IS THERMAL INSULATION ALWAYS BENEFICIAL IN HOT CLIMATE?

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ABSTRACT

An analysis on determining the energy performance of commercial buildings in Brazil based on the influence of the thermal insulation material in a building envelope was carried out. A practical application on optimizing the insulation thickness was performed, and the effective parameters on the optimum value were investigated. Depending on which weather conditions the commercial building is located, the use of insulating material can increase the integrated annual thermal load. The 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.

INTRODUCTION

Buildings envelope have a significant impact on the space cooling and heating of a building. The rate of heat transfer is influenced mainly by the characteristics of building envelope. A proper building design help to reduce the annual energy requirements for cooling and heating.

Studies have been demonstrated that thermal insulation can improve building thermal performance (Kosseca and Kosny, 2002; Daouas et al, 2010; Bojic et al, 2001; and Bojic et al, 2002) by reducing building energy use. However, the optimum insulation thickness for wall and roof configurations to reduce the heat transfer will depend on building type, orientation, efficiency of the air conditioning system, and others; but especially on the building climatic conditions.

Sisman et al. (2007); Ozel and Phtili (2007); Papakostas et al. (2010) and Friess et al. (2012) showed that the use of thermal insulation in building envelope reduces the energy consumption and the peak demand. In addition, it contributes to reduce the cooling and heating degree hours and the cooling degree-days (Durmayaz et al, 2000; Yu et al, 2009; Yua et al, 2011; and Daouas, 2011). However, most of these studies have been carried out for residential buildings located in climates with hard winters and mild summers.

For buildings located in hot climates, the use of wall and roof insulation may contribute to increase the cooling load and peak demand. Melo and Lamberts (2007) analyzed several combinations of different input data for two commercial buildings located in Florianópolis, Curitiba and São Luís. It was observed that depending on the internal load density and pattern of use values for commercial buildings, a non-insulation wall and roof may let to dissipate the internal load to the exterior ambient. Masoso and Grobler (2008) observed an increase in the cooling load for an office building located in Botswana with 0.08 m of extrude polystyrene after a temperature of 26°C. Chvatal and Corvacho (2009) analyzed highly insulated envelopes for an office and residential building located in Porto, Evora and Lisbon. The results indicate that it is essential to control solar and internal gains to bring some benefit related to reduce of the energy consumption. Chirarattananon et al. (2012) observed the economic and energy performance of walls in two rooms located in Thailand based on an experimental and simulation study. Both rooms have the same characteristics, except the insulation thickness. Three different usage schedule were analyzed: 24 hours (hotel); day time (office), and department store. The results show that the use of thermal insulation according to the energy performance and cost effective depend on the usage schedule.

Melo et al. (2014) compared the building energy performance assessment between ANSI/ASHRAE Standard 90.1 - 2007 and the Regulation for Energy Efficiency Labeling of Buildings in Brazil. Two commercial and one residential buildings were adopted, located in three cities in Brazil: Brasília, Rio de Janeiro and Belém. The results presented an equivalence between levels A to C of the Brazilian regulation and the reference model from ANSI/ASHRAE Standard 90.1 - 2007 for commercial buildings. For the residential building, the energy consumption of the reference model from ANSI/ASHRAE Standard 90.1 - 2007 presented higher result than the level C of the Brazilian regulation. The significant difference observed between the two models is related to the wall and roof thermal transmittance as ANSI/ASHRAE Standard 90.1 - 2007 requires more insulated buildings. According to ASHRAE Standard 90.1, the reference building should contain all the mandatory and prescriptive requirements related to the bioclimatic zone of the building location.
In this context, the objective of this study is to analyze the energy performance of commercial buildings in Brazil based on the influence of the use of thermal insulation. The assessment will take into account the influence of different parameters applied into two typologies located in Curitiba, Florianópolis and Salvador. In addition, the heat balance method through the EnergyPlus program was applied to analyze the heat gains and losses associated with the opaque elements. A comparison between maximum limits of overall heat transfer coefficient for walls and roof given in the ASHRAE Standard 90.1 and the most used enclosure wall and roof construction in buildings in Brazil was also applied.

METHOD

Typology definition
Two different typologies with different external wall and roof geometries were considered to make it feasible to evaluate the influence of each separate component on the building energy consumption. Typology 01 has dimensions of 40 m x 80 m x 10 m and it has air conditioning in all thermal zones. Typology 02 has dimensions of 30 m x 50 m x 3.5 m and it is also all air conditioning, except in the central area which is related to the elevators and stairs. Figure 1 represents the 3D model of both typologies considered. The main façade is oriented to north. The typology 01 was divided into two thermal zones, and typology 02 into 5 thermal zones (representing a core and shell building). Both typologies have the higher dimension of the façade oriented to North/South.

Climatic zones
According to NBR – 15220-3: Thermal performance of buildings (Brazilian Association for Technical Standards, 2005) the Brazilian territory is divided into 8 climatic zones. Therefore, it was considered three different zones: Curitiba (zone 1), Florianópolis (zone 3), and Salvador (zone 8). Table 1 presents the degree-hours for heating (18°C) and cooling (24°C) (Goulart et al., 1998) for these zones.

Although Curitiba requires so much heating than cooling during the year, Salvador requires practically any heating during the year. For Florianópolis, it is possible to observe that this city requires almost the same amount of cooling and heating.

Wall and roof constructions
In Brazil, walls made of clay blocks are the most used enclosure wall construction in buildings. During the last few years, many insulation materials are available in the Brazilian market due to the fact that designers and constructors are concerned with energy savings. However, insulated walls still are not an even approach.

For this study, the thermal transmittance of the external walls varies from 0.66 to 4.40 (W/(m².K)) and for the roof varies from 0.62 to 4.56 (W/(m².K)). The calculation for each of these construction types was based on the Brazilian standard NBR – 15220-2: Thermal performance of buildings (Brazilian Association for Technical Standards, 2005).

Data base
Several combinations were adopted. The main building properties are described in Table 2. The values assumed for the parameter internal load density include the gains associated with lighting, equipment and people.

The air conditioning system adopted was a split system with a coefficient of performance (COP) of 3.20 W/W, considered as an efficient system based on INMETRO (2014). The set point assumed was 24°C
for cooling and 20°C for heating with an outdoor air flow rate per person of 0.0075 m³/s.

For this study, parametric combinations were adopted to generate all samples. The combinations were generate through jEPlus program (jEPlus, 2013). All simulations were carried out using the EnergyPlus program, version 8.0. The JESS Client computer software was used to process the 464,640 simulations cases (JESS Client, 2013). The final energy consumption for the conditioned floor (kWh/m²) was considered as output data.

Heat balance
The accurate determination of the insulation thicknesses effects on the heating and cooling loads is very important in selecting the type and efficiency of the air conditioning system.

The application of the heat balance method through the EnergyPlus program enabled an understanding of the heat gain and loss through the opaque elements. The process involves the internal gains from lighting, equipment, people, infiltration and the air conditioning system. The heat balance through the surface is based on convective air (Melo and Lamberts, 2009).

Based on the application of the heat balance method it is possible to verify the building annual thermal load and cooling and heating peak

ASHRAE Standard 90.1
A reference building according to ASHRAE Standard 90.1 (2013) should contain all mandatory and prescriptive requirements. Based on the bioclimatic zone related to the building location, ASHRAE Standard 90.1 establishes requisites of some parameters such as walls and roof thermal transmittance, window-to-wall ratio (WWR) and glass solar factor.

For this study, a comparison between the wall and roof thermal transmittance according to ASHRAE Standard 90.1 (2013) with some most used wall and roof construction in Brazil was applied. This comparison was realized through the heat balance method.

According to Table B1-3 - International Climate Zones from ASHRAE Standard 90.1 (2013) the representative zone for the weather file of Salvador is zone 1. For the weather file of Florianópolis and Curitiba, ASHRAE Standard 90.1 (2013) classifies the climates on the basis of the calculation of heating and cooling degree-day. According to Table B1-4 - International Climate Zones Definitions from ASHRAE Standard 90.1 (2013) it was possible to calculate and select the represent zone for Florianópolis (zone 3C) and Curitiba (zone 3C).

The limits of the wall and roof thermal transmittance values for zones 01 and 3C according to Table 5.5-1, and Table 5.5-3 from ASHRAE Standard 90.1 (2013) are presented in Table 3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Zone 1</th>
<th>Zone 3C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls thermal transmittance (W/(m²·K))</td>
<td>0.233</td>
<td>0.233</td>
</tr>
<tr>
<td>Roofs thermal transmittance (W/(m²·K))</td>
<td>0.705</td>
<td>0.435</td>
</tr>
</tbody>
</table>

RESULTS
Only the representative results for the influence of wall and roof thermal transmittance versus other parameters will be reported, due to the page number restriction imposed.

The results for typology 01 will be presented according to the roof thermal transmittance, and the results for typology 02 according to the wall thermal transmittance.

Roof thermal transmittance
The results showing the main variables influencing the building energy consumption are presented in boxplots. Medians, quartiles, and maximum/minimum values are also reported. It is important to note that each figure presents the results of all parameters combined, being stratified by the values according to each parameter.

The results for the roof thermal transmittance versus internal load density for typology 01 for the weather of Curitiba, Florianópolis and Salvador are presented in Figure 2.

As expected, on considering the internal load density versus roof thermal transmittance, it can be observed that the final energy consumption increases as the value for the interval load increases for all climates. The climate of Curitiba has the minimum energy consumption for all cases and Salvador has the maximum energy consumption.

The value of 1.92 (W/(m²·K)) for the roof thermal transmittance was associated with the peak energy consumption value for all cases. However, it can be seen that the final energy consumption increases as the roof thermal transmittance of 0.62 (W/(m²·K)) and 1.18 (W/(m²·K)) for the roof thermal transmittance of 0.62 (W/(m²·K)) and 1.18 (W/(m²·K)): 1% (0.7 kWh/m²) para Curitiba, 5.3% (3.83 kWh/m²) para Florianópolis e 3.3% (3.25 kWh/m²) para Salvador. The same energy consumption reduction can be also seen for roof thermal transmittance of 0.62 (W/(m²·K)) and 2.22 (W/(m²·K)) for Florianópolis and Salvador: 3.5% (2.51 kWh/m²) and 2.3% (2.28 kWh/m²), respectively. Comparing the cases with internal load densities of 65 W/m² and 20 W/m² it can be seen that the energy consumption reduction for roof thermal transmittance of 0.62 (W/(m²·K)) and 1.18 (W/(m²·K)) is more representative for the cases with higher internal load: 3% (5.1 kWh/m²) for Curitiba, 3.7% (7.3 kWh/m²) for...
Florianópolis and 3.5% (8.10 kWh/m²) for Salvador.

The roof thermal transmittance parameter showed non-linearity in relation to the building energy consumption. However, depending on the internal load density value, it can be observed that the behaviour of some cases is similar.

Based on the dispersion presented in each graph, the difference among all cases can be even higher. Building energy simulation programs help users to observe and evaluate in detail the building thermal performance integrating a considerable number of input data and physical processes.

**Wall thermal transmittance**

The results for the wall thermal transmittance versus internal load density for typology 02 for the weather of Curitiba, Florianópolis and Salvador are presented in Figure 3.

Comparing the cases with internal load densities of 65 W/m² it can be seen that the energy consumption reduction for wall thermal transmittance of 0.70 (W/(m².K)) and 3.70 (W/(m².K)) is more representative for the cases with higher internal load for Curitiba (1.10%) and Florianópolis (1.80%). The weather of Salvador presented an increase on the energy consumption of 1.6% for the case with internal load densities of 65 W/m².

Comparing the mean of the cases with internal load densities of 20 W/m² it can be seen almost the same result for the energy consumption among all values of wall thermal transmittance. The same performance can be observed for the internal load value of 40 W/m² for Curitiba. For Florianópolis, a reduction on the energy consumption for the cases with internal load densities of 40 W/m² can be seen for wall thermal transmittance of 0.70 (W/(m².K)) and 3.70 (W/(m².K)): 1.9% (2.8 kWh/m²). However, for Salvador it is possible to observe an increase on the energy consumption for the cases with internal load densities of 40 W/m²: 2.3% (3.6 kWh/m²).

A less insulated envelope can contribute to dissipate the building internal load from the interior to the exterior environment.
For some cases, an isolated surface restrains the dissipation of the internal gain to the exterior ambient. This performance can be seen especially for those cases that have high internal load value, and located in a hot climate.

**ASHRAE Standard 90.1**

The wall and roof thermal transmittance limits according to ASHRAE Standard 90.1 (2013) were compared to the wall and roof thermal transmittance value that presented the lowest energy consumption for each weather file according to the previous results. The values assumed are presented in Table 4. Only the representative results will be reported here in, due to the page number restriction imposed.

The heat balance method was applied in the thermal zone 02 for both typology, according to Figure 4. It is important to mention that the thermal zone 02 of the last floor of typology 02 was selected.

The heat balance calculation presented in Figure 5 is related to the influence of roof thermal transmittance versus internal load density for typology 01 adopting the weather file of Curitiba and Salvador. The method was applied to those cases considering a window to wall ratio of 30%, an internal load density of 65 W/m², a solar heat gain coefficient of 0.59, and a wall and roof absorptance of 0.2.

Only the cooling load was analyzed due the fact the heating load is not used for the weather of Salvador. Comparing the cases with a roof thermal transmittance of 1.18 (W/(m²·K)) and a wall thermal transmittance of 2.490 (W/(m²·K)) with the ASHRAE limits it can be observed that the case with a roof thermal transmittance of 1.18 (W/(m²·K)) and a wall thermal transmittance of 2.490 (W/(m²·K)) requires less thermal load than the case according to the ASHRAE limits for Curitiba and Salvador. This increase in the wall and roof thermal transmittance reduced the heat gain from the walls, floor, roof and windows.

According to the ASHRAE limits the wall and roof heat gain was increased to 0.4 kWh/m² (4.8%) and 1.5 kWh/m² (12.3%), respectively for Curitiba. For Salvador, the increase was more representative due the fact that heating load is not used: 15.8 kWh/m² (44.5%) and 8.2 kWh/m² (25.2%), respectively.

### Table 4. Values of thermal transmittance – ASHRAE Standard 90.1 (2013).

<table>
<thead>
<tr>
<th>Weather</th>
<th>U Wall W/(m²·K)</th>
<th>U Roof W/(m²·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curitiba</td>
<td>0.233</td>
<td>0.435</td>
</tr>
<tr>
<td>No insulation</td>
<td>2.490</td>
<td>1.180</td>
</tr>
<tr>
<td>Florianópolis</td>
<td>0.233</td>
<td>0.435</td>
</tr>
<tr>
<td>No insulation</td>
<td>2.490</td>
<td>1.180</td>
</tr>
<tr>
<td>Salvador</td>
<td>0.233</td>
<td>0.705</td>
</tr>
<tr>
<td>No insulation</td>
<td>2.490</td>
<td>1.180</td>
</tr>
</tbody>
</table>

Note: U Wall: Wall thermal transmittance  
U Roof: Roof thermal transmittance
For the case with no insulation for Curitiba, the total heat gain is 33.9 kWh/m². It represents a reduction of 5.8 kWh/m² compared to the case according to the ASHRAE limits. For Salvador, the reduction was 33.7 kWh/m².

The cooling peak of the air conditioning system was also analyzed. The cooling peak for the air conditioning system in the case with no insulation for Curitiba is 81 kW. On the other hand, on increasing the wall and roof thermal transmittance the cooling peak is increased to 114 kW, that is, the cooling peak increases by 33 kW (29%). For Salvador, an increase of 55 kW (33%) is observed.

The heat balance calculation presented in Figure 6 is related to the influence of roof thermal transmittance versus internal load density for typology 02 adopting the weather file of Florianópolis and Salvador. The method was applied to those cases also considered a window to wall ratio of 30%, an internal load density of 65 W/m², a solar heat gain coefficient of 0.59, and a wall and roof absorptance of 0.2.

Comparing the cases with no insulation and according to the ASHRAE limits it can be observed that the case with no insulation requires less thermal load than the case according to the ASHRAE limits for Florianópolis and Salvador. This increase in the wall and roof thermal transmittance reduced the heat gain from the walls, floor, and windows.

According to the ASHRAE limits the wall and roof heat gain was increase to 1.1 kWh/m² (61%) and 0.4 kWh/m² (36%), respectively for Florianópolis. For Salvador, the increase was: 1.2 kWh/m² (50%) and 0.4 kWh/m² (25%), respectively.

For the case with no insulation for Florianópolis, the total heat gain is 6 kWh/m². It represents a reduction of 1.5 kWh/m² compared to the case according to the ASHRAE limits. For Salvador, the reduction was 1.4 kWh/m².

The cooling peak for the air conditioning system in the case with no insulation for Florianópolis is 9 kW. On the other hand, on increasing the wall and roof thermal transmittance the cooling peak is increased to 10 kW, that is, the cooling peak reduces by 1 kW (10%). For Salvador, the cooling peak was also reduced in 1 kW (12.5%).

It is important to mention that the thermal zone of typology 01 selected to calculate the heat balance method has a higher total area than the thermal zone of typology 02. In addition, it is possible to observe that the floor represents a significant part of the heat gains for all cases analysed. This is a consequence of the gains via irradiation through the windows.

The benefits of increasing the insulation thickness are more perceptible in climates with winter predominate situation. The insulation layer helps to reduce the building heating needs. However, the consequence by applying insulation in the building envelope with summer dominate may reflect in an increase in the cooling peak.

Therefore, depending on the case and climate analysed the limits of wall and roof thermal transmittance adopted by ASHRAE Standard 90.1 (ASHRAE, 2013) can be exceeded, minimizing the air conditioning.
energy consumption.

**FLORIANÓPOLIS: No Insulation**

![Heat balance method - typology 01](image)

**FLORIANÓPOLIS: ASHRAE limits**

![Heat balance method - typology 02](image)

**SALVADOR: No Insulation**

![Heat balance method - typology 03](image)

**SALVADOR: ASHRAE limits**

![Heat balance method - typology 04](image)

**Figure 6: Heat balance method - typology 02**

**CONCLUSIONS**

In this study, an analysis on determining the energy performance of commercial buildings in Brazil based on the influence of the thermal insulation material in a building envelope was carried out. The methodology was based on several combinations of different input data. In addition, the influence of the building components on the heating and cooling load was investigated based on the heat balance method using the EnergyPlus program. Based on the results the following conclusions can be made:

- A roof thermal transmittance of 1.18 (W/(m².K)) represented the lowest energy consumption for all cases in typology 01;
- A wall thermal transmittance of 3.70 (W/(m².K)) represented the lowest energy consumption for cases with internal load densities of 65 W/m² for Curitiba and Florianópolis;
- Depending on the weather conditions, applying insulation material to building surfaces increases the annual thermal load. An isolated surface restrains the dissipation of the internal gain to the exterior ambient. Consequently, it reflects in an increase in the use of the air conditioning system;
- The 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;
- The accurate determination of heat gain and loss through the walls and roof can be used to optimize the envelope characteristics based on a combination of input data and the building geometry. However, it is important to remember the importance of considering the weather conditions and the building and system characteristics.

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**REFERENCES**


