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Opaque envelope parameters *versus* energy consumption in commercial buildings in Brazil

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This article presents an analysis of the energy performance of commercial buildings as a function of the influence of the overall heat transfer coefficient of the external walls and roof. Cases with different internal load densities, exterior absorptance, patterns of use, window-to-wall ratios and other parameters were simulated to analyse their influence on the annual energy consumption. The analysis was carried out through computer simulation using the EnergyPlus program and weather files for Florianopolis, Curitiba and Sao Luis. Two building typologies were adopted: a five-storey office building and a one-storey commercial store. These results show that the limits adopted by ASHRAE Standard 90.1 can be exceeded, depending on the case and climate analysed, as using high values of overall heat transfer coefficient in the walls can help to dissipate the internal heat gain to the exterior, minimizing the air conditioning energy consumption.

Keywords: heat transfer coefficient; thermal performance; commercial buildings

1. Introduction

Commercial and public buildings are responsible for a great part of air conditioning system energy consumption due to the influence of the architectural design, material specifications and building pattern of use (Brasil 2001a,b, 2005).

Through computational tools it is possible to evaluate the energy performance of buildings already constructed, as well as future buildings, thus enabling the introduction of alternatives to increase the building energy efficiency.

The use of simulation programs can assist in the development of new standards of energy efficiency and in the design of more efficient buildings. During the oil crisis in the 1970s, the first standards for energy efficiency in buildings began to appear. For example, the United States published the ASHRAE Standard 90 in 1975 (ASHRAE 1975) which was updated to the ASHRAE Standard 90.1 in 1989 (ASHRAE 1989). This standard establishes minimum requirements for the design of efficient buildings, except for low-rise residential buildings. It has been adopted as a basis for the development of laws regarding building energy efficiency in many countries, including Brazil. The prescriptive criteria of ASHRAE Standard 90.1 (ASHRAE 2004) states the maximum limits for the overall heat transfer coefficient of walls and roofs, according to the climate in which the building is located, but it does not consider the thermal load of the building or its pattern of use.

Many studies found in literature indicate that the use of thermal insulation makes a building more efficient. However, most of these studies were carried out in regions where a cold climate (winter) is predominant. The use of thermal insulation in the walls of buildings located in climates with rigorous winters makes the building more comfortable inside because it keeps the internal temperature constant for longer, thus leading to a reduction in the value of the electric energy bill.

However, Chvatal *et al.* (2005) have shown that, depending on the climate, pattern of use and other parameters related to the building, the use of thermal insulation can increase the building energy consumption. In hotter regions, a highly insulated building makes it difficult to dissipate the internal and solar gains to the exterior. This contributes to a rise in the internal temperature, increasing the use of the air conditioning system.

Given that most studies relate to climates with severe winters, this study focuses on commercial buildings located in regions with hot summers and short winters. Also, commercial buildings have different values for internal load density and pattern of use than residential construction.

The objective is to identify the influence of the overall heat transfer coefficient of the walls and roof, as well as other parameters, on the electric energy consumption and thermal load of commercial buildings located in three Brazilian cities: Florianopolis,

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Curitiba and Sao Luis. To this aim, the influence of the construction design on the building response to different conditions of cooling and heating degree and time was analysed.

2. Methodology

2.1. *The simulation program*

For the analysis of the thermal performance of a building, the EnergyPlus 2.1 (DOE 2008) simulation program was used. The EnergyPlus program was developed through combining the programs DOE-2 and BLAST, in order to create a tool that allows the simulation of the thermal load and the analysis of the building energy and its systems. This program calculates the thermal load necessary to heat or to cool an environment. This calculation is based on the thermal behaviour and energy consumption of the building, the climate in which it is located and the thermal load values. This program was used in this research to simulate two typologies with different values of overall heat transfer coefficient.

2.2. *Typology definition*

Two typologies with different wall and roof geometries were adopted, it thus being possible to analyse the gain and loss of each opaque element. A difference in the amount of floors of the typologies adopted was also analysed.

Typology 1 (Figure 1) represents a five-storey building. The building has a total area of 1000 m^2 and has air conditioning on all floors, but not in the areas corresponding to the stairs and elevators. This typology will be used to know the effect of wall insulation.

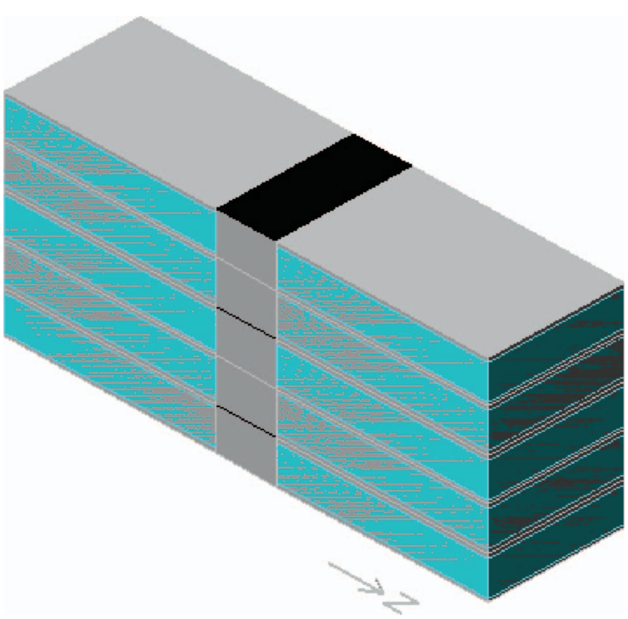

Figure 1. A 3D representation of Typology 1.

The second typology corresponds to a commercial building, with a total area of 2500 m^2, as shown in Figure 2. The building has an air conditioning system in all areas. This typology has a dimension of 50 m $\times$ 50 m $\times$ 5 m, being representative of a department store with few internal divisions. This second typology will be used to know the influence of roof insulation.

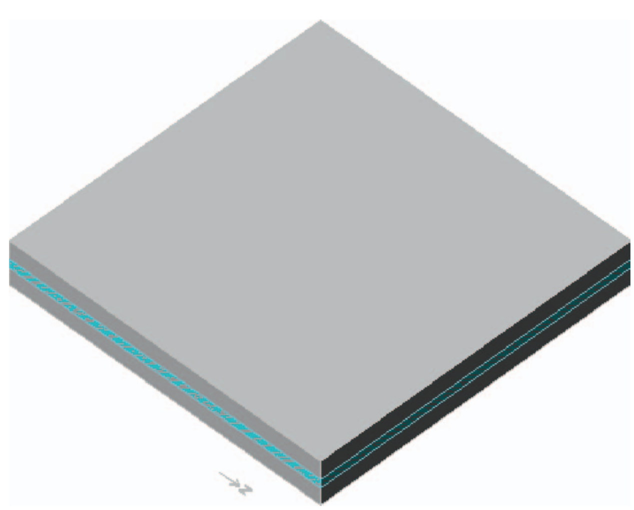

Figure 2. A 3D representation of Typology 2.

2.3. *Parameters analysed*

To analyse the influence of the overall heat transfer coefficient of the walls and roof in relation to the electric energy consumption of the adopted typologies, several combinations were simulated, which can be observed in Table 1.

The Test Reference Year (TRY) climatic archives were used for the typology simulations for the cities of Florianopolis, Curitiba and Sao Luis of 1963, 1969 and 1966, respectively. These archives contain information on the characteristics of the region adopted and also represent a typical year from a series of 10 years (Goulart 1993).

The maximum temperature value for Curitiba from the TRY climatic archives is 33.3°C and the minimum is −5.3°C. For Florianopolis, the maximum temperature value is 36.4°C and the minimum is 2.0°C. For Sao Luis, the maximum and minimum temperature values are 28.5 and 19.7°C, respectively.

Through the climatic archives of the city of Florianopolis, Curitiba and Sao Luis the total degree-hours of heating and cooling, adopting the base temperatures of 18 and 24°C, respectively, were calculated, as shown in Table 2. Also, the amount of degree-days of cooling and heating, with base temperatures of 10 and 18°C, respectively, were determined. These values are adopted by the ASHRAE Standard 90.1 to characterize the climate of a city, indicating the maximum levels of acceptable overall heat transfer coefficient for each building component based on the climate where it is located.

It was observed that the three climates analysed have different values for heating and cooling degree-hours. The climate of Curitiba has a total number of heating degree-hours approximately four times that of Florianopolis. Although the climate of Sao Luis does not have a heating degree-hour using the base temperature of 18°C, the total cooling degree-hour value was higher than those for the other two cities. On analysing the heating degree-day it was observed that Curitiba has the highest value for heating degree-day and the climate of Sao Luis has the highest value for cooling degree-day.

The ASHRAE Standard 90.1 classifies the climates on the basis of the calculation of heating and cooling degree-day. According to the definition of the climatic zones adopted by Standard 90.1, Florianopolis and Curitiba belong to climatic zone 2 and Sao Luis belongs to climatic zone 1. The overall heat transfer coefficient of the walls and roofs of commercial buildings indicated by ASHRAE Standard 90.1 for Brazilian cities belonging to climatic zone 1 and 2 have the same maximum value. In this study, this maximum value will be compared with the overall heat transfer coefficient values obtained in this research for the climates under study.

Table 1. Values assumed for the parameters.

Parameters	Values assumed
1. Building typologies	Two different typologies
2. Climates	Florianopolis, Curitiba, Sao Luis
3. Pattern of use (h/day)	8, 12
4. Internal load density (W/m^2)	30, 70
5. Window-to-wall ratio (%)	20, 50, 80
6. Solar heat gain coefficient (SHGC)	0.87 (colourless), 0.58 (reflective)
7. Wall absorptance of solar radiation	0.20 (white), 0.90 (black)
8. Roof's absorptance of solar radiation	0.20 (white), 0.90 (black)
9. Overall heat transfer coefficient of walls and roof (W/m^2 K)	1.00, 1.50, 2.00 and 4.00
10. Air infiltration (ACH)	0.3
11. COP (W/W)	3.19

Two values for interior load density (ILD) were adopted. These values include the lighting, equipment and people gains, as described in Table 3. The first half is related with ILD value of 30 W/m^2 and the second with ILD value of 70 W/m^2. Both ILD values are used in both typologies. Because the study was carried out for commercial buildings, the value adopted for the heat dissipated by people was 120 W/person (sensible heat), representing office activity. During the simulation, these values are constant throughout the use time.

The quantity of lighting represents the total value of W/m^2. The total value of W/m^2 represented by person (m^2/person) is the value adopted for the heat dissipated by person (120 W/person) divided by the quantity of people (15), resulting in 8 W/m^2. The total W/m^2 of equipment (W/person) is the total quantity of equipment (150 W) divided by the quantity of people (15), resulting in 10 W/m^2.

The solar factor (SF) is the ratio of the solar heat gain through a certain type of glass to that through a standard glass type (defined as colourless glass of 3 mm), under identical circumstances. This is also sometimes referred to as the shading coefficient. This is the best known and generally accepted index used to compare types of glass, both in industrial and civil construction. In the simulations, the values adopted were 0.87, which represents colourless glass, and 0.58, representing a reflective glass.

In relation to the absorptance of the external surfaces of the walls and roof, the values adopted were 0.20 (white surface) and 0.90 (black surface), in order to analyse the influence of this parameter in relation to the building electric energy consumption. For the period of the simulations, when a low (20%) or high (90%) value for the absorptance of solar radiation was adopted for the walls of the building, an average value for solar radiation absorptance of 50% was adopted

Table 2. Degree-hour and degree-day calculation.

City	Heating		Cooling	
	Degree-hour (bt = 18°C)	Degree-day (bt = 18°C)	Degree-hour (bt = 24°C)	Degree-day (bt = 10°C)
Florianopolis	6880	163	4517	3894
Curitiba	25999	892	1940	2360
Sao Luis	0	0	22828	6112

for the roof. Conversely, in the analysis of roofs with a low (20%) and high (90%) value, an average value for absorptance by the walls of 50% was adopted.

The overall heat transfer coefficient (U) and thermal capacity (C) values for the four different constructions of walls and roofs were obtained through NBR-15220: *Thermal performance of buildings – Section 3* (Brazilian Association for Technical Standards 2005). Typical constructions of commercial buildings in Brazil were considered. The calculation of the overall heat transfer coefficient and thermal capacity of the walls and roofs was carried out according to NBR-15220: *Thermal performance of buildings – Section 1*. For this research, Section 2 of NBR-15220 was consulted regarding the methods of calculation for the U and C for the opaque components, and in Section 3, there is a table (Table D.3) with values for wall and roof overall heat transfers coefficient and thermal capacity previously calculated for some types of constructions. Table 4 gives the values for the overall heat transfer coefficient and thermal capacity of the walls and roofs of the adopted constructions.

The value adopted for infiltration was 0.3 air exchanges per hour. For this parameter, a schedule of 100% functioning during a period of 24 h was used.

The floor of the typologies was made up of a layer of mortar, concrete flagstone, layer of mortar and ceramic floor, resulting in an overall heat transfer coefficient of 3.20 W/m^2 K. For the ground temperature, the values established in the climatic archives were adopted.

The air conditioning system type adopted was the window system, with a coefficient of performance of 3.19 W/W (Watts of capacity of refrigeration for Watts of electric energy consumed), which can be considered as efficient. The air conditioning system was adopted throughout the year and control temperatures of 20°C for heating and 24°C for cooling were used.

Table 3. ILD values.

	Quant.	W/m^2
Lighting (W/m^2)	12	12
People (m^2/people)	15	8
Equipment (W/people)	150	10
Total	–	30
Lighting (W/m^2)	16	16
People (m^2/people)	5	24
Equipment (W/people)	150	30
Total	–	70

Table 4. Overall heat transfer coefficient and thermal capacity of walls and roofs adopted.

	U (W/m^2 K)	C (J/m^2 K)
Walls		
Double brick wall with eight circular holes (20 cm)	1.00	328
Double bricks wall with six circular holes (10 cm)	1.50	268
Brick wall with six square holes (14 cm)	2.00	200
Concrete wall (10 cm)	4.00	286
Roofs		
Asbestos cement roof tile, thermal insulation and concrete slab	1.00	78
Asbestos cement roof tile and concrete slab	1.50	77
Clay roof tile and com wood ceiling	2.00	60
Clay roof tile	4.00	77

3. Results

3.1. *Typology 1*

3.1.1. *Patterns of use*

For cases with a pattern of use of 8 h, low internal load density (30 W/m^2), low superficial absorptance by external walls (20%), SF of reflective glass (0.58) and window-to-wall ratio of 20%, it was noted that an increase in the wall overall heat transfer coefficient (from 1 to 4 W/m^2 K) resulted in a reduction in the energy consumption of the simulated models as shown in Figure 3, for Florianopolis (5%) and Curitiba (2%). In the case of Sao Luis, the energy consumption remained practically constant.

On increasing the pattern of use for these cases to 12 h, it was noted that the reduction in the annual consumption for Florianopolis and Curitiba increased to 6% (5.354 kWh) and 4% (3.394 kWh), respectively. For the climate of Sao Luis the annual consumption still remained almost constant. The value of the annual

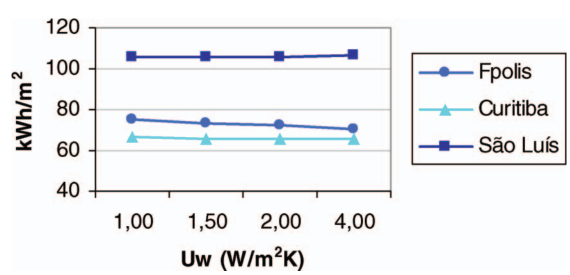

Figure 3. Consumption based on pattern of use of 8 h in Typology 1.

consumption includes lighting, equipment and air conditioning system.

An increase in the pattern of use in these cases resulted in a greater internal load density, reflecting in an increase in the building annual consumption. However, an increase in the wall overall heat transfer coefficient facilitates a dissipation of the internal gains to the external environment, reducing the annual consumption, as can be observed for the climates of Florianopolis and Curitiba. The air conditioning system energy consumption is reduced by 19% for Florianopolis and 17% for Curitiba. For Sao Luis the air conditioning system energy consumption remains almost constant. However, the peak load of the air conditioning system increases by 13% with the increase of wall overall heat transfer coefficient.

3.1.2. *Wall-to-window ratio (WWR)*

For the cases with a WWR of 20%, pattern of use of 12 h, ILD of 70 W/m^2, absorptance of 20% and SF of 0.58, it was observed (Figure 4) that for all climates the annual consumption is reduced with an increase in the wall overall heat transfer coefficient. The main difference from the previous figure is higher ILD and pattern of use.

On comparing the annual consumption values for a wall overall heat transfer coefficient of 1 W/m^2 K with those for 4 W/m^2 K, reductions of 5% (9.962 kWh) for Florianopolis, 7% (12.917 kWh) for Curitiba and 2% (4.504 kWh) for Sao Luis were observed. For the air conditioning system energy consumption, it was observed that for Curitiba the reduction was 26% with an increase in the wall overall heat transfer coefficient, whereas Florianopolis and Sao Luis had reductions of 15 and 4%, respectively.

A 50% increase in the percentage of windows in the façade led to an increase in the annual consumption for the cases simulated, due to the increase in the solar gains through the windows to the internal environment. However, on analysing the increase in the wall overall heat transfer coefficient with the new WWR value, it was observed that the annual consumption of the buildings also reduces by 3% for Florianopolis, 5% for Curitiba and 2% for Sao Luis.

The use of a WWR of 80% in these cases also led to a reduction in the annual consumption. It was observed that the reductions are less significant when compared with the cases using WWR values of 20 and 50%, because the building is receiving a greater amount of energy from solar radiation through the windows. The 80% of WWR is a little unrealistic, but this research is just using it as hypothetical variable.

3.1.3. *Internal load density (ILD)*

For the cases with an ILD of 30 W/m^2, pattern of use of 8 h, WWR of 50%, absorptance of 20% and SF of 0.58, the increase in the wall overall heat transfer coefficient led to a reduction in the building annual consumption, as can be observed in Figure 5.

It can be observed that the use of a wall with an overall heat transfer coefficient of 4 W/m^2 K reduces the annual consumption for the climates of Florianopolis and Curitiba in 5% when compared with the use of the wall with a transmittance of 1 W/m^2 K. For the climate of Sao Luis this reduction was 1%. On analysing the air conditioning system energy consumption it was observed that the reduction in this value was 16% for Curitiba, 13% for Florianopolis and 2% for Sao Luis.

On increasing the internal load density for these cases to 70 W/m^2 (Figure 6), a respective increase was observed in the annual consumption. However, the increase in the wall overall heat transfer coefficient in these cases, simulated with high internal load density, led to a reduction of 4% (5.008 kWh) for Florianopolis and 5% (6.188 kWh) for Curitiba. For Sao Luis, the reduction in the annual consumption was more representative for this case when it was compared with the cases simulated with low internal load density.

It was observed that using a high internal load density in the combination of these cases, the annual consumption reduced with an increase in the wall

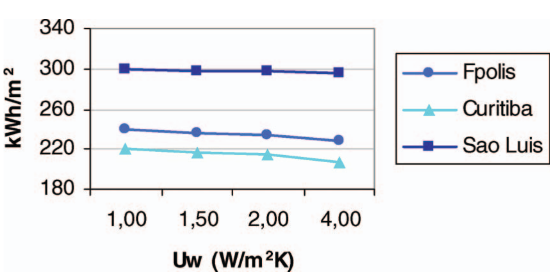

Figure 4. Consumption based on WWR of 20% in Typology 1.

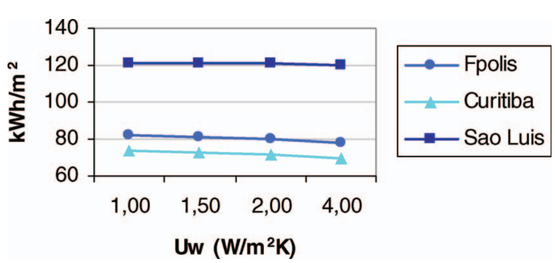

Figure 5. Consumption based on ILD of 30 W/m^2 in Typology 1.

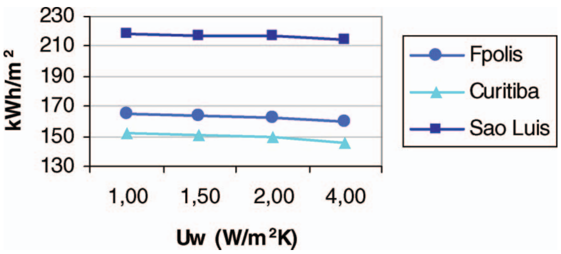

Figure 6. Consumption based on ILD of 70 W/m^2 in Typology 1.

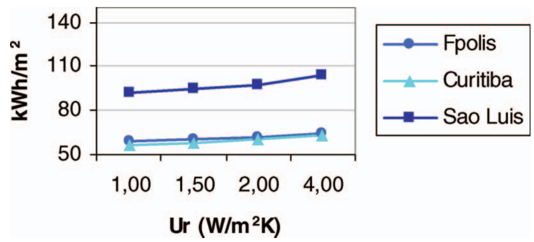

Figure 7. Consumption based on pattern of use of 8 h in Typology 2.

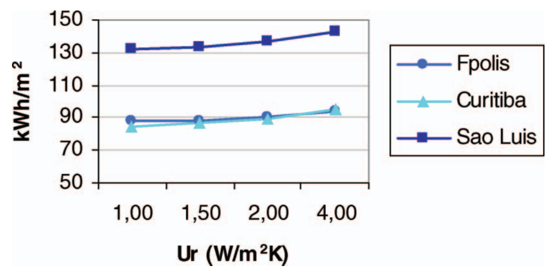

Figure 8. Consumption based on pattern of use of 12 h in Typology 2.

overall heat transfer coefficient. The increase in the wall overall heat transfer coefficient facilitates the dissipation of the internal gains to the external environment, reducing the use of the air conditioning system. For Curitiba, the reduction in the consumption of the air conditioning system was 16%, for Florianopolis 10% and Sao Luis 3%. But, increasing the wall overall heat transfer coefficient reflects in a higher peak load of the air conditioning system by 8% for Curitiba.

3.2. Typology 2

3.2.1. Patterns of use

For the cases with a pattern of use of 8 h, ILD of 30 W/m^2, WWR of 20%, absorptance of 20% and SF of 0.58, it was observed that an increase in the overall heat transfer coefficient of the roof led to an increase in the annual consumption, as can be observed in Figure 7.

For the climate of Florianopolis, the increase in the annual consumption of the building in relation to a roof thermal resistance increase from 1 to 4 W/m^2 K was 10% (14.149 kWh). For Curitiba and Sao Luis, this increase was 11% (16.380 kWh) and 12% (27.827 kWh), respectively. In relation to the air conditioning system energy consumption, both for heating and cooling, the building also showed an increase for all the simulated climates, the highest value being observed for the city of Curitiba, which had a 36% increase.

An increase in the pattern of use for these cases, from 8 to 12 h (Figure 8) also resulted in an increase in the building annual consumption. However, on comparing the roofs with a overall heat transfer coefficient of 1 W/m^2 K with those of 4 W/m^2 K, it was observed that, for a pattern of use of 12 h, there was a lesser increase in the building annual consumption, when compared with a pattern of use of 8 h, for the climates of Florianopolis and Sao Luis. For Florianopolis, the increase was 7% (15.984 kWh) and for Sao Luis it was 8% (26.770 kWh) when the cases have a pattern of use of 12 h. For the climate of Curitiba, the increase in the annual consumption was 1% higher for the cases with a pattern of use of 12 h than of 8 h. The air conditioning system energy consumption increased by 39% for the city of Curitiba with the increase in the overall heat transfer coefficient of the roof to 4 W/m^2 K. For Florianopolis and Sao Luis, this increase was 24 and 14%, respectively.

An increase in the roof overall heat transfer coefficient results in an increase in the building annual consumption because this opaque component has solar gains during a great part of the day. Thus, the higher the roof overall heat transfer coefficient, the higher the external gains to the internal environment. In the cases with a longer pattern of use, the increase in the overall heat transfer coefficient aids the dissipation of the internal gains to the external environment.

3.2.2. Internal load density (ILD)

For the cases with an ILD value of 30 W/m^2, pattern of use of 8 h, WWR of 50%, absorptance of 20% and SF of 0.58, it was observed that an increase in the roof overall heat transfer coefficient led to an increase in the building annual consumption, as can be observed in Figure 9.

The greatest increase in the consumption occurs when the roof overall heat transfer coefficient is 4 W/m^2 K. For Florianopolis, the increase was approximately 8% and for Curitiba and Sao Luís it was approximately 10%. The greatest increase in the

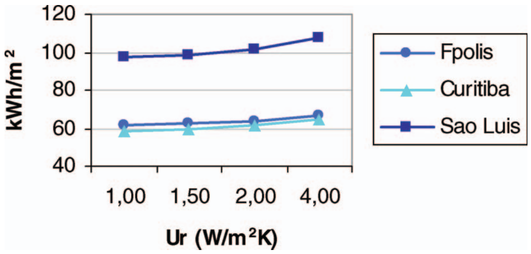

Figure 9. Consumption based on ILD of 30 W/m^2 in Typology 2.

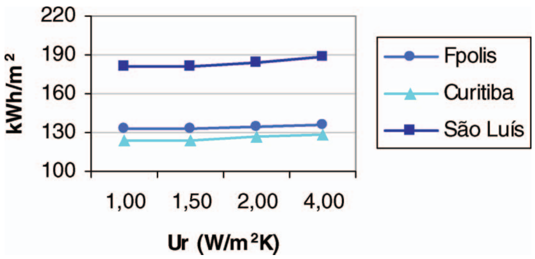

Figure 10. Consumption based on ILD of 70 W/m^2 in Typology 2.

air conditioning system energy consumption was observed for Curitiba with approximately 38%.

An increase in the internal load density to 70 W/m^2 (Figure 10) also resulted in an increase in the annual consumption. It was observed that for Florianopolis and Curitiba the increase in the annual consumption was approximately 3% and for Sao Luis it was 4%.

A comparison of the annual consumption of a roof with a transmittance of 1 W/m^2 K with that of 4 W/m^2 K showed that the consumption was influenced to a greater extent for cases simulated with an internal load density of 30 W/m^2 than those with 70 W/m^2. The increase in the roof overall heat transfer coefficient in these models facilitates the dissipation of the internal gains to the external environment and also leads to a reduced effect on the air conditioning system energy consumption when compared with the previous case.

The use of the air conditioning system for the cases with low internal load density was greatest for Curitiba, because this city has cold winters, and thus the buildings lose more heat in winter. For the cases with a greater internal load density, the need for the use of an air conditioning system is lower.

4. Conclusions

This study analysed the influence of the overall heat transfer coefficient of the opaque surfaces of two commercial building typologies in Brazil, with different internal load density conditions, on the electric energy consumption. The climates of Florianopolis, Curitiba and Sao Luis were analysed to understand the behaviour of the buildings under different conditions of cooling and heating degree-hour. The tool used for the simulation of the cases was the EnergyPlus program, version 2.0.

Through the analysis of the annual simulated cases, it was observed that depending on the density of the internal load, pattern of use, WWR, SF and the absorptance of the external surfaces, the increase in the envelope overall heat transfer coefficient can result in a decrease in annual building energy consumption.

The case where the building annual energy consumption was reduced the most when the wall overall heat transfer coefficient was increased was for the typology of the commercial building with five storeys (Typology 1) simulated with a low absorptance of the external surfaces (20%), with high density of internal load (70 W/m ^{2}), longer pattern of use (12 h) and WWR of 20%. This behaviour was obtained for the three different climates in Brazil, with Florianopolis and Curitiba having the greatest reductions in the annual consumption. On analysing the behaviour of the cases, it was noted that the increase in the overall heat transfer coefficient of the walls results in a lower annual energy consumption in overheated climates. Also, an increased overall heat transfer coefficient can contribute to dissipate the building internal load during the night. In the typology with one floor (Typology 2), the increase in the roof overall heat transfer coefficient led to an increase in the building annual electric energy consumption for the three simulated climates.

These results contradict the maximum limits of overall heat transfer coefficient for walls given in the ASHRAE Standard 90.1, at least for hot climates dominated by cooling energy use. However, this standard does not mention the building conditions of use when establishing these limits. The results of this study showed that, depending on the internal load density and pattern of use values used in the simulations, the external walls may be optimized with a overall heat transfer coefficient higher than 3.293 W/m^2 K, which is the value adopted by the ASHRAE. It was observed that, for some cases, walls simulated with an overall heat transfer coefficient of 4 W/m^2 K reduced the building consumption for the climates analysed when compared with a value of 1 W/m^2 K. For the maximum limits of overall heat transfer coefficient for roofs the values found were similar to ASHRAE, at least for building with a large roof to wall ratio.

The outputs of the computational program were used to analyse the air conditioning system, and it was observed that an increase in the wall overall heat transfer coefficient of 1 to 4 W/m^2 K resulted in an increase in the peak load of the air conditioning system by approximately 10% depending on the case analysed. These results were expected as during the day the building has solar radiation gains combined with high value of internal load, increasing the cooling loads.

This study identified the influence of the wall and roof overall heat transfer coefficient and other parameters related to commercial buildings located in three Brazilian cities, on the final electric energy consumption and thermal load. However, it must be emphasized that the economy of energy will be dependent on the climate, building size and building geometry, window areas, internal load density and properties of the materials used in the building, along with the type and efficiency of the existing air conditioning systems.

Also, it must be noted that cooling potential of ventilation and controls of solar gain have not been tested. With efficient ventilation and an appropriate control of solar gains, an increase of the thermal transmittance of walls may, possibly, lead to an increase in energy consumption.

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