DETERMINATION OF ENERGY INDEX FOR SHOPPING CENTERS IN BRAZIL

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Abstract. *Several actions are implemented in Brazil in order to reduce the energy consumption in buildings. One of the main issues related to energy efficiency in buildings is the development of benchmarking for the several uses of energy in buildings. One of the sources that have been used for defining the characteristics of a more efficient building and its systems is ASHRAE Standard 90.1 -2007. This standard provides guidelines for parameters such as building envelop, lighting and equipment power density, air conditioning efficiency, etc. that defines the characteristics of a building in specific climate conditions. The annual energy consumption of such building (namely baseline) represents a benchmark which provides a reference for analysis of building energy efficiency. Therefore, by comparing the energy consumption of the baseline building with the energy consumption of different buildings, one can evaluate the level of the energy efficiency of those buildings. Besides, the use of simulation tools increased due to the their capability of providing detailed evaluation of the energy consumption of a building based on its envelop materials and systems efficiency. Among the available simulation tools, EnergyPlus is one of the most used because its capability of simulating the whole building and its systems (lightning, equipments, air conditioning, etc.). Besides, EnergyPlus also fulfills the technical requirements as a simulation tool based on ASHRAE Standard 140, which evaluates simulation tools for LEED certification purposes. Among the several types of building, the shopping centers are quite important because it represents more than 390 buildings with approximately 19.6 million square meters in Brazil. The objective of this paper is to evaluate the energy performance index for shopping centers in five different major cities in Brazil. The energy consumption of such buildings will be evaluated through the simulation of a model of this type of building using Energy Plus. The envelop materials and the technical requirements of each system of the building will be defined based on the guidelines of ASHRAE Standard 90.1-2007. Based on simulation results, it was possible to determine indexes of energy efficiency of such buildings. The energy matrix obtained from the simulation shows that the largest part of the power consumption corresponds to the air conditioning system. A sensibility analysis of some variables (occupancy, lightning power density, COP, etc.), was made and provided some insights for the energy behavior of such buildings. Finally, some indexes such as kWh/m².ºC .month and kWh/m².ºC .year were analyzed for five different climate regions of Brazil. One can verified that these indexes can provide a good forecast of the energy consumption.*

Keywords*: shopping center, energy index, building simulation.*

1. Introduction

The concept of sustainability has been spread more and more among the several levels of the society. The energy consumption is the main focus to be analyzed in the search of the energy efficiency. The policies of energy conservation in Brazil are still deficient and make more difficult the implementation of actions to avoid the energy waste.

The use of energy indexes for buildings could help the development of benchmarks for efficient constructions. It should be pointed out that these benchmarks have to be specific energy values for each construction type. Therefore a reliable data basis has to be created which relies in detailed studies of representative building models. These models can be study using simulation tools in order to identify the appropriate energy indexes and the parameters for such buildings can be obtained through standards such as ASHRAE 90.1 (2007) and NBR 16401 (2008).

Among the several building types, shopping center are a commercial building that is quite disseminated in Brazil. According to ABRASCE (2010), there are more than 390 shopping centers in Brazil, occupying an area of approximately 19.6 million square meters. Hence, the use of energy benchmarks for such building type can be useful in order to provide references for new and existing buildings with this particular occupancy.

In this paper, the analysis of energy consumption of typical shopping center (namely baseline building) will be analyzed by developing a virtual building that reproduces the characteristics of a shopping center. This virtual building will be simulated using EnergyPlus® as simulation tool and it will be simulated for five different climate data that represents the climate conditions of five different cities in Brazil (São Paulo, Rio de Janeiro, Belém, Brasília e Porto Alegre). Those cities were chosen for representing good examples of the diversity of climate conditions in Brazil.

2. Description of the building

Based on the data provided by ABRASCE (2010), ASHRAE (2007) and ABNT (2008), the typical characteristics of shopping centers in Brazil are:

- Total area: 27536 m^2;
- Conditioned area: 27536 m^2;

- Five stories building, including the underground floor;
- Building divided in 45 thermal zones (all with air conditioning);
- Window area: 40% of the total wall area;
- Window openings in the roof: maximum of 5% of total roof area;
- Air conditioning with fan-coils and VAV boxes, two chillers (COP=6.1) and a boiler (fuel: gas and efficiency of 0.8).

Based on appendix G of Standard ASHRAE 90.1 (2007), others parameters for the baseline building are defined such as global heat transfer coefficient for the walls (0.705 W/m^2) and solar heat gain coefficient for the windows (0.25). The lightning level of the virtual model is also based on the information supplied by the Standard ASHRAE 90.1 where the lightning power density for circulation areas is 16 W/m^2; for the food court 30 W/m^2; and for big stores they vary between 40 W/m^2 and 50 W/m^2, depending on the area. Regarding the electrical equipments and occupancy densities, there are no specific data in Standard 90.1-2007 (2007). Therefore, the levels used in this paper are based in typical values used by air condition experts and some references in the open literature (Barros Filho, 2005 and Lam&Danny, 2002). Hence, the occupancy density was set as 8 persons/m^2 for the circulation area; 2 persons/m^2 for the food court and 5 persons/m^2 for the big stores. Regarding the electrical equipment power density, a value of 2 W/m^2 is used for most of the building areas except for food court where a value of 15 W/m^2 is used.

3. Simulation results

Based on the assumptions made previously, an annual simulation was carried out using EnergyPlus® for a typical climate data of the city of São Paulo, available in U.S. Department of Energy (2010). Figure 1 shows the North side of the tridimensional model used in such simulation.

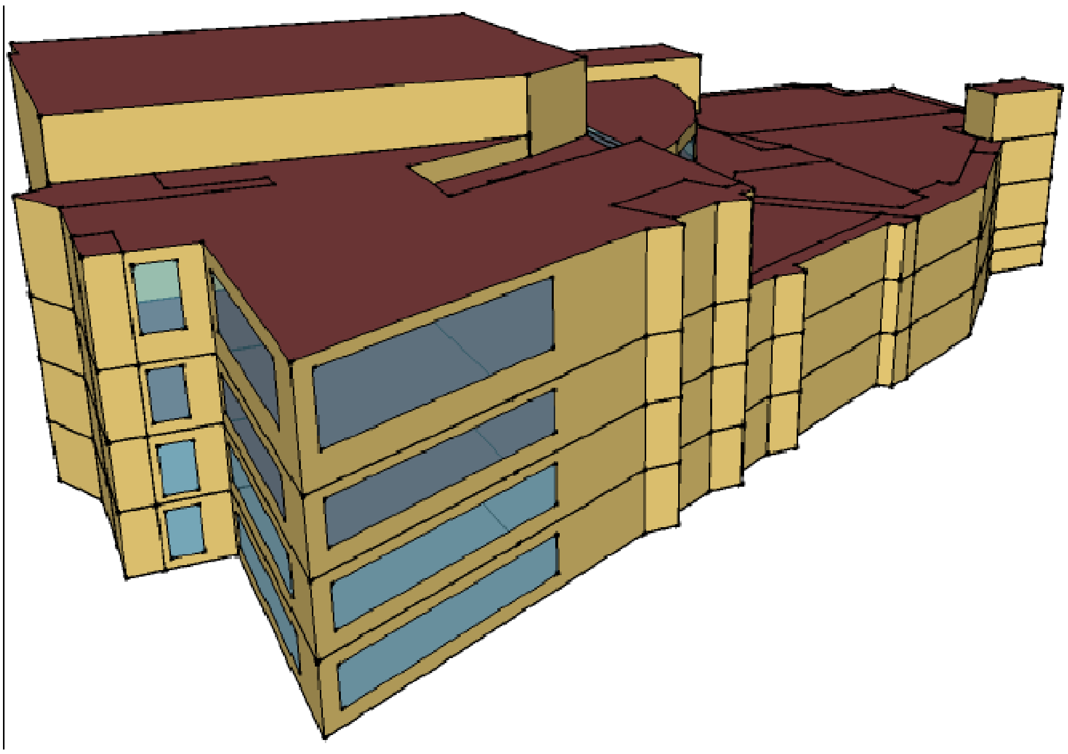

Figure 1. Tridimensional model – North side.

The annual electrical energy consumption obtained from the simulation is 7.401.683 kWh and it can divided in the building main systems shown in Table 1.

Table 1: Distribution of the shopping center energy consumption.

System	Energy consumption (kWh)	Percentual contribution [%]
Air conditioning	3.693.012	49.89
Lightning	2.601.488	35.15
Equipment	1.104.873	14.93
Heating	2.311	0.03

One can observe from Table 1 that the main contribution in the energy consumption is the air conditioning system followed by the lightning system.

The energy consumption along the year is presented in Figure 2 where the air conditioning is highly dependent on the climate conditions.

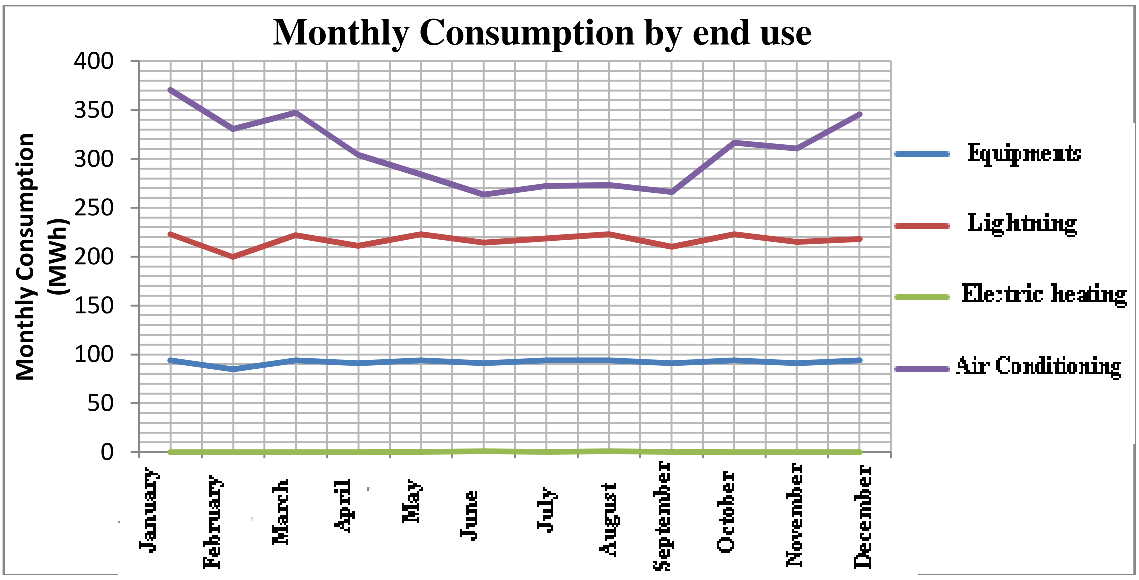

Figure 2. Monthly consumption by end use of reference model.

4. Sensitivity analysis

In order to evaluate the effect of some parameters in the energy consumption profile of a shopping center, a sensitivity analysis was carried out for the climate data of São Paulo. In this analysis, three parameters were varied in a range of ±20%: occupancy density, lightning power density and COP of the air conditioning and heating systems. For each parameter, the variation was imposed while the others parameters remain constant and the results are compared with the results simulation without any variation (baseline). The first parameter analyzed was the lightning power density and the results are shown in Figure 3. One can observe a linear variation of the energy consumption regarding this parameter that affects not only the energy consumption of the lightning system but also the air conditioning system (±7%).

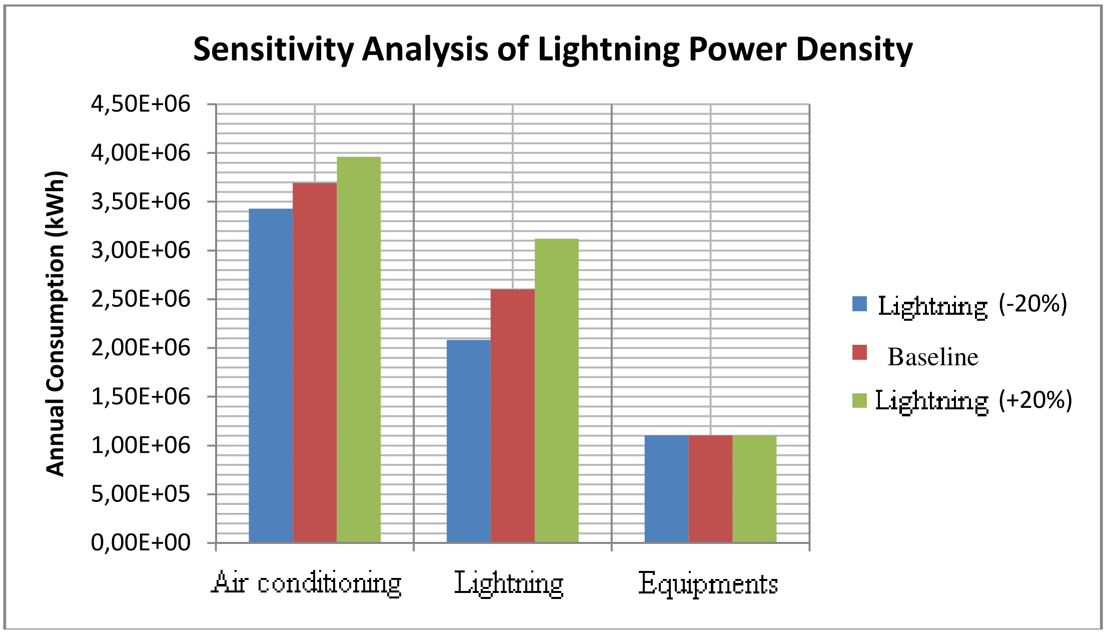

Figure 3: Impact of lightning power density on the energy consumption of air conditioning system, lightning system and electrical equipment for the city of São Paulo.

Figure 4 shows the effect of occupancy variation on the shopping center for the annual energy consumption of air conditioning system, lightning system and electrical equipment. It can be found out that there is a variation of ±11,65% on the energy consumption of air conditioning while the energy consumption of the lightning and electrical equipments remain constant. It should be point out that the occupancy defined here is the ratio between occupied area per person. Therefore a reduction of such parameter implies in an increase of the total number of persons in the shopping area.

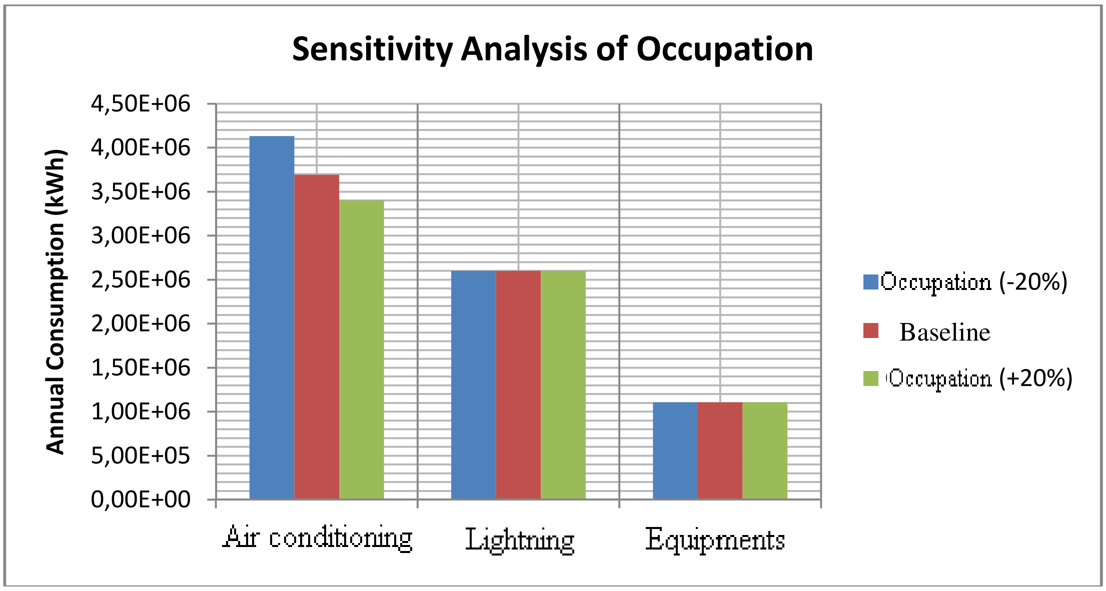

Figure 4: Impact of occupancy on the energy consumption of air conditioning system, lightning system and electrical equipment for the city of São Paulo.

Figure 5 shows the effect of the variation of the COP of the air conditioning and heating system for energy consumption. One can be observe that a variation of such parameter imposes a variation of ±7% in the energy consumption of the shopping center.

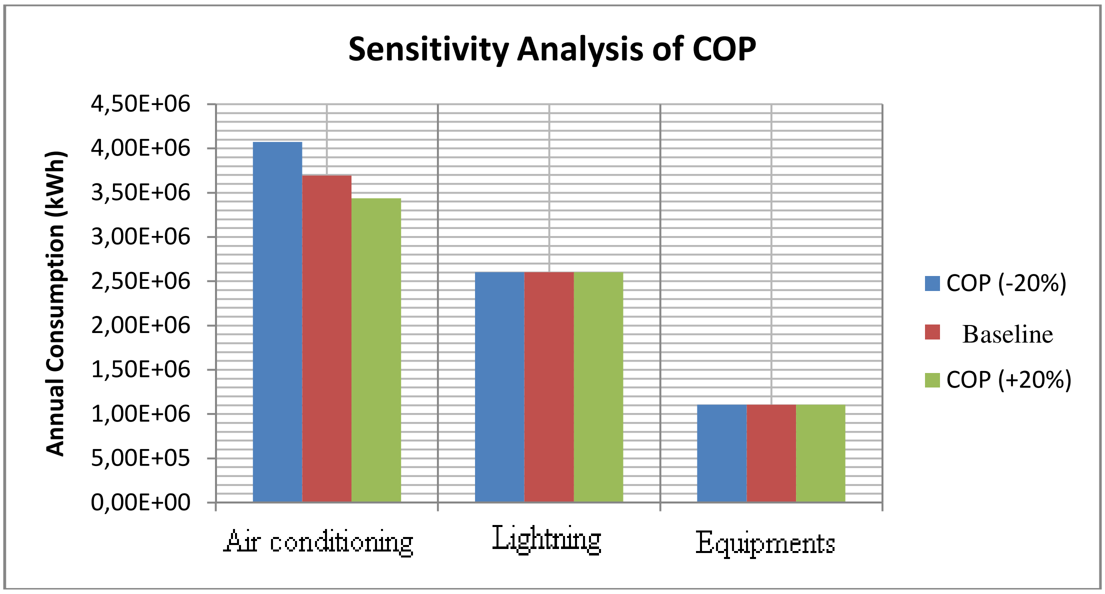

Figure 5. Impact of the COP of the air conditioning and heating system on the energy consumption of air conditioning system, lightning system and electrical equipment for the city of São Paulo.

5. Evaluation of energy index for shopping center

Based on the simulation results showed previously, a first energy index for shopping centers in Brazil is proposed. This index is defined as the ratio between the total annual energy consumption of the shopping center and total building area. Figure 6 and Table 2 shows the values of such index for five different climate data related to five Brazilian cities and the deviation from the average energy index evaluated for all cities (287.9 $kWh/m^2.°C$).

Table 2. Energy index of shopping centers for five Brazilian cities and deviation related to average energy index.

	kWh/m².year	Deviation [%]
São Paulo	268.8	-6.6
Belém	327.9	+13.9
Brasília	276.5	-4.0
Porto Alegre	269.9	-6.3
Rio de Janeiro	296.4	+3.0

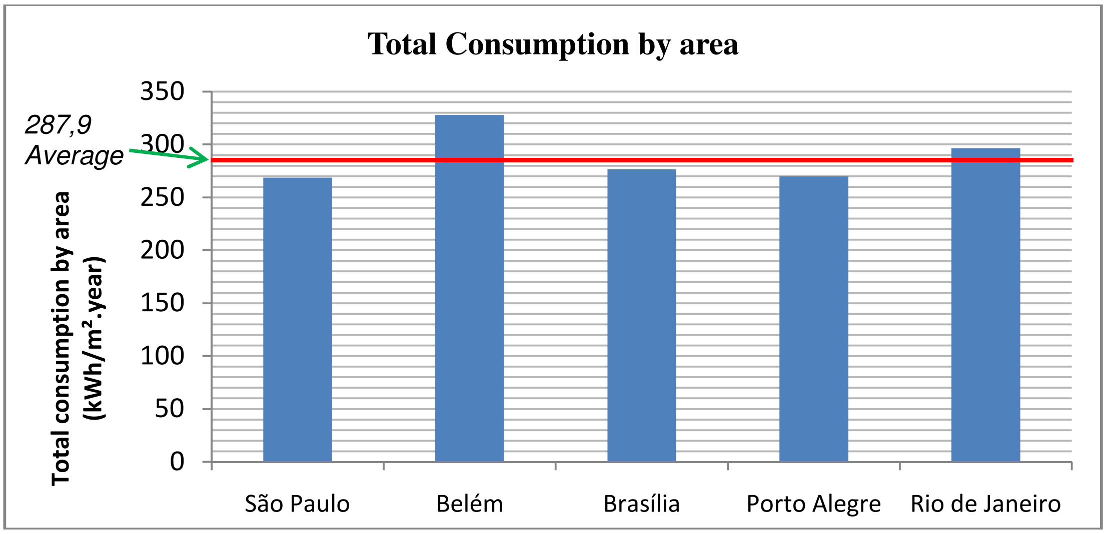

Figure 6: Energy index for the different climate data.

Part of the deviation shown for the energy index can de explained due to the lack of any contribution in the energy index related of the climate conditions Therefore, in order to introduce the climate contribution, it was proposed to divide the energy index by the annual average dry bulb temperature for each climate and the results as well the comparison between this new energy index for each climate is shown in Table 3 and Figure 7 where the average of this new energy index for all climates is 13.1 kWh/m^2.°C.year. The deviation of this average energy index and the energy index for each climate is shown in Table 3. The difference between this evaluation and the virtual building energy index is shown. It can be noticed that the energy index provides a better prediction for the energy index for the analyzed building and climates (a range from +7.6% to -5.3%).

Table 3. Energy index divided by the annual dry bulb temperature (DBT) for each climate.

	Virtual building Energy Index kWh/m².year	Average DBT (°C)	Virtual building Energy Index kWh/m².°C.year	Deviation [%]
São Paulo	268.8	19.9	13.5	+3.1
Belém	327.9	26.5	12.4	-5.3
Brasília	276.5	21.5	12.9	-1.5
Porto Alegre	269.9	19.2	14.1	+7.6
Rio de Janeiro	296.4	23.6	12.6	-3.8

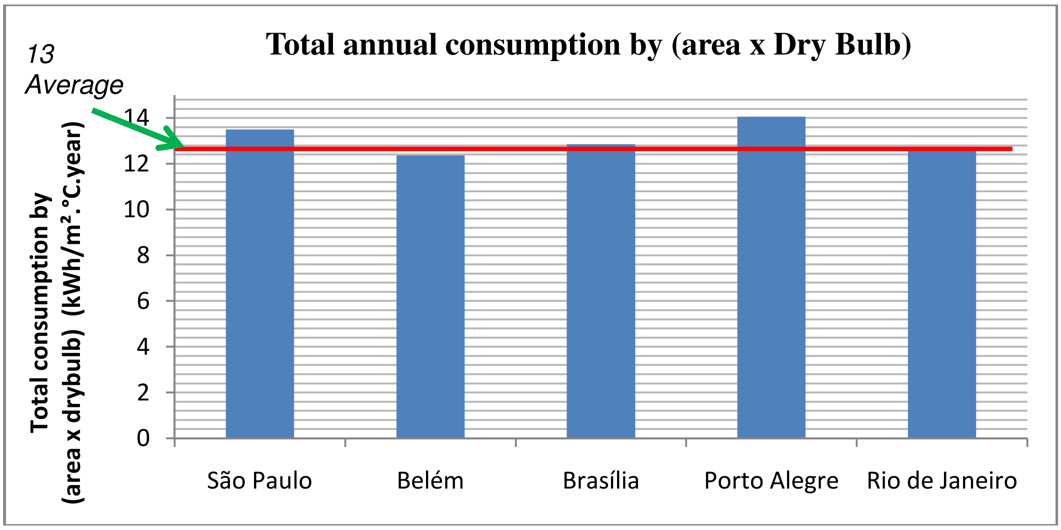

Figure 7: Energy index divided by the annual average dry bulb temperature.

In order to improve the prediction of the energy index here proposed, another analysis was carried out where the energy consumption per total building area of air conditioning system was separated from total energy consumption of the building per total area for each climate . The energy index of the air conditioning system for each climate is shown in the first column of Table 4 where the average value of energy consumption index for the air conditioning system is 152, 2 kWh/m^2.year. Based on this average value, the percentual deviation between this average and the value achieved in each climate is shown in the second column of Table 4. One can observe that the differences are quite high and this can be attributed to the climate characteristics that highly influence the energy performance of the air conditioning system. Figure 8 shows the comparison between the average energy index for the air conditioning system for each climate and its average value.

Table 4: Building air conditioning energy index.

	Building Air Conditioning energy index (kWh/m².year)	**Percentual deviation [%]**
São Paulo	133.8	12.1
Porto Alegre	134.3	25.4
Rio de Janeiro	160.6	-7.0
Belém	190.9	-11.8
Brasília	141.5	5.5

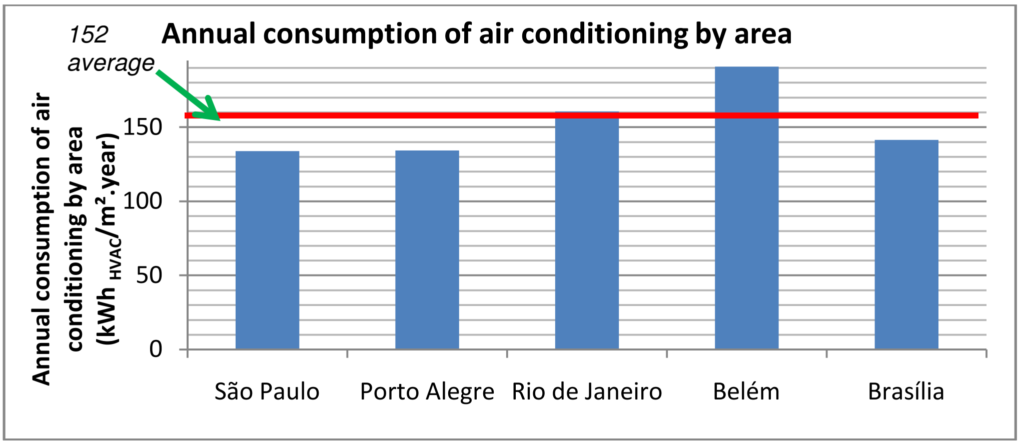

Figure 8: Annual energy consumption index for air conditioning system in a shopping center.

Due to the influence of climate shown before, the average annual dry bulb temperature was included in the denominator of the energy index for the air conditioning system (see Table 5 and Figure 9). The average value for this new energy index evaluated for the five climate is 6.9 kWh/m^2.°C.year and one can notice that the difference between this value and the ones for each lies in a range of difference of ±5%, which can be considered quite adequate for such index because it is almost the same value of the uncertainty evaluated from more complex software such as EnergyPlus®.

Table 5. Energy consumption index for the air conditioning divided by the average annual dry bulb temperature (average DBT).

	Energy index (kWh/m².°C.year)	Average DBT (°C)	Difference between average energy index [%]
São Paulo	6.7	19.9	-2.0
Porto Alegre	7.2	19.2	+5.0
Rio de Janeiro	6.6	23.6	-4.1
Belém	7.0	26.5	+1.9
Brasília	6.8	21.5	-0.8

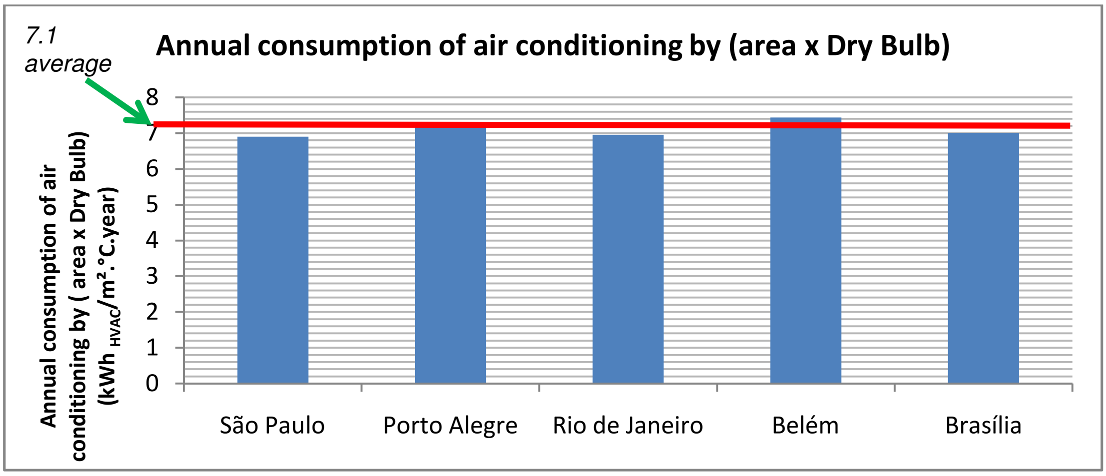

Figure 9. Energy consumption index for the air conditioning divided by the average annual dry bulb temperature (average DBT).

The energy consumption of the lightning and electrical equipment are unaffected by the climate characteristics. Therefore, they are evaluated as a constant of 135.7 kWh/m^2.year. Thus, this energy index can be combined with the one for the air conditioning system in order to improve the prediction of such energy index for shopping centers in Brazil. This combined energy index can be translated in the Equation 1.

TEI = AEI*ADBT+CEI, where: (1)

TEI = total benchmark energy index, kWh/m^2;
AEI = air conditioning system energy index, kWh/m^2.°C;
ADBT = annual average dry bulb temperature, °C;
CEI = energy index for the electrical equipments and lightning systems = 135.7 kWh/m^2;

The TEI was calculated for the five climates and it was compared to the energy index evaluated through the simulation of the shopping center for each climate. The results of such comparison are shown in Table 6. It can be noticed a significant reduction of the deviation between the TEI evaluated from the simulation of the baseline building ($TEI_{simulation}$) and the one calculated by Eq. 1 ($TEI_{Eq.1}$) as shown in Table 3. Therefore, the energy index TEI calculated from Eq. 1 can be considered an adequate index to evaluate the energy consumption of shopping centers in the analyzed Brazilian climates.

Table 6. Energy consumption index for the air conditioning divided by the average annual dry bulb temperature (average DBT).

Climate	$TEI_{simulation}$ (kWh/m².year)	ADBT (°C)	AEI (simulation) (kWh/m².°C.year)	$TEI_{Eq. 1}$ (kWh/m².year)	($TEI_{simulation}$ - $TEI_{Eq. 1}$)/ $TEI_{simulation}$ [%]
São Paulo	268.8	19.9	6.7	272.2	-1.3
Belém	327.9	26.5	7.2	317.5	+3.2
Brasília	276.5	21.5	6.6	283.2	-2.4
Porto Alegre	269.9	19.2	7.0	267.4	+0.9
Rio de Janeiro	296.4	23.6	6.8	297.6	-0.4

6. Conclusions

This paper proposes to evaluate an energy index in order to predict the annual energy consumption of shopping centers in five different climates in Brazil. A virtual model of shopping center was developed based on the criteria found on Standards ASHRAE 90.1-2007 (2007) and NBR-160401 (2008). The climate data used are for the cities of São Paulo, Rio de Janeiro, Belém, Brasilia and Porto Alegre. Using the climate data of São Paulo, a sensitivity analysis was carried out in order to evaluate the parameters that influence more the energy consumption on such building. It was found that occupancy density, lightning power density and the COP of the air conditioning promotes the highest influence on the energy consumption of such buildings.

Some possibilities of energy index were tested and the one which separates the influence of the air conditioning system turned out to be the index that provides the lower difference to predict the annual energy consumption of such buildings (±3.2%).

Further studies should be implemented to better characterized the energy consumption of such buildings specially by increasing the range of climate data as well the evaluation of others parameters such as the COP of air conditioning for partial load operation.

7. References

ABNT. NBR 16401- Instalações de ar-condicionado - Sistemas centrais e unitários – Parte 1: Projeto das instalações. 63 p., 2008.

ASHRAE, AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIRCONDITIONING ENGINEERS. **Energy Standard for Buildings Except Low-Rise Residential Buildings**. ASHRAE Standard 90.1 – 2007. American Society of Heating, Refrigerating and Air- Conditioning Engineers, Inc. Atlanta, 2007.

ABRASCE - ASSOCIAÇÃO BRASILEIRA DE SHOPPING CENTERS. Disponível em: http://www.portaldoshopping.com.br/index.asp> Acesso em: 21 de outubro de 2010.

BARROS FILHO, A. M. **Consumo desagregado de energia elétrica por uso final em shopping centers na cidade de São Paulo: estudo de casos.** Dissertação (mestrado) - Escola Politécnica da USP, Departamento de Engenharia de Construção Civil. São Paulo, 2005. 102 p.

LAM, J. C.; DANNY, H. W. L. **Electricity consumption characteristics in shopping malls in subtropical climates.** Artigo **-** Department of Building and Construction, Building Energy Research Group, City University of Hong Kong, 2002. 8p.

U.S. DEPARTMENT OF ENERGY/ ENERGY EFFICIENCY & RENEWABLE ENERGY. Disponível em: http://apps1.eere.energy.gov/buildings/energyplus > Acesso em: 10 de abril de 2010.

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