THERMAL INSULATION OF BUILDING ENVELOPE TOWARD ZERO ENERGY DESIGN IN HOT-HUMID CLIMATE

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ABSTRACT

The use of thermal insulation in the building envelope in hot and humid climate is investigated through computer simulation. A total of 1,944 parametric simulation runs were carried out for three different cities and climate zones in Brazil (Curitiba, Brasilia and Salvador), considering variation of window-to-wall ratio, SHGC of the glazing system, insulation thickness in exterior walls, type of walls, and internal load densities. The results have confirmed that the building envelope has more influence on cooling energy consumption for building models with low interior load densities. Thermal insulation of exterior walls has negative impact for Brazilian cold climate, increasing the energy consumption for cooling as avoid the internal heat dissipation to the exterior environment. But in hot climate the energy consumption for cooling can be decreased with thermal insulation of exterior walls. In this case, the energy savings for cooling achieved up to 3.3%. Thermal insulation of exterior walls revealed to be a good solution to reduce peak cooling loads for the three climates under analysis, with 7.8% of maximum cooling capacity saving for the hottest city.

INTRODUCTION

Recent changes in the construction sector in Brazil have guided to more energy efficient design for lighting and HVAC systems. Plug loads density has also been decreased due to more intensive use of laptop computers and LCD flat screens monitors. In this new scenario, the thermal performance of the building envelope cannot be neglected, even for a mild climate. Thermal insulation of façades and glazing systems has always been ignored in Brazilian buildings due to the low delta temperature between the indoor and the outdoor environment. Previous research has shown that the high level of insulation in the exterior walls and glazing in buildings with high interior loads densities in hot and humid climate may decrease the heat dissipation through the envelope, increasing the energy consumption for cooling (Signor et al., 2001; Westphal and Lamberts, 2007; Melo and Lamberts, 2009). For these types of weather, the building design with an adequate U-value and thermal mass can lead to a low energy dependent facility.

In this work, this theory has been investigated for an up to date energy efficient building model toward a zero energy building design. EnergyPlus software was used to analyze the thermal performance of a high rise office building, looking for the optimum level of thermal insulation for each climate, or the best U-value for the type of building use and weather.

Lam et al (1997) have been also developed this type of parametric analysis in order to estimate the electric energy consumption of commercial buildings in Hong Kong. Through parametric analysis and sensitivity analysis O'Neill et al (1991) identified those parameters with major impact on building thermal loads of commercial rooms in the USA.

Multiple linear regression analysis was applied by Chung et al (2006) to evaluate the energy efficiency of commercial buildings and establish a ranking of efficiency through multiple linear regression. Such a procedure can lead to an optimization of the building design with focus on energy performance. If the energy use pattern is moving to a low energy intensive activity inside the building, investigation on envelope performance should also be updated to this new condition, especially when the look for a zero energy building is put in the sustainable development agenda.

SIMULATION

Parametric simulation runs were carried out using the EnergyPlus software. The model of a typical floor in three different shapes representing an office building was modelled with the same size of 1,600 m². The first shape has 40x40m. The second shape is rectangular, 60m width and 26.7m depth. The last shape modelled is also rectangular, but with the large façades oriented to east and west (Figure 1).

The air conditioning system was represented through packaged terminal heat pumps with COP equal to

3.0W/W. In Figure 1, zones 1 to 4 are artificially conditioned and zone 5 is unconditioned. The zone 5 correspond to 25% of the floor area in each model, representing elevator shafts, stairs, mechanical rooms, restrooms and circulation areas.

Figure 2 shows the pattern of use (occupancy) considered for weekdays and Saturdays. The building was considered unnocupied on Sundays and Holidays. The operation of HVAC system follows the same schedule. The use of artificial lighting system and plug load equipments has similar patter of use, but with residual loads switched on during the night.

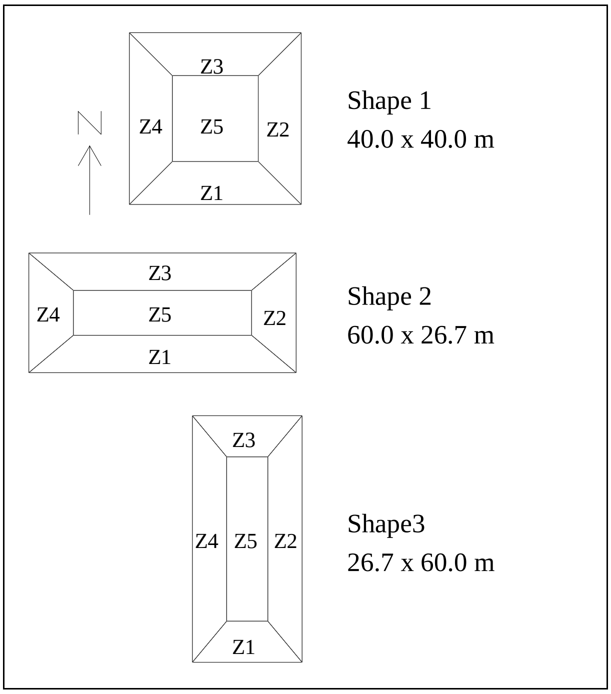

Figure 1 Building shapes under analysis.

Six parameters were selected to analyse the influence of building characteristics in conjunction with thermal insulation of exterior walls. The reason to chose each parameter is explained below.

Weather

It is expected that in climates with more hours with occurrence of high temperatures, the use of thermal insulation in the building envelope can minimize the heat gain through conduction. Brazilian territory is divided into 8 climatic zones, from the coldest zone (number 1) to the hottest zone (number 8). Thus, three cities were selected to conduct this study: Curitiba, located in zone 1; Brasilia, in zone 4, and Salvador, from zone 8. A data summary for each city is presented in Table 1 and the location in Brazilian map is presented in Figure 3.

The hourly variation of dry bulb temperature for the three TMY weather files is presented in Figures 4 to 6.

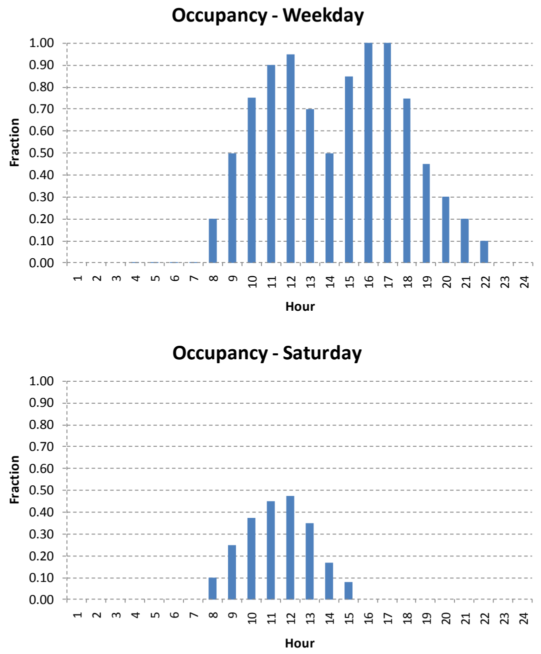

Figure 2 Schedules of occupancy for Weekdays, Saturdays and Sundays/Holidays.

Table 1 – Cities considered in the analysis.

City:	**Curitiba**	**Brasília**	**Salvador**
Geographic coordinates			
Latitude	25°31'S	15°52'S	12°53'S
Longitude	49°10'W	4756°'W	38°19'W
Altitude	910 m	1,061 m	13 m
Degree-hours (8,760 hours)			
Heating (tb=18°C)	21,308	5,092	0
Cooling (tb=24°C)	2,007	6,909	18,405
Degree-hours (work hours only)			
Heating (tb=18°C)	7,152	620	0
Cooling (tb=24°C)	1,588	5,374	10,150

Wall type

Masonry with clay blocks is the most common wall type in Brazilian buildings. The use of thermal insulation is not a regular practice. Thus, one of the objectives of this study is to analyse if thermal insulated steel frame wall can be adopted in place of masonry wall.

Figure 3 Cities location in the map of Brazil.

Internal loads density (ILD)

With high level of internal loads inside the building, the influence of the envelope on thermal performance is minimized. Thus, three levels of internal loads density (ILD) were tested in conjunction with thermal insulation of building envelope. The three levels represent different conditions of occupancy density, which are listed in Table 2. Activity level of 120 W per person were considered to account as heat gain from people.

Table 2
Internal load density levels

ILD level:	36 W/m^2	48 W/m^2	60 W/m^2
Occupancy:	10 m^2/person	8 m^2/person	6 m^2/person
Lights:	10 W/m^2	13 W/m^2	15 W/m^2
Equipment:	14 W/m^2	20 W/m^2	25 W/m^2

Window-to-wall ratio (WWR)

A high window-to-wall ratio (WWR) represents a low exterior wall area, i.e., less opaque walls to promote heat exchange with the environment. Three levels of WWR were selected in order to identify the influence of building envelope insulation. These three levels (40%, 50% and 60%) were selected from the actual common practice of commercial building design in Brazil.

Solar Heat Gain Coefficient (SHGC)

If the heat gain from windows is low, the influence of exterior walls in building cooling load should be low too. With the actual demand for green building certification in Brazil, commercial buildings has been adopting glazing façades with low SHGC. Three levels of SHGC were selected to be studied in this analysis: 0.25, 0.30 and 0.35. Only monolithic glass units were selected, as is the usual practice in Brazil.

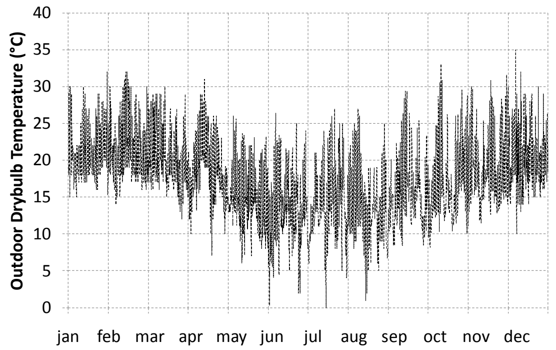

Figure 4 Hourly outdoor dry bulb temperature data from Curitiba TMY weather file.

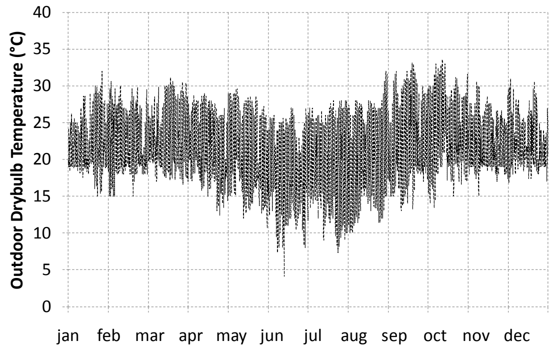

Figure 5 Hourly outdoor dry bulb temperature data from Brasília TMY weather file.

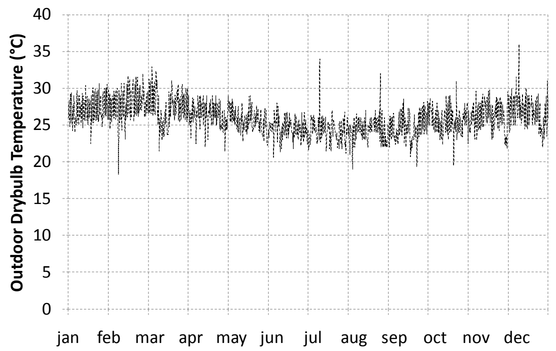

Figure 6 Hourly outdoor dry bulb temperature data from Salvador TMY weather file.

Insulation thickness

Three levels of thermal insulation were tested: 25mm, 50mm and 75mm; that represent, respectively, 0.55, 1.11 and 1.66 m^2.K/W of thermal resistance. One option without thermal insulation was also simulated.

Total of cases

Table 3 list a summary of parameters under analysis. The combinatory analysis were carried out to generate a total 1,944 cases.

Table 3
List of parameters under analysis

#	PARAMETER	VALUES
1	Building shape	• #1: Square • #2: Rectangle W-E • #3: Rectangle N-S
2	City	• Curitiba • Brasília • Salvador
3	Wall type	• Steel frame • Masonry
4	Internal loads density	• 36W/m² • 48W/m² • 60W/m²
5	Window-to-wall ratio	• 40% • 50% • 60%
6	SHGC	• 0.25 • 0.30 • 0.35
7	Insulation thickness	• 0mm (no insulation) • 25mm • 50mm • 75mm

DISCUSSION AND RESULT ANALYSIS

Figures 7 to 9 present the variation in the annual energy consumption for cooling due to increasing in the thermal insulation thickness on exterior walls. Each graph presents 12 simulated cases. Those models correspond to shape 1 (square format), with steel frame exterior walls, the lowest internal load density (36W/m²) and the lowest WWR (40%). These conditions were selected as the situation where the higher differences were detected as a consequence of insulation thickness variation.

As it can be observed in the graph of Figure 7, the thermal insulation of exterior walls increases the energy consumption for cooling in the building models simulated for Curitiba weather file. That is the coldest city from the three under analysis. In that case, the use of thermal insulation avoid the heat dissipation to the exterior environment. The increase in annual cooling energy achieves up to 11.8% for the model with SHGC of 0.25 and 75 mm of thermal insulation against the building model without insulation.

The energy consumption for cooling is still increased due to the use of a more insulated building envelope even for Brasilia weather file, as can be observed in Figure 8.

But for Salvador city (Figure 9), the energy savings for cooling is evident with the use of thermal insulation in exterior walls. The highest reduction in annual energy consumption for cooling was 3.3% for the case with SHGC 0.25 and 75 mm of insulation thickness.

It is important to highlight that these cases have the highest opaque envelope area and the lowest ILD, which results with building models with thermal performance high dependent on exterior walls.

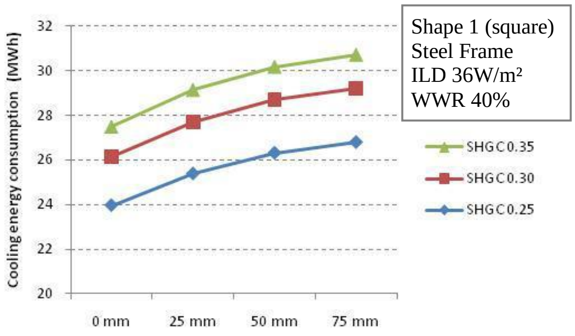

Figure 7 Cooling energy consumption as a function of thermal insulation thickness for Curitiba

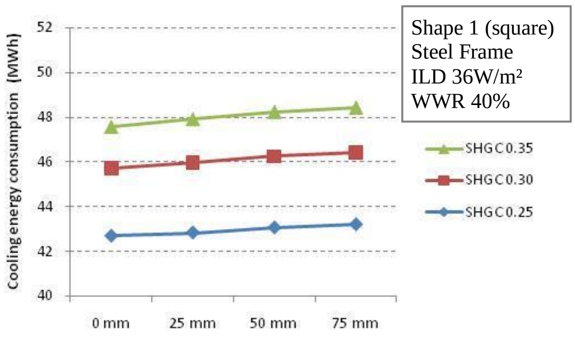

Figure 8 Cooling energy consumption as a function of thermal insulation thickness for Brasília

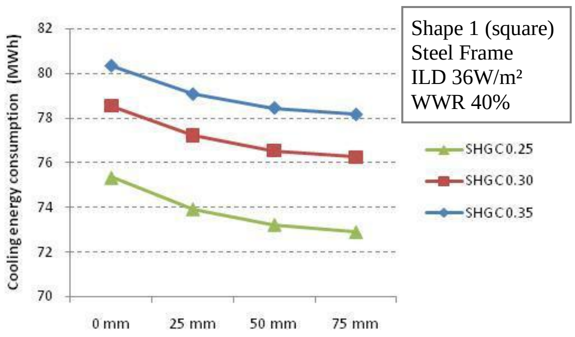

Figure 9 Cooling energy consumption as a function of thermal insulation thickness for Salvador

The same pattern of performance was obtained for the other two shapes of building – rectangular oriented west-east, and rectangular oriented north-south. But the difference of performance between shape and orientation was evident. The graph on Figure 10 shows the average cooling energy savings for the same 12 cases shown in Figures 7 to 9, calculated for each group of cases in each city. The difference on energy consumption was calculated between the rectangular shapes against the square one. It can be seen that changing from square pattern to rectangular shape oriented through the axis north-south can increase up to 5.2% the cooling energy consumption for this type of building in Brasilia weather; and changing to rectangular shape oriented through axis east-west can provide a low energy savings, of 2.0% in this city. This Figure shows that even for a well specified building envelope – with WWR 40% and SHGC 0.25 – and low internal load density, the building orientation can cause an influence around 5% in the annual energy consumption for cooling in a tropical weather as Brasilia (cooling degree-hours of 5,374).

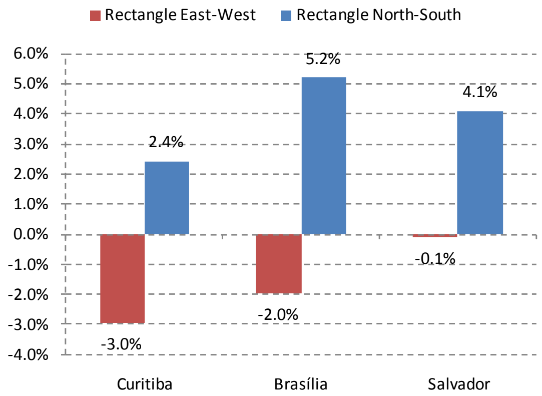

Figure 10 Difference between cooling energy consumption for fior different building shapes.

Wall type

The use of masonry with clay blocks is a common practice in Brazil. But the number of buildings constructed with steel frame has increased in the last years. This growth has been criticized, as Brazilian weather requires high density exterior walls in order to minimize indoor air temperature fluctuation. But this condition may not be taken into account for commercial buildings, with intensive use in daytime hours.

Figure 11 shows that the use of steel frame as exterior walls did not cause any significant influence on annual energy consumption for this type of building, with square format (Shape 1), low ILD (36W/m²) and low WWR (40%). The graph shows the same cases presented on Figures 7 to 9, plus the condition of different exterior walls construction. The highest difference between the two types of walls was identified in Brasilia, achieving 5.2% of energy consumption increase for cooling when changing from masonry to steel frame, maintaining all other parameters the same, and without the use of thermal insulation.

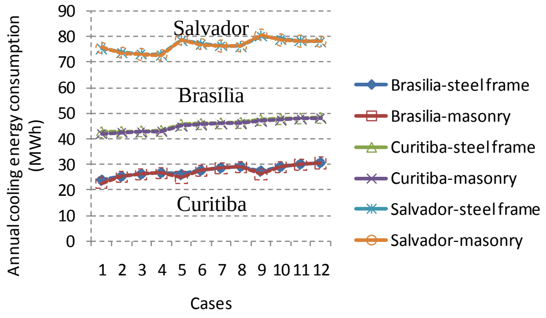

Figure 11 Annual cooling energy consumption for two types of exterior walls: steel frame and masonry, for each city under analysis.

Cooling capacity

From all cases under analysis, the cooling energy savings identified due to the use of thermal insulation on exterior walls was very low. The values did not reach 4%. This scenario confirms that the use of thermal insulation for this kind of building use, shape and weather cannot bring significant benefits in terms of energy savings.

But the analysis over the peak cooling load or installed HVAC capacity has revealed higher benefits when using thermal insulation on walls.

Figure 12 shows the cooling capacity savings for the 3 shapes of building under analysis for Curitiba city, with WWR of 40%, SHGC 0.25, steel frame walls and ILD 36 W/m². It can be seen that for the rectangular shape oriented through east-west axis (Shape 3), the peak cooling loads reduction was higher than the other two shapes, achieving 7.1%. This can be explained as the shape 3 has the largest façade areas faced to east and west, that are the most sun lighted areas during the year.

The results for Brasilia are presented in Figure 13, which reveals an increase in the peak cooling load for the Shape 1 (square format) and reduction in the cooling loads for the other two shapes. The highest economy was again achieved for the Shape 3 (8.6%).

Figure 14 presents the cooling loads savings due to thermal insulation in Salvador city. The largest reduction was obtained for Shape 3, with 8.2%, but the value was very similar to the cooling load reduction identified for the Shape 2, with 7.9%.

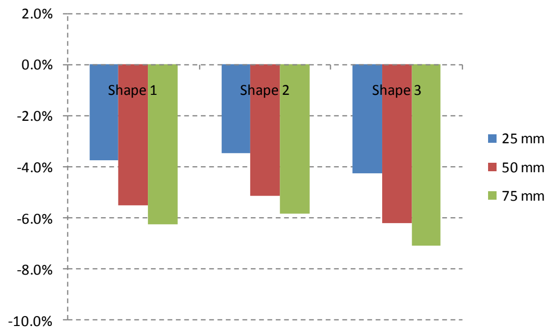

Figure 12 Cooling capacity savings due to insulation thickness and building shape for Curitiba

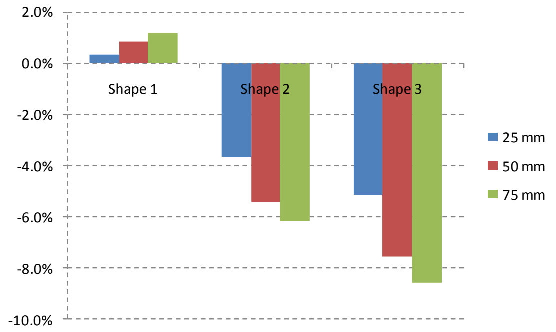

Figure 13 Cooling capacity savings due to insulation thickness and building shape for Brasília

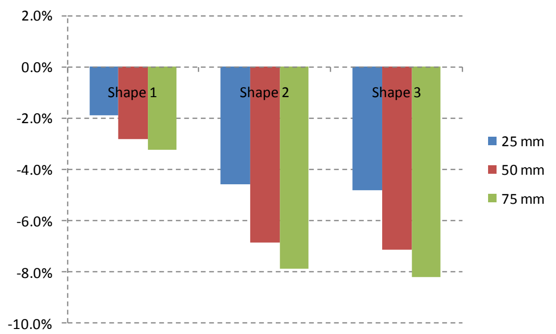

Figure 14 Cooling capacity savings due to insulation thickness and building shape for Salvador

CONCLUSION

The main objective of this study was to identify were the use of thermal insulation on walls could bring significant performance benefits in order to design a zero energy building. The parameters under analysis focused on changing the influence of exterior walls in the annual energy consumption for cooling the building.

It was identified that for the types of building simulated here, and between the intervals of variation of those architecture parameters, the use of thermal insulation, with thickness ranging from 25mm to 75mm has little impact in the annual energy consumption for cooling. The differences from using 75mm of thermal insulation to no use of insulation achieved at maximum 3.3% of energy savings in annual cooling energy. But higher differences were obtained in the total cooling capacity, with 8.2% of savings for the building rectangular shape with higher façades area faced to east and west, for Brasilia weather file.

The use of steel frame wall was also compared against the use of masonry wall, which is the most common situation in Brazil. The highest annual energy consumption increasing due to the use of steel frame, i.e., low thermal mass, was identified for Brasilia weather. This is the city with the highest daily temperature range from the list of three cities under analysis.

The conclusions presented in this paper refers only to the building and climate characteristics described here. More investigation can be made over thermal balance for specific thermal zones in the building models in order to seek a better understanding where the thermal insulation could result in higher benefits for thermal performance in hot and humid climate.

This analysis can be the first step in the research for a zero energy design for this kind of building. The next step may be exploring the adoption of passive cooling strategies, in conjunction with a more adequate building shape to avoid the use of artificial lighting and HVAC systems.

Although the annual energy savings due to the use of thermal insulation on exterior walls had presented modest results, the analysis over the life cycle of the building can present good benefits. This can be also explored in a next step.

REFERENCES

Chung, W.; Hui, Y.V.; Lam, Y.M. Benchmar-king the energy efficiency of commercial buildings. Applied Energy. 2006. v. 83, p. 1-14.

Lam, J.C.; Hui, S.C. M.; Chan, A.L.S. Regression analysis of high-rise fully air-conditioned office buildings. Energy and Buildings. v. 26, p. 189-197, 1997.

Melo, A. P., Lamberts, R. Envelope insulation and heat balance in commercial buildings. Building Simulation 2009, Glasgow. P. 2243-2250.

O'Neill, P.J.; Crawley, D.B.; Schliesing, S. Using regression equations to determine the relative importance of inputs to energy simulation tools. In: Proceedings of the Building Simulation 1991, Australia, p 283-289.

Signor, R.; Westphal, F. S.; Lamberts, R. 2001. Regression analysis of electric energy consumption and architectural variables of conditioned commercial buildings in 14

Brazilian cities. Building Simulation 2001, Rio de Janeiro, p. 1373-1379.

Westphal, F. S., Lamberts, R. regression analysis of electric energy consumption of commercial buildings in brazil. Building Simulation 2007, Eindhoven. p. 1543-1550.