy the building with the smallest envelope areas facing the east-west axis, because they are problematic in almost everywhere. In addition to the selection of ideal materials to make up the enclosure of the west facade, Keeler and Burke (2010), point out that the windows oriented to such direction do not work as a good heat source in winter whereas in summer time it heats too much. This situation creates a reverse condition from what is expected from the environment.

However some terrain and surroundings constraints may often cause the designer run out of choices to connect the built area to the outside through doors and windows. When taking such decisions it is necessary to think on solutions that protect and / or limit the size of the windows, the type and composition of glass and other materials to be used on the facade.

With building materials evolution, new thermal insulation materials were introduced to the market. In Europe, cellulose insulation has been widely used with steel and wood frame structures, which according to manufacturers of the material provides good thermal and acoustic insulation. As in Brazil this product is just beginning to be used, this study aims to evaluate what the behaviour of such kind of material is when compared to the glass-wool and masonry, which are traditional materials used in construction in this country.

Moreover, in commercial buildings there is a need to keep a comfortable indoor environment for clients' reception while allowing a good employees' productivity, so it is usually applied artificial air conditioning. Thus some issues were brought into question, for instance how to save energy just by changing the thermally most problematic facade, the west facade. Moreover, how would mechanical air conditioning system consumption behave and what would be the most suitable materials to be used in two cities located in different Brazilian Bioclimatic Zones (BRBZ) which have quite different climates.

2. METHODOLOGY

The insulation characteristics of three different construction materials were compared in two different climatic zones through the use of EnergyPlus software. A temperature setpoint was selected to control room temperature for mechanical air conditioner. The simulation results were used to define the most suitable material to each town regarding the annual energy consumption for the specified temperature setpoint.

2.1 Simulation model

The typical climate conditions of Salvador represent approximately 54% of Brazilian climate and according to NBR 15220-3 (2005), this city is located in BRBZ 8. According to this standard the buildings should have large and shaded openings, its exterior walls should be light colored and have light reflecting surfaces, as well as its cover. In contrast, Porto Alegre, which belongs to BRBZ 3, the standard recommendations are different: for instance medium size openings, exterior walls and cover should be light colored, with light reflective surfaces and thermal insulation. In order to illustrate the two chosen Brazilian bioclimatic zoning, Figure 1 shows the representation of BRBZ.

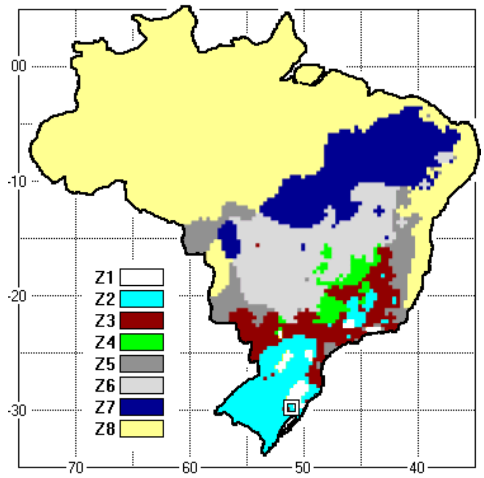

Figure 1. Bioclimatic classification of Brazilian Municipalities (UFSC)

Regardless of where the building is located, the parameters that directly affect the internal temperature are: the solar orientation, its latitude and surroundings, the shape of the building, the thermal properties of the materials that comprise the envelope, occupation type, amount of equipment and lighting.

Therefore, in order to verify the behaviour of some materials on the west facade at the two locations mentioned, a computational model was generated in EnergyPlus software to simulate energy consumption. A scope was determined as being a business room; a place where some employees spend most of their day and artificial air conditioner is used for climate comfort, the west facade was assessed in three different materials, the time was a typical year. Table 1 shows the characteristics that have been inserted into computational model for simulation.

Table 1. Key features considered in the model simulations

Characteristics	Description
Dimensions	Length X Width: 4,50 x 3,50 m Building height: 2,70 m Window dimensions: 1,50 x 1,20 m
Built area	15,75 m²
Conditioned area	15,75 m²
Air conditioner system type	Window, inserted in EnergyPlus as PTAC
Thermostat	Heating at 20 ºC and cooling at 24 ºC
Occupation	6 People
Illumination	300 W
Equipment	1500 W

The office activities run on weekdays, from Monday to Friday. The level of activity during a typical day is shown in Figure 2. There is no use of the room on weekends and holidays.

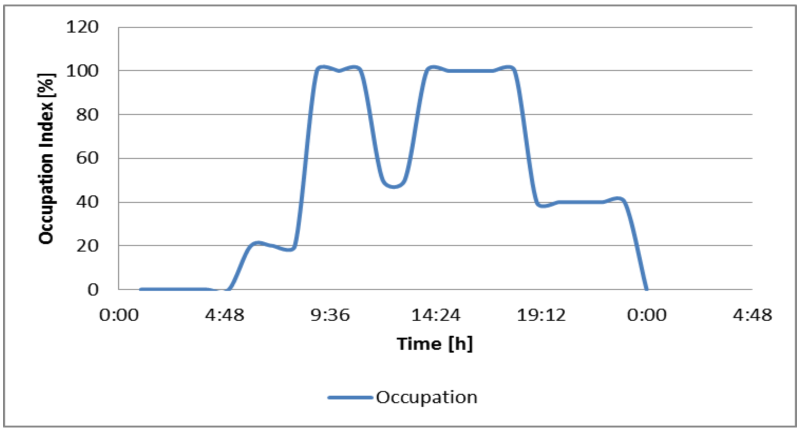

Figure 2. Daily employees' activities

Furthermore, the model has some fixed characteristics such as: the interior walls are adiabatic and its composed of bricks with two layers of grout, one internal and one external; resulting a total thickness of 0.15 m. The wall facing the north is composed by the same materials and has a thickness of 0.25 m, and there is a window on it. Also fixed, the parameters of the roof (or ceiling) and the floor, both adiabatic, are composed of concrete slabs 0.10 m thick. The window has fixed size and materials, a 6 mm colourless glass where the following parameters are applied:

- Thickness - 6 mm;
- Visible Transmission - 88%;
- Heat Transfer Coefficient - 5.80 [W/(m2.K)];
- Solar factor - 84%.

The aim of this study is to understand what happens when changing the west facade materials from the masonry wall to the two different thermal insulation materials, both in Porto Alegre and in Salvador. So the west wall composition is changed three times. Analyses were performed with the following variations: grout + cement board + cellulose + plasterboard; grout + cement board + glass wool + plasterboard; and finally grout + 24 cm of masonry + grout. The latter composition is designed to have a parameter compared to the buildings that are usually employed in Brazilian buildings. The thermal properties of the materials are listed in Table 2.

Taking in consideration the properties and thickness of each material showed in Table 2 the thermal characteristics of each wall studied in this article were determined according to Table 3. It's possible to understand that the masonry wall is able to delay the heat transfer and store some heat, although it allows a greater heat gain due to its smaller thermal resistance when compared to the insulating walls.

Table 2. Thermal properties of the materials

Material	Thickness [m]	Thermal conductivity [W/(m.K)]	Density [kg/m³]	Specific heat [J/(kg.K)]
Ceramic brick[1]	0,15 -interior walls 0,25- external wall	0.90	1600	920
Grout[1]	0.01	1.15	2000	1000
Glass wool[1]	0.075	0.045	50	700
Cellulose[2]	0.075	0.037	50	2150
Plasterboard[1]	0.0125	0.35	750	840
Concret[1]	0.1	1.75	2400	1000
Cement board[1]	0.0125	0.65	1800	840

(1)Source: NBR 15220-2 (ABNT, 2005)
(2)Source: ISOFLOC (Aisla y Ahorra, 2015)

Table 3 – Thermal characteristics of each wall for an unitary area

Wall	Thermal capacity ($e.\rho.C_p$) [kJ/K]	$1/\Sigma R_{th}$ [W/K]
grout + cem. board + cellulose + plasterboard	55	0,48
grout + cem. board + glass wool + plasterboard	49	0,58
grout + 24 cm of masonry + grout	408	3,39

For the weather data integration in this simulations, climate data files from the cities of Porto Alegre (BRBZ 3) and Salvador (BRBZ 8), were obtained from SWERA (Solar and Wind Energy Resource Assessment) in TRY format (Typical Reference Year) (LabEEE, 2015). For the maximum and minimum temperatures predefined it was possible to generate output data for energy consumption for air conditioning and relate this data to the type of material composition of the west outdoor wall.

3. RESULTS

The energy performance of two offices were compared, one located in Porto Alegre and another located in Salvador, by varying the material composition of the west wall facade, generating simulations of these variations in the EnergyPlus software in order to compare energy consumption during a typical year on each bioclimatic zone.

The results of the energy consumption of artificial air conditioner only affected the demand for cooling, since the energy consumption for heating in both cities analysed resulted in a very low value due to the fact that internal load is too high and there is little air exchanged with the outside. In Porto Alegre, the material which has shown best performance was conventional masonry, despite the resulting difference between the materials is negligible. This happens due to the high thermal load of equipment, people and lighting. Masonry walls allow heat exchanging when outside temperatures are lower and therefore require less energy from the air conditioner to keep the setpoint during warm seasons. The big temperature variation in this bioclimatic zone, considering that in this city high temperatures does not occur in most periods of the year, the alternative to replace masonry walls by the composite insulators regardless other considerations is not prospective, Figure 3.

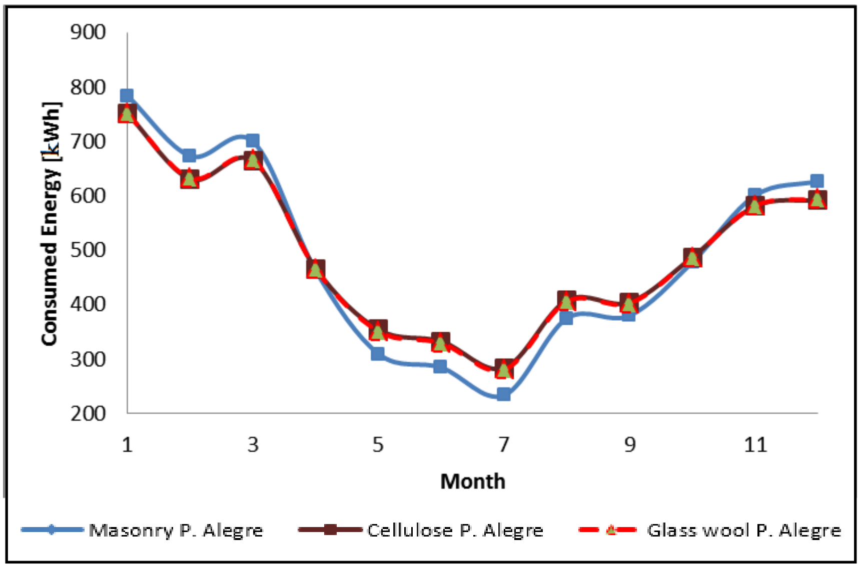

Figure 3. Annual energy consumption of air conditioner for cooling in P. Alegre

It was observed that in Salvador, Figure 4, the energy consumption for air conditioner was lower by approximately 5% on the insulated walls comparing to the masonry wall. This happens because in most part of the year the external temperature is high and the masonry wall facilitates heat gain from outdoors. There was no significant difference between the cellulose and the glass wool insulations.

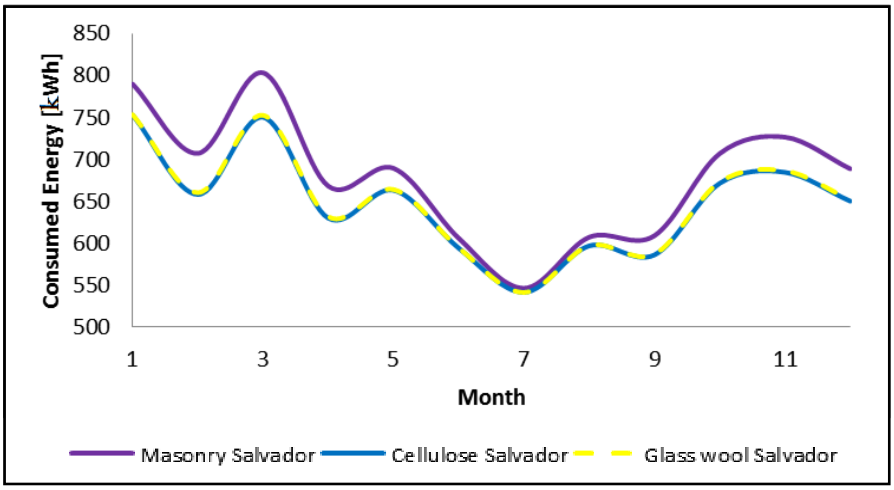

Figure 4. Annual energy consumption of air conditioner for cooling in Salvador

The internal wall surface temperature of the west facade was also simulated for the two cities and the three materials during the typical year. As illustrated in Figure 5, the same materials have different behaviours when changing the cities, due to bioclimatic conditions of the different zones.

It was observed that the indoor surface temperature of the masonry wall in Porto Alegre has a higher temperature when compared to the walls having insulation during the summer months. This is because the thermal conductivity of the ceramic wall, which is composed of bricks, is greater than the thermal conductivity of the walls composed by thermal insulating components leading to a higher temperature gradient in the ceramic wall. In contrast, in winter months, the temperature of the indoor masonry wall surface is approximately 12% lower than those with thermal insulated materials causing the indoor temperature to be low. However, there is a high internal heat load generated by people, equipment and lighting and artificial cooling is frequently needed.

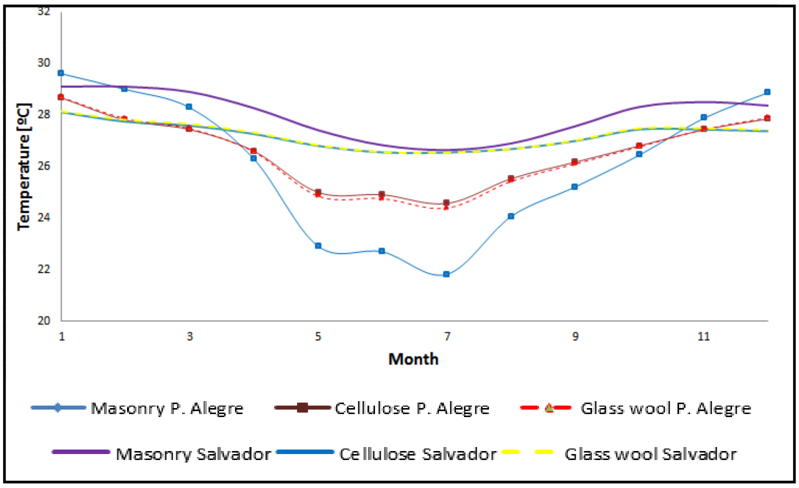

Figure 5. Annual average temperatures of the interior surface of the west wall in Salvador and P. Alegre

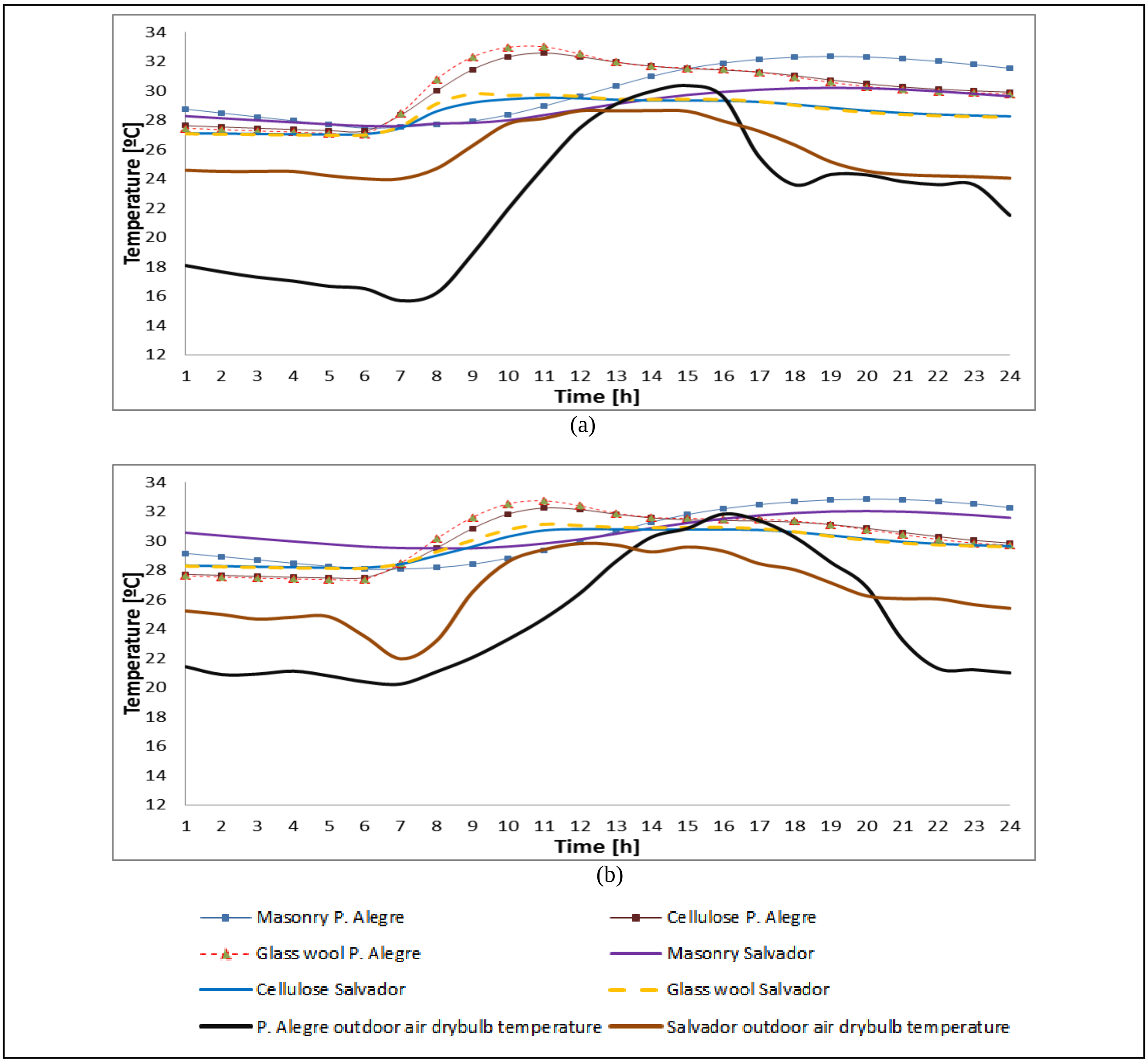

Figure 6. Hourly average temperatures of the interior surface of the west wall and outside air temperature for the seasons (a) Spring and (b) Summer.

For a better visualization on daily behaviour of temperature changes on the indoor wall surface during a typical year for the two cities, four days of each season were selected according to the following: October 15, January 15, 15 April and July 15th.

Figure 6 represents the days from spring and summer seasons in (a) and (b) respectively while Figure 7 represents the days from autumn (c) and winter (d). The outdoor temperatures used on the simulation are dry bulb temperatures and were generated from the climate file data. These simulations show that outdoor temperatures varies in a range of 10 degrees during the day in spring, summer and autumn, while in winter it is more steady varying only two or three Celsius degrees in Porto Alegre. Meanwhile, in Salvador the temperature remains steady in all the seasons, varying only a few Celsius degrees.

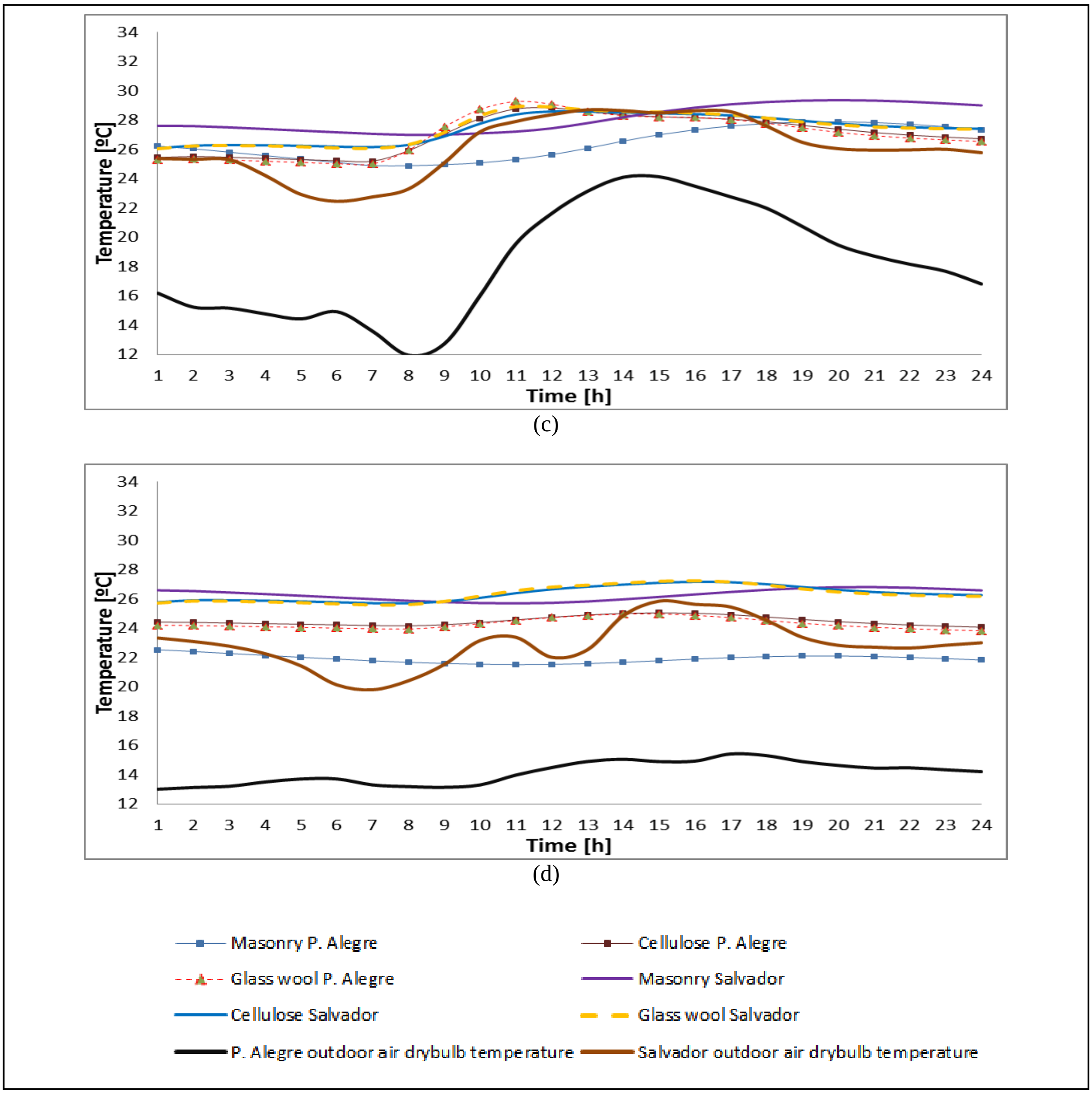

Figure 7. Hourly average temperatures of the interior surface of the west wall and outside air temperature for the seasons (c) Autumn and (d) Winter.

In both situations the temperature of masonry walls follows the outdoor temperature profile and it's possible to see a delay in the temperature rise, but due to its high thermal capacity its temperature varies gently.

Additionally, the indoor surface temperatures of the walls with the glass wool and cellulose insulation in Porto Alegre, were higher from the morning until the early afternoon compared to the masonry. Moreover, these wall surfaces were also warmer than in Salvador, in the same periods. The difference between Porto Alegre and Salvador is that, in the former the mean temperature was higher in both insulated walls compared to masonry wall, and in the later the mean temperature of the insulated walls were lower than the masonry wall.

Salvador has a more steady and high temperature throughout the year, so a material with lower heat capacity and higher thermal resistance showed to be more suitable. While in Porto Alegre the daily high variations in temperature affect the balance of indoor temperature. In addition, when outdoor temperatures are lower, the insulation avoided heat exchange, therefore the use of air conditioner was needed.

4. CONCLUSION

In this study, the relationship of some building materials applied in vertical closure's walls on west oriented facades were evaluated. The methodology utilised was *EnergyPlus* computational analysis of three different construction materials in two cities located in distinct bioclimatic zones. In the analysis, the performance of the materials were compared in a period of a typical year according to the energy consumption of artificial air conditioner to keep the temperature amongst 20 and 24 Celsius degrees. With the analysis it was concluded that masonry walls are thermally more efficient in Porto Alegre city compared to the insulated walls which showed not to be advantageous as expected. Meanwhile in Salvador the thermally insulated walls, with cellulose or glass wool, showed to be somewhat thermally more efficient than the masonry, but the saving of electricity was only around 5% per year. However, considering that Salvador, which is situated near to the sea and its temperatures are steadier, lighter walls are more suitable. Also, the masonry wall has a higher thermal conductivity coefficient than the walls built up with heat insulation, so masonry walls are not the most interesting for Salvador.

Furthermore, the results obtained show that the main problem is not the composition of the wall material, instead, the internal load is more related to the type of activity which is often very high and increase the consumption of the air conditioner. Therefore the NBR 15220-3 is correct in stating that light walls with reflective surfaces are ideal for BRBZ 3 and 8 because, despite the facades oriented to the west being very problematic, the adoption of thermal insulation did not return an impressive result. However, considering that the world is in the quest of energy saving technologies, adopting such alternatives to reduce consumption even a little, is worth.

Considering all these issues, this research contributes by evaluating technical information. This may help designers at the time of decision-making regarding the selection of some materials for west facade and demonstrate the relevance of energy simulation at conception projects.

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