

EVALUATION OF THERMAL PERFORMANCE INDEX FOR AIR CONDITIONED COMMERCIAL BUILDINGS

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***Abstract.**. Commercial buildings are great energy consumers due to the need of using air conditioning systems in order to assure thermal comfort of the occupants as well the temperature and humidity conditions for an efficient equipment operation. These air conditioning systems have a huge impact in energy consumption, representing 40 to 50 % of overall electrical energy consumption in such buildings. As consequence, evaluations of the thermal performance of commercial buildings is a common practice. Nevertheless, there is a lack of database for Brazilian climate conditions and materials in order to evaluate energy indexes for such buildings. The purpose of this paper is present a thermal evaluation of four buildings in different locations on Brazilian territory and compare different energy indexes that are presented in the open literature. Using a simulation tool, some changes in the air conditioning are applied and the impact on energy consumption is evaluated.*

***Keywords:** energy conservation, simulation, air conditioning.*

1. Introduction

Electricity is a major factor in a nation economic growth. In Brazil it represents approximately 40% of our energetic income and its consumption increases 6,5%/year (MME, 1999).

The Brazilian main source of electrical energy is hydraulic. However, due to a lack of investments in new projects and delays in conclusion of old ones, the country experienced a shortage in electrical energy supply in the last year. More and more, an effective and proper use of energy is important, and questions concerning to efficient use of equipment, natural resources preservation and decreasing of environmental impacts must be considered.

Regarding the efficiency issue, a consumer conscientiousness about a more rational use of energy must be emphasized, and it should be encouraged the development of more efficient technologies.

Commercial buildings are great energy consumers due to the need of using air conditioning systems in order to assure the thermal comfort of the occupants as well the temperature and humidity conditions for an efficient equipment operation. Such air conditioning systems have a huge impact in energy consumption, representing 40 to 50 % of overall electrical energy consumption of commercial buildings.

Evaluation of the thermal performance of a building and its air conditioning system should not address only the air conditioning system and its components. An analysis of building structure, construction and occupation should be not left out due to their importance in the evaluation of the cooling load profile (Hernandez et al., 1998; Tribess et al., 2000). Besides, the use of strategies that incorporates the thermal passive behavior can reduce cooling loads with a low investment (Givoni, 1994).

During the design process, the study of these technical aspects should be considered in order to assure the desired thermal comfort and temperature/humidity conditions. In such scenario, an adequate selection of building envelope and the proper air conditioning system is a must. In this sense, it is necessary to define how efficient the several possible solutions are, and this can be achieved by establishing an energetic index for evaluating if a given building/air-conditioning solution is efficient or not.

Nowadays Brazil does not have an energetic index for this purpose. In several countries, this kind of indexes already belong to construction practices and legislation. Unfortunately, those indexes cannot be applied directly for Brazilian climate and construction materials.

This paper presents an evaluation of such energetic index for commercial buildings in Brazil. This evaluation is applied to actual buildings as study cases and comparisons are made in order to verify the consistency of such methodology.

2. Methodology

There are many energy end uses in a commercial building but the ones that most contribute for the energy consumption are lightning, equipment (computers, faxes, printers, etc.) and air conditioning, which is the biggest contribution (see Figure 1).

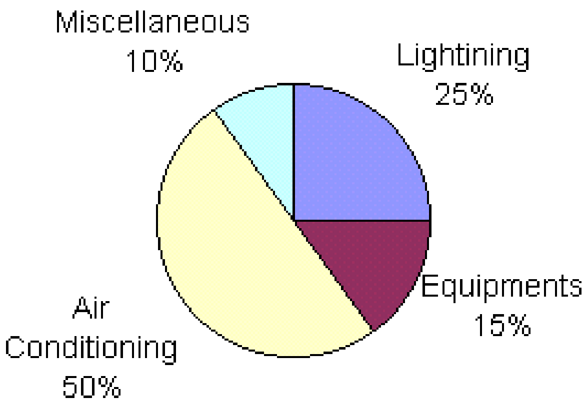

Figure 1. Energy end use distribution in a commercial building.

Several efforts have been made to evaluate the energy consumption in commercial buildings and formulate actions toward the rational use of energy in such applications. One of these efforts is to establish a performance index that should be achieved by a given building.

Up today Brazil has not established an energetic index for evaluating how efficient (or not) a given building is. In several countries, such indexes already belong to construction practices and legislation. A first approach would be using those international indexes, but unfortunately they cannot be applied directly for Brazilian climate and construction materials without a prior analysis.

One of those international indexes is the ASHRAE Standard 90.1 (ASHRAE, 2001), which is widely used as a reference for envelope energy estimation, where one can verify if the choice in materials and equipment provides lower energy consumption levels. Briefly, the ASHRAE Standard 90.1-2001 (ASHRAE, 2001) provides thermal characteristics for the envelope materials (based on climate data) and energy indexes for the equipment, including some criteria for the system operation.

This paper presents an evaluation of such energetic index for commercial buildings in Brazil based on the ASHRAE Standard 90.1 methodology. This evaluation is applied to actual buildings as study cases and comparisons are made in order to verify the consistency of such methodology for Brazilian conditions.

For this study, an evaluation of the thermal characteristics of the building envelope was made and also the energy consumption of each main energy end use was performed.

Based on those measurements and evaluations, a comparison between those data and the values suggested by ASHRAE Standard 90.1 was implemented.

Using BLAST (Pedersen, 1993) as a simulation tool, modifications in some characteristics of buildings and air conditioning systems were implemented in order to verify the impact of such modifications on the energy consumption profile, using as reference the existing buildings and other energy indexes sampled among the open literature.

Among those energy indexes, some can be pointed out as follows:

- Cooling load per floor area [W/m^2]: ratio between total building cooling load [W] and total conditioned floor area [m^2];
- Specific energy coefficient [kW/TR]: ratio between the energy consumption of the refrigeration/air conditioning system [kW] and the refrigeration capacity [Tons of refrigeration ,TR];
- Coefficient of performance (COP) [kW/kW]: ratio between capacity of refrigeration [kW] and energy consumption of the refrigeration/air conditioning system [kW];
- Air conditioning specific energy demand [x10^{-2} kW/m^2]: ratio between energy consumption of the refrigeration/air conditioning system [kW] and the total floor area [m^2].

It should be pointed out that those energy indexes are related only to air conditioning/refrigeration performance. In order to evaluated the building envelope, one can use the ASHRAE 90.1 (ASHRAE, 2001) parameters which is based on several building characteristics such as maximum walls and windows and minimum insulation thermal resistance values.

These values are correlated to climatic data based on the cooling degree-days method in order to take into account the behavior of building envelopes in different climates. Besides, the windows thermal resistance is correlated to glazing total area, and limit values for lighting power densities are provided. Therefore, if a building envelope did not meet the thermal resistance requirements, the following procedure should be carried on:

- A cooling load calculation for the prospective building envelope should be done by means of certified simulation tools such as Energy Plus, DOE-2, ESP-r.
- A cooling load calculation for the building envelope with the thermal resistance suggested by ASHRAE 90.1 should be done using the same simulation tool.
- By comparing these two cooling load profiles, if the prospective building envelope provides lower cooling load profiles then the construction meet the requirements of ASHRAE 90.1. If not, the design team should change materials, orientation and so on to meet the cooling load profile requirements.

3. Case studies

Four buildings were selected which have similar characteristics, i.e.: administration services; working hours: 9:00 to 17:00; use of office appliances only. These four buildings are located in Brazilian regions with higher temperatures and humidity levels, listed in Tab. (1). Theirs envelope construction is practically the same and it is reproduced in Tab. (2).

Table 1. Climatic conditions

Location	**DBT maximum (ºC)**	**DBT minimun (ºC)**	**WBT maximum (ºC)**	**Solar Radiation (W/m^2)**
Brasília	33,0	22,0	24,0	8327
Porto Alegre	35,0	24,0	27,0	8103
Rio de Janeiro	35,0	25,0	28,0	8325
São Paulo	31,4	20,2	26,7	8290

Obs.: DBT = dry-bulb temperature, WBT = wet-bulb temperature.

Table 2. Building envelope materials.

Element	**Material**	**Conductivity [W/m.K]**	**Specific Heat [J/kg.K]**	**Density [kg/m^3]**	**Thickness [m]**
Walls	gypsum	0,72	780	1860	0,02
	brick	1,3	2080	800	0,15 to 0,25
	gypsum	0,72	780	1860	0,02
Roofs and floors	concrete	1,0	960	1980	0,2
Glazing (*)	common glass	0,81	790	2500	0,004

(*) Glazing area varies from 10 to 15% of floor area.

It should be pointed out that the four buildings were constructed on the 1970´s with similar pattern and few variations on walls thickness and glazing area. A comparison between the actual envelope building global heat transfer coefficient and the values suggested by ASHRAE 90.1 (ASHRAE, 2001) is presented on Tab. (3).

Table 3. Global heat transfer coefficient comparison.

		Global Heat Transfer [W/m2.K]			
Building #		Building #01	Building #02	Building #03	Building #04
Location		Brasília	Porto Alegre	Rio de Janeiro	São Paulo
Walls	Actual Building	2,192	2,637	2,192	2,394
	ASHRAE 90.1	3,293	3,293	3,293	3,293
Floors	Actual Building	0,192	0,192	0,192	0,192
	ASHRAE 90.1	1,825	0,780	1,825	1,825
Glazing	Actual Building	4,689	4,689	4,689	4,689
	ASHRAE 90.1	6,930	6,930	6,930	6,930

As it can be seen on Tab. (3), the four actual buildings presented lower global heat transfer coefficient for the walls, floors and glazing comparing to the ones suggested by ASHRAE 90.1. Therefore, it can be concluded that if the analyzed buildings were built using materials that will achieve the thermal characteristics required by ASHRAE 90.1 theirs cooling load profiles will have higher values comparing to the profile of the actual buildings and, consequently, increasing the air conditioning energy consumption.

Besides the building envelope analysis, an evaluation of several energy parameters for the four buildings were performed and it is shown in Tab. (4).

Table 4. List of energy parameters.

Parameters	Building #01	Building #02	Building #03	Building #04
Location	Brasília	Porto Alegre	Rio de Janeiro	São Paulo
Floor area [m^2]	60000	17782	82010	4559
Chiller installed capacity [kW]	2816	2534	8740	1146
Energy demand [kW]	1289	644	5092	404
COP [kW/kW]	2,2	3,9	1,7	2,8
Air conditioning specific energy demand [$x10^{-2}$ kW/m^2]	2,1	3,6	6,2	8,9

Based on the parameters of Tab. (2), an analysis of some energy indexes is performed and the results are shown in Tab. (5).

Table 5. List of energy indexes.

Variables	Building #01	Building #02	Building #03	Building #04	Average
Location	Brasília	Porto Alegre	Rio de Janeiro	São Paulo	
Floor area [m^2]	60000	17782	82010	4559	41088
Cooling load per floor area [W/m^2]	47	143	107	251	137
Specific Energy Coefficient [kW/TR]	1,6	0,9	2,1	1,2	1,5

Table 6. List of energy indexes by Yu et all (2001).

Variables	Average	Minimum	Maximum	Median	Standard deviation
Cooling load per floor area [W/m^2]	56,1	24,4	107,8	53,9	17,9
COP [kW/kW]	3,0	2,3	3,4	3,0	0,3

Yu et all (2001) performed an analysis of 20 commercial buildings were some energy indexes were evaluated as shown in Tab. (6). Bhatt (2000) also evaluated a specific energy coefficient for commercial buildings with air conditioning systems that provides an average value of 1,5 kW/TR for commercial buildings.

One can verify that the average specific energy coefficient for the four buildings (1,5) is the same to the one predicted by Bhatt (2000). But the cooling load per floor area are quite higher comparing to the values evaluated by Yu et all (2001). This can be explained by the higher latent heat that has to be removed in the four buildings and it is mainly related to the climate these buildings are exposed.

4. Actions for energy efficiency improvement

Due to the fact the envelope buildings cannot be changed, the only action that can be taken is toward the efficiency improvement of the air conditioning and lighting systems.

Therefore, higher efficiency ratio equipment were implemented in the Blast simulation in order to verify the impact on the energy consumption and cooling load and the results are shown in Tab. (7). It should be pointed out that, for those simulations, the cooling load requirements were kept the same as the original building.

Table 7. Modified equipment performance.

Variables	Building #01	Building #02	Building #03	Building #04
Low efficiency				
COP [kW/kW]	2,2	3,9	1,7	2,8
Specific Energy Coefficient [kW/TR]	1,6	0,9	2,1	1,2
Air Conditioning Specific Energy Demand [x10^{-2} kW/m^2]	2,1	3,6	6,2	8,9
High efficiency				
COP [kW/kW](*)	4,5	4,5	4,0	3,2
Specific Energy Coefficient [kW/TR]	0,8	0,8	0,9	1,1
Air Conditioning Specific Energy Demand [x10^{-2} kW/m^2]	1,0	3,2	2,7	7,9

Obs.: (*) Based on ASHRAE Standard 90.1 (ASHRAE, 2001)

One can observe on Tab. (5) that the major gains on energy conservation are on buildings 01 and 03 due to their bigger difference on COP. On those buildings it should be stressed that the air conditioning systems were away past their life time cycle (approximately 20 years).

5. Conclusions

An energy evaluation was performed on four buildings in different location in Brazil using energy indexes based on ASHRAE Standard 90.1 and open literature references.

A comparison between global heat transfer coefficients was made and showed that the values suggested by ASHRAE 90.1 are higher than the actual ones. Therefore, it can also be implied that, if a modification of the envelope buildings materials were implemented in order to achieve the ASHRAE 90.1 coefficients values, these buildings will experience an increase in their energy consumption profile, which is the opposite of ASHRAE 90.1 goals. Therefore, a better analysis of such coefficients should be made for Brazilian climate and materials.

The results showed that older systems had bigger gains on reduction of energy consumption due to changes for higher efficient energy equipment. Nevertheless, the change for higher efficiency equipment solves partially the problems related to a more rational use of energy in commercial buildings. The authors believe that bigger reductions on energy consumption could be achieved with a more integrated approach on building design.

These results reinforces the need for more researches towards the evaluation of energy indexes adapted to Brazilian conditions, materials and equipments.

6. References

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