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An Assessment in the Heat Gain and Loss Through Opaque Elements in Commercial Buildings in Brazil

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Assessment of heat gain and loss through opaque elements in commercial buildings in Brazil

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ABSTRACT

This paper presents an analysis of the energy performance of commercial buildings in Brazil based on the influence of the thermal transmittance of the external walls and roof. Several combinations were simulated taking into account different input data such as the internal load density, window to wall ratio, solar absorptance and other parameters to evaluate their influence on the annual energy consumption. The sampling techniques are based on the application of the Latin Hipercube method to generate samples, which considers the interaction of two or more parameters for the same case. The influence of different components on the annual heating and cooling load was also investigated through the heat balance method in order to verify the feasibility of analyzing the heat gain and loss through the opaque elements. The analysis was performed using the EnergyPlus program and weather files related to three cities in Brazil (Florianópolis, Curitiba and Salvador).

1. INTRODUCTION

The definition of sustainability is changing practices on the civil construction sector. New commercial buildings are incorporating green technology and using more resource-efficient models of construction. Sustainable buildings, which are built with minimal environmental impact, are enhancing the awareness of this concept on the market and contributing to the conception of more energy efficient buildings. However, it is important to emphasize the integration between the architecture, the air conditioning system, the lighting and equipment in terms of their design to enhance the thermal performance of these buildings.

Building energy efficiency may be initially understood to be primarily concerned with the use of more efficient lighting and equipment systems. On the other hand, studies have demonstrated that the building envelope represents a significant fraction of the final energy consumption of a building (Tsilingiris, 2004; Dombayci, 2007).

The concerns regarding rational energy use are increasingly in evidence because of the operating cost for conditioned buildings. As a consequence, solutions are being investigated to provide a reduction in the energy consumption. It can be noted that most studies are performed using computational tools which allow the impact of each parameter on the final energy consumption of the building to be analyzed before it is finally adopted.

Computational simulation helps to enhance studies related to the use of thermal insulation in building walls and roofs. A simulation tool lets the user ascertain the influence of thermal insulation on the output parameter. Many studies have shown that the use of wall and roof insulation reduces the thermal load of the building. However, most of these studies have been carried out in climates with hard winters and mild summers. For buildings located in climates with hot summers, wall and roof insulation may contribute to raising the internal temperature, increasing the use of the air conditioning system (Melo, 2007; Masoso and Grobler, 2008; Chvatal and Corvacho, 2009).

Melo and Lamberts (2008a) showed that depending on the case and climate analyzed the limits of wall and roof thermal transmittance adopted by ASHRAE Standard 90.1 (ASHRAE, 2004) can be exceeded, minimizing the air conditioning energy consumption. It was observed that depending on the internal load and pattern of use values, a wall thermal transmittance of 4 (W/(m^2.K)) reduced the building energy consumption as a higher value of wall thermal transmittance let to dissipate the internal load to the exterior ambient.
In most studies the parametric method has been applied as a sampling technique to evaluate the influence of thermal insulation on the output data (Karlsson and Moshfegh, 2006; Kim and Moon, 2009). This method permits just one parameter to be changed for each new case, in order to understand the influence of the respective parameter on the final result. However, this method doesn't allow the interaction of two or more new parameters to be observed for each case.
On the other hand, new updated sampling techniques consider a group obtained from a population of simulations. These techniques have the advantages of reducing the time required to analyze the final results and also producing acceptable results (Vose, 2000). One example of such techniques is the Latin Hypercube Method.
In this context, the objective of this study is to analyze the heat gain and loss through opaque elements in commercial buildings in Brazil. The assessment will take into account the influence of different values for the wall and roof thermal transmittance versus internal load density, window to wall ratio and wall and roof solar absorptance. The Latin Hypercube Method was applied to generate the samples for two different typologies located in Florianópolis, Curitiba and Salvador. Also, the heat balance method through the EnergyPlus program will be applied to understand the heat gains and losses associated with the opaque elements.

2. METHODOLOGY

2.1 Typology definition

All of the simulations are based on two different typologies. Both of them have different external wall and roof geometries to make it feasible to evaluate the influence of each separate component on the building energy consumption.
Typology 01 represents a one-storey building with a total building area of 3200 m^2. This typology has dimensions of 40 m x 80 m x 10 m and has air conditioning in all thermal zones.
Typology 02 represents a commercial seventeen-storey building with dimensions of 30 m x 50 m x 3.5 m. The total building area is 25500 m^2. This typology has air conditioning on all floors, except in the central area which is related to the elevators and stairs.
The influence of roof insulation versus different input data will be based on Typology 01 and the influence of wall thermal transmittance will be based on Typology 02. Representations in 3D of the two typologies are presented in Figure 1.

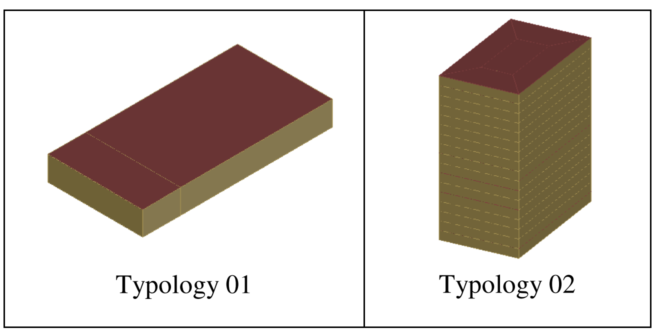

Figure 1: 3D representations of Typology 01 and Typology 02

2.1 Parameters analyzed

Several combinations of input data were analyzed to understand the effect of the thermal transmittance of the external walls and roof on the building energy consumption. The different input data considered are presented in Table 1.
Both typologies were simulated based on the weather files for Florianópolis, Curitiba and Salvador. These weather files were taken from the TRY (Test Reference Year) archives, which represent a typical year from a series of 10 years (Goulart, 1993). Curitiba and Florianópolis are located in the south of Brazil, and according to the weather

files these cities have maximum / minimum temperatures of 33.3 °C / -5.3 °C and 36.4 °C / 2.0 °C, respectively. Salvador is located in the northeast of Brazil and has maximum / minimum temperatures of 33.03 °C / 14.31 °C. The degree-hours for heating (18 °C) and cooling (24 °C) were calculated for each climate (Goulart *et al*., 1998). The results are presented in Table 1.

Table 1: Calculated degree-hours for heating and cooling

City	Heating Degree hours (18 °C)	Cooling Degree hours (24 °C)
Florianópolis	6880	4517
Curitiba	25999	1940
Salvador	55	16113

The values assumed for the parameter internal load density include the gains associated with lighting, equipment and people. The total gain for the lighting system was considered in W/m^2 and the value for people was considered in m^2/people based on a total heat dissipation of 120 W/people. For the equipment gain a total quantity of 150 W for people working on a computer was considered.
The absorptance of solar radiation was considered as 0.20 (white surface), 0.5 (green surface) and 0.9 (black surface).
The building orientation is based on the largest façade and defined as North-South or East-West. This parameter allows the heat gain through the opaque elements and its influence on the total building energy consumption to be analyzed.
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 (2011). 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 m^3/s.

Table 2: Values assumed for each parameter

Parameters	Values assumed
1 – Architectural typologies	Two different typologies
2 – Climates	Florianópolis. Curitiba. Salvador
3 – Window to wall ratio (%)	5; 15; 30; 45; 65; 90
4 – Internal load density (W/m^2)	20; 35; 40; 70
5 – Thermal transmittance of external walls (W/(m^2.K))	0.66; 1.61; 2.02; 2.28; 2.49; 3.7; 4.4
6 – Thermal transmittance of roof (W/(m^2.K))	0.62; 1.03; 1.18; 1.75; 1.92; 4.56
7 – Vertical shading	0 (without brise-soleil); 35; 45
8 – Horizontal shading	0 (without brise-soleil); 45
9 – Solar Heat Gain Coefficient	0.87; 0.81; 0.76; 0.59; 0.49; 0.25
10 – Infiltration (air changes per hour - ACH)	0.5; 1; 3
11 – External wall absorptance of solar radiation	0.2; 0.5; 0.8
12 – Roof absorptance of solar radiation	0.2; 0.5; 0.8
13 – Patterns of use (hours/day)	11; 14
14 – Building orientation (° True North)	North-South; East-West
15 – Air conditioning system	Split - COP of 3.20 (w/w)

The characteristics of the external walls and the roof considered are given in Table 3. The thermal transmittance (W/(m^2.K)) of the external walls varies from 0.66 to 4.40 and for the roof varies from 0.62 to 4.56. The calculation for each of these construction types was based on the Brazilian standard NBR – 15220: Thermal performance of buildings (Brazilian Association for Technical Standards, 2005).

The thermal transmittance and thermal capacity of an internal wall are 2.27 (W/(m^2.K)) and 168 (kJ/(m^2.K)), respectively. This wall was considered to be made of the following layers: mortar, bricks with 6 circular holes, air, bricks with 6 circular holes and mortar. The floor was considered to comprise a layer of ceramic flooring, mortar, concrete and mortar, resulting in a thermal transmittance value of 3.22 (W/(m^2.K)) and a thermal capacity of 445(kJ/(m^2.K)).

Table 3: Thermal transmittance and thermal capacity for external walls and roof adopted

External walls	**U (W/(m^2.K))**	**C (kJ/(m^2.K))**
Double bricks with 6 circular holes	0.66	202
Single bricks with 8 circular holes	1.61	232
Single bricks with 6 square holes	2.02	192
Single bricks with 6 circular holes	2.28	168
Single bricks with 4 circular holes	2.49	129
Single solid bricks	3.70	162
Concrete	4.40	240
Roof	**U (W/(m^2.K))**	**C (kJ/(m^2.K))**
Clay roof tile + thermal insulation + wood ceiling	0.62	34
Clay roof tile + aluminum + concrete slab	1.03	571
Asbestos cement roof tile + aluminum + concrete slab	1.18	80
Clay roof tile + concrete slab	1.75	568
Clay roof tile + mixed slab	1.92	227
Clay roof tile	4.56	18

2.1 Sampling technique

The appropriate choice of sampling technique is an important factor in the initial analysis to ensure that the final results will not include errors. Also, it is essential that the sample is representative of the population under study, presenting the same basic characteristics as the initial population.

Thus, the Latin Hypercube Method was adopted to generate the samples for this study. This method selects the input data randomly. Different groups are previously divided and then data from each group are randomly selected.

It is possible to observe the influence of a combination of two or more different factors in the same new case by applying the Latin Hypercube method, for example, the window to wall ratio and the solar heat gain coefficient. Also, this method allows different probabilities to be determined for each input data point. Another advantage is that the Latin Hypercube method reduces the number of cases that need to be simulated without losing the quality of the results.

A macro developed by Hoes (2007) was considered to analyze the interaction among all of the different parameters of the two typologies by applying the Latin Hypercube Method. This macro adopts the SimLab program (SimLab, 2011) and the MatLab program (MatLab, 2011). It is possible to determine the probability of each input data point and the number of cases to be generated. For this study, it was determined that all input data points have the same probability and a total of 200 cases for each typology need to be run. The ideal number of cases will be dependent on the quantity of the input data and the complexity of each typology. Thus, after the conclusion of the total number of new cases it is important to analyze the final results to be confident that they represent the characteristics of the initial population.

As a final result, this macro generates .idf files that contain the characteristics of each input data point based on its probability. The .idf files were simulated by adopting the EnergyPlus program version 6.0 (DOE, 2011). The final energy consumption for the conditioned floor (kWh/m^2) was considered as output data.

First of all, the 200 cases were run taking into account the weather data for Florianópolis. Based on the final energy consumption result, two cases were selected for each typology based on the weather file for Florianópolis: one representing the maximum energy consumption and other representing the minimum energy consumption. The influence of the thermal transmittance of the wall and roof versus other parameters was then investigated.

Firstly, the wall and roof thermal transmittance values were varied at the same time as the internal load density for the case with the maximum and minimum energy consumption. All other parameters were kept fixed and only the roof thermal transmittance and the internal load values were changed. All of the interactions were also applied based on the weather files for Curitiba and Salvador, adopting the same cases presented above. Next, the wall and roof thermal transmittance values were varied together with the wall and roof abosrptance values for the case with the maximum and minimum energy consumption and also for the window to wall ratio.

2.2 Heat balance

The influence of different roof and wall constructions was also investigated through the heat balance procedure in the EnergyPlus program. The application of the heat balance method 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.

The methodology is based on Melo and Lamberts (2008b) taking into account the follow outputs from the EnergyPlus program to calculate the heat balance: Surface Int Convection Heat Gain for Air, People Convective Heat Gain, Lighting Convective Heat Gain, Equipment Convective Heat Gain, Zone Infiltration Sensible Heat Loss, Zone Infiltration Sensible Heat Gain, Zone/Sys Sensible Heating Rate and Zone/Sys Sensible Cooling Rate.

3. RESULTS

3.1 Typology 01

From the total of 200 cases for Typolgy 01, adopting the weather file for Florianópolis, the cases which provided the maximum and minimum final energy consumption were select. The final energy consumptions for these cases and their characteristics are presented in Table 4.

For the case with maximum energy consumption the external wall and roof thermal transmittance values were 4.4 (W/(m^2.K)) and 4.56 (W/(m^2.K)), respectively. Also, the absorptance of solar radiation for the external walls and roof is 0.8. For the case with minimum energy consumption, the external walls and roof thermal transmittance are 0.66 (W/(m^2.K)) and 1.03 (W/(m^2.K)), respectively.

The building orientation is also an important factor as depending on the period of the year some walls receive a higher solar incidence than other walls of the building. An appropriate orientation can reduce the building thermal load as noted for the case with the minimum final energy consumption.

Table 4: Cases with maximum and minimum energy consumption for Florianópolis – Typology 01

Parameters	Maximum energy consumption	Minimum energy consumption
Climate	Florianópolis	Florianópolis
Window to wall ratio (%)	45	45
Internal load density (W/m^2)	35	20
Thermal transmittance of external walls (W/(m^2.K))	4.4	0.66
Thermal transmittance of roof (W/(m^2.K))	4.56	1.03
Vertical shading	35	0
Horizontal shading	0	0
Solar Heat Gain Coefficient	0.87	0.49
Infiltration (ACH)	3	0.5
External wall absorptance of solar radiation	0.8	0.2
Roof absorptance of solar radiation	0.8	0.8
Patterns of use (hours/day)	11	14
Building orientation (^{o}True North)	East-West	North-South
Final energy consumption	**192.39**	**47.86**

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

The results for the roof thermal transmittance versus internal load density for Typology 01 are presented in Figure 2. These results are based on the case with the minimum energy consumption. On considering the roof thermal transmittance versus internal load density it can be observed that the final energy consumption increases as the value for the interval load increases for all climates. The climate of Salvador has the maximum energy consumption for all cases. The value of 4.56 (W/(m^2.K)) for the roof thermal transmittance was associated with the peak energy consumption value for all cases. However, it can be observed that the value of 1.18 (W/(m^2.K)) led to a reduction in the final energy consumption for all climates. Comparing the cases with internal load densities of 65 W/m^2 and 20 W/m^2 for Salvador it can be seen that the energy consumption reduction for roof thermal transmittance of 0.62 (W/(m^2.K)) and 1.18 (W/(m^2.K)) is more representative for the cases with higher internal load. A less insulated envelope can contribute to dissipating the building internal load from the interior to the exterior environment.

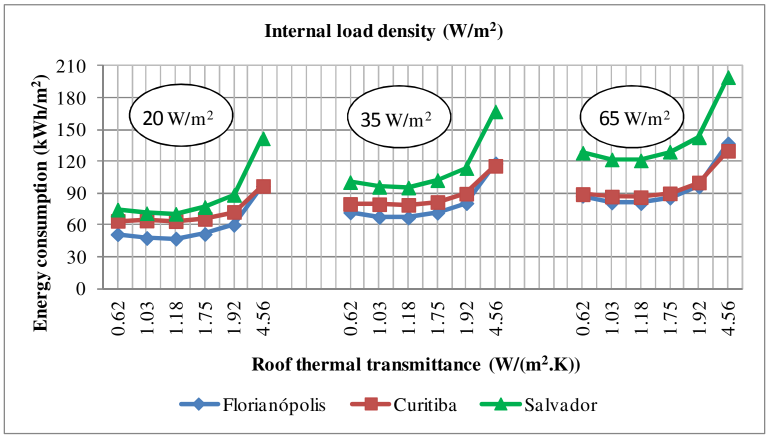

Figure 2: Case with minimum energy consumption – Typology 01: Internal load density

A comparison between roof thermal transmittance versus window to wall ratio can be observed in Figure 3. For this analysis the case with minimum energy consumption was also selected. As the window to wall ratio increases the final energy consumption also increases, due to the increase in the solar gains through the windows. The final energy consumption of the building increases on adopting the value of 4.56 (W/(m^2.K)) for the roof thermal transmittance. For these cases, the value of 1.18 (W/(m^2.K)) represented the lowest energy consumption.

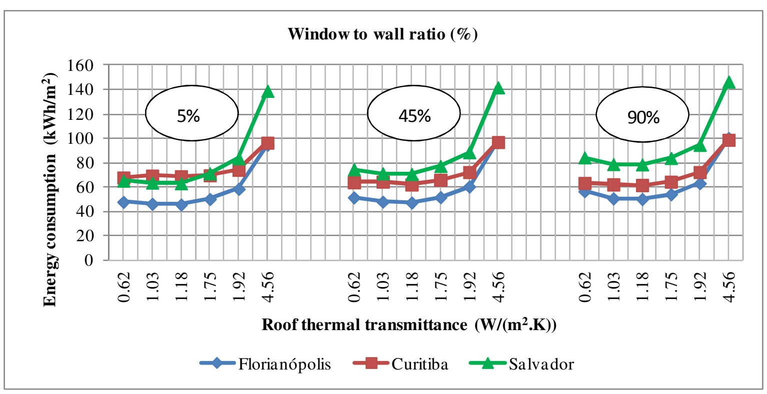

Figure 3: Case with minimum energy consumption – Typology 01: Window to wall ratio

3.2 Typology 02

The characteristics and the final energy consumption for the cases with the maximum and minimum final energy consumption are presented in Table 5. For Typology 02, the case with maximum energy consumption has 90% of windows in the façade and the pattern of use is 14 hours/day. For the case with minimum energy consumption, the window to wall ratio value is 15% and the pattern of use is 11 hours/day.

Table 5: Cases with maximum and minimum energy consumption for Florianópolis – Typology 02

Parameters	Maximum energy consumption	Minimum energy consumption
Climate	Florianópolis	Florianópolis
Window to wall ratio (%)	90	15
Internal load density (W/m^2)	40	20
Thermal transmittance of external walls (W/(m^2.K))	3.7	2.28
Thermal transmittance of roof (W/(m^2.K))	1.92	1.18
Vertical shading	0	45
Horizontal shading	0	45
Solar Heat Gain Coefficient	0.87	0.49
Infiltration (ACH)	3	1
External wall absorptance of solar radiation	0.2	0.2
Roof absorptance of solar radiation	0.5	0.5
Patterns of use (hours/day)	14	11
Building orientation (^{o}True North)	East-West	North-South
Final energy consumption	**176.17**	**62.00**

The external wall absorptance of solar radiation versus the external wall thermal transmittance was also analyzed (Figure 4). A value of 0.8 for the external wall absorptance increases the solar radiation through the wall, which is reflected in the final energy consumption. Adopting a value of 0.2 for the external wall absorptance for Florianópolis and Salvador for different values of external wall thermal transmittance does not reflect in the final energy consumption. However, for external wall absorptance values of 0.5 and 0.8 this parameter is reflected. For Curitiba, it can be observed that all of the values for the external wall absorptance lead to an increase in the final energy consumption.

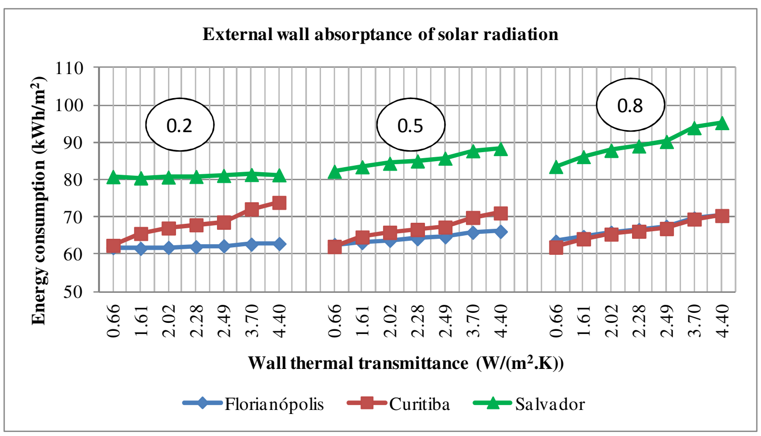

Figure 4: Case with minimum energy consumption – Typology 02: External wall absorptance

External wall absorptances of 0.5 and 0.8 for Curitiba decreased the energy consumption when adopting an external wall transmittance of 4.40 (W/(m^2.K)). As this case represents the case with minimum energy consumption, the internal load considered is 20 W/m^2 according to the previous table. The climate of Curitiba requires the use of heating during the winter, so a less insulated wall with an absorptance of 0.2 will allow dissipation of the internal

load to the exterior environment. However, adopting an absorptance of 0.5 or 0.8 will help to maintain the internal load in the interior environment reducing the heating needs associated with the air conditioning system.
Based on the window to wall ratio parameters versus external wall transmittance (Figure 5) the case with the maximum energy consumption for Typology 02 can be identified. Increasing the percentage of windows in the façade leads to an increase in the final energy consumption. Florianópolis and Salvador present the same performance: the final energy consumption has almost the same result for different external wall thermal transmittance values. For Curitiba it is possible to observe the influence of the external wall thermal transmittance values for the minimum percentage of windows (5%) in the building façade. However, on adopting a window to wall ratio of 90% the influence of the external wall transmittance is not observed. For these cases, the climate of Salvador has the maximum energy consumption.

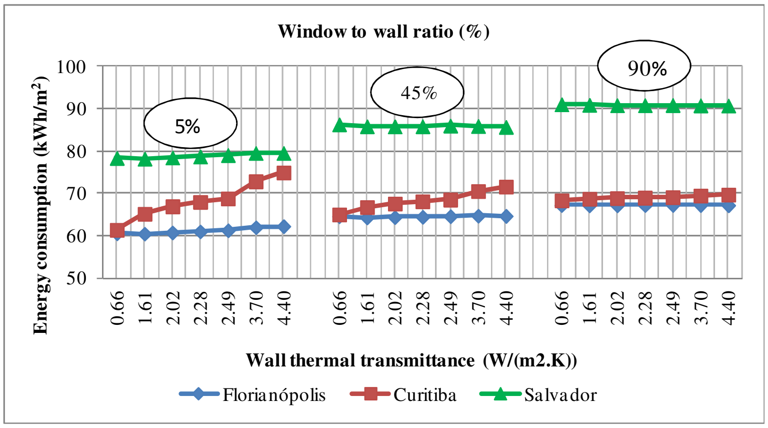

Figure 5: Case with maximum energy consumption – Typology 02:
Window to wall ratio

3.3 Heat balance

The heat balance calculation presented in Figure 6 is related to the case with the minimum energy consumption taking into account the influence of roof thermal transmittance versus internal load density for Typology 01 adopting the weather file of Salvador (Figure 2). The method was applied to the cases with roof thermal transmittance values of 0.62 (W/(m^2.K)) and 1.18 (W/(m^2.K)), considering an internal load density value of 20 W/m^2 and 65 W/m^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 an internal load density of 20 W/m^2, it can be observed that the case with a roof thermal transmittance of 0.62 (W/(m^2.K)) requires a greater thermal load than that with 1.18 (W/(m^2.K)). This increase in the roof thermal transmittance reduced the heat gain from the walls, floor, roof and windows. The most representative reduction is related to the roof heat gain. For the case with a roof thermal transmittance of 0.62 (W/(m^2.K)) the heat gain is 26.8 kWh/m^2 and for the case with 1.18 (W/(m^2.K)) the heat gain is reduced to 21.1 (21%).
For the cases with an internal load of 65 W/m^2 the difference between the thermal load and heat gain results is even higher. On increasing the roof thermal transmittance from 0.62 (W/(m^2.K)) to 1.18 (W/(m^2.K)) the thermal load is reduced by 9.2 kWh/m^2 (4.5%) and the roof heat gain is reduced by 7.5 kWh/m^2 (23%). All of the heat gains from the windows, walls, floor and roof were also reduced when the roof thermal transmittance was increased.
The cooling peak of the air conditioning system was also analyzed. The cooling peak for the air conditioning system in the case with an internal load density of 20 W/m^2 and a roof thermal transmittance of 0.62 (W/(m^2.K)) is 342182 W. On the other hand, on increasing the roof thermal transmittance to 1.18 (W/(m^2.K)) the cooling peak is reduced to 313214 W, that is, the cooling peak reduces by 28968 W (8.5%).
Considering an internal load of 65 W/m^2 and a roof thermal transmittance of 0.62 (W/(m^2.K)), the cooling peak is 364506 W. On increasing the roof thermal transmittance to 1.18 (W/(m^2.K)), the cooling peak decreases to 326923 (a reduction of 37583 W (10%)).
The result for the cooling peak of the air conditioning system for the case with an internal load of 65 W/m^2 and a roof thermal transmittance of 1.18 (W/(m^2.K)) is lower than the case with an internal load density of 20 W/m^2 and a roof thermal transmittance of 0.62 (W/(m^2.K)).

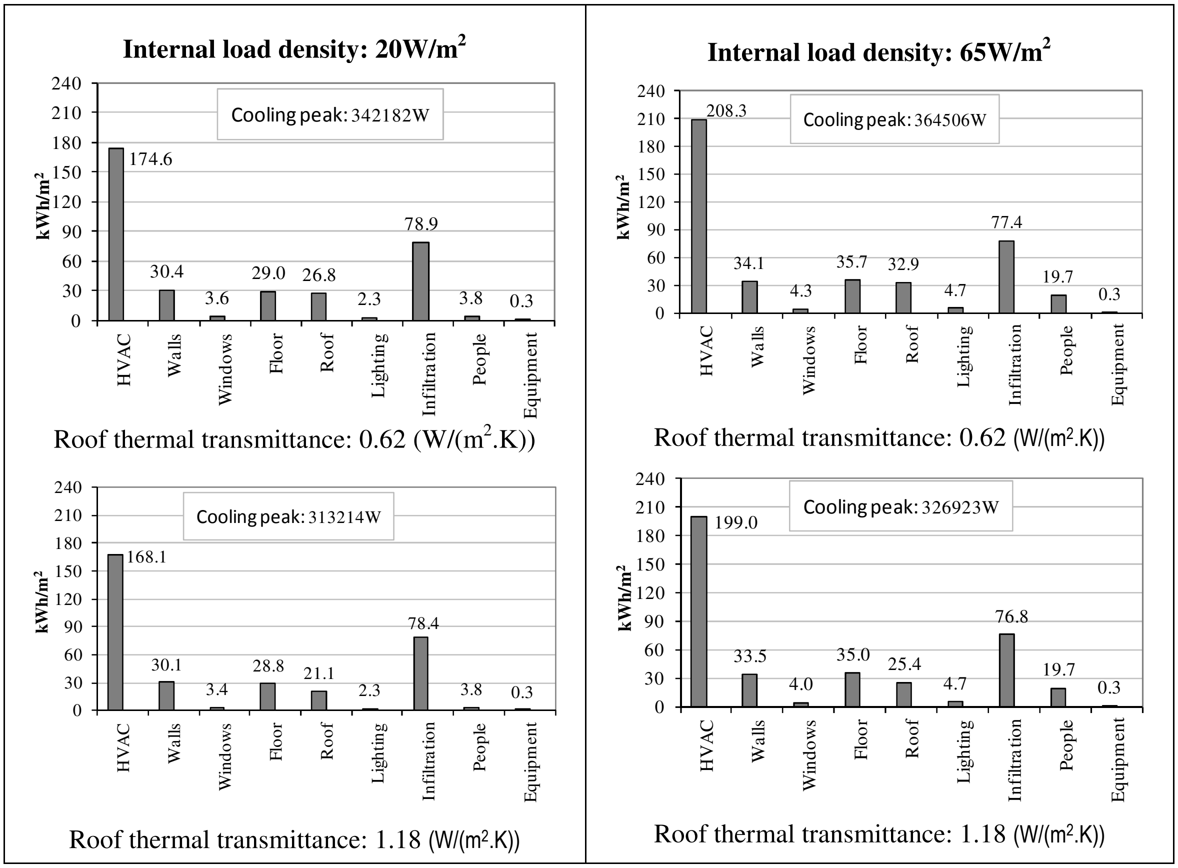

Figure 6: Heat balance calculation – Typology 01

Thus, adopting a high thickness for the roof insulation for all of these cases will not allow the dissipation of internal loads to the exterior ambient. Consequently, the air conditioning system has to work more to maintain the internal temperature between the heating and cooling set points. Thus, increasing the roof thermal transmittance allowed the internal load to dissipate from the interior to the exterior environment.

For all cases, the floor represents a significant part of the heat gains. This is a consequence of the gains via irradiation through the windows. It is important to remember that the weather conditions of the cities adopted in this study require more cooling by the air conditioning system to reduce the interior temperature since they have hot summers and mild winters. For climates with hard winters, for example Denver – USA, a well insulated wall and roof will decreased the building thermal load, as the internal load is more likely to remain within the set-points limits (Melo and Lamberts, 2009).

4. CONCLUSIONS

In this study, an assessment of the heat gain and loss through opaque elements in commercial buildings in Brazil was carried out. The methodology was based on several combinations of different input data applying the Latin Hypercube method to generate the samples. Also, 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:

- The Latin Hypercube method allowed the influence of two or more parameters to be analyzed for the same case. Moreover, the application of this sampling technique reduced the number of cases to be simulated in a specific analysis without influencing in the quality of the results.
- 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.

- A roof thermal transmittance of 1.18 (W/(m^2.K)) represented the lowest energy consumption for all cases in Typology 01 and the roof thermal transmittance of 4.56 (W/(m^2.K)) the peak for the energy consumption.
- The external wall thermal transmittance versus absorptance and window to wall ratio showed a more representative behavior for the climate of Curitiba.
- The heat balance method using the EnergyPlus program can help the users to understand the influence of each component present in the building through the heat gains and losses. Based on the results, the user can investigate strategies to improve the building thermal performance. Also, it helps the user to verify the cooling and heating peaks of the air conditioning system, allowing the user to verify whether or not the system can supply the building needs.
- The heat balance method 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.

REFERENCES

ASHRAE (American Society of Heating and Air-Conditioning Engineers), 2004. ANSI/ASHRAE Standard 90.1-2004: energy standard for building except low-rise residential buildings.

Brazilian Association for Technical Standards, 2005, National Standard 15220: methods for calculating thermal transmittance, thermal capacity, thermal delay and solar heat factor of opaque building components (in Portuguese).

Chvatal, K., Corvacho, H, 2009, The impact of increasing the building envelope insulation upon the risk of overheating in summer and an increased energy consumption, *Journal of Building Performance Simulation*, v.2, n.4, p 267-282.

DOE - Department of Energy. Available at http://apps1.eere.energy.gov/buildings/energyplus/

Dombayci, O., 2007, The environmental impact of optimum insulation thickness for external walls of buildings. *Building and Environment*, v. 42, p. 3855-3859.

INMETRO - Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (in Portuguese), 2011. Available at http://www.inmetro.gov.br/consumidor/pbe/split2.pdf

Hoes, P., 2007, *Gebruikersgedrag in gebouwsimulaties van eenvoudig tot geavanceerd gebruikersgedragmodel* (in Dutch). Thesis (Masters). Technische Universiteit Eindhoven, Eindhoven, 118 p.

Goulart, S.V.G., 1993, Dados Climáticos para Avaliação de Desempenho Térmico em Florianópolis (in Portuguese). Thesis (Masters). Federal University of Santa Catarina, Florianópolis, 124 p.

Goulart, S.V.G., Lamberts, R., Firmino, S., 1998, *Dados climáticos para projeto e avaliação energética de edificações para 14 cidades brasileiras* (in Portuguese), Eletrobrás/Procel, Florianópolis, 350 p.

Kim, J. J.; Moon, J. W. Impact of insulation on building energy consumption, *Proceedings of Building Simulation 2009:11th Conference of International Building Performance Simulation,* IBPSA: p. 674-680.

Karlsson, F.; Moshfegh, B., 2006, Energy Usage and Thermal Environment in a Low-Energy Building - changed boundary conditions and control strategies, *Energy and Buildings*, v.38, n.4, p.315-326.

Masoso, O.T.; Grobler, L.J, 2008, A new and innovative look at anti-insulation behaviour in building energy consumption, *Energy and Buildings*, v. 40, p. 1889-1894.

Mathworks, MATLAB, 2011. Available at: http://www.mathworks.com/products/matlab/index.html

Melo, A.P., Lamberts, R., 2008a, Opaque envelope parameters versus energy consumption in commercial buildings in Brazil, *Journal of Building Performance Simulation*, v.1, n.4, p.237-244.

Melo, A.P., Lamberts, R., 2008b, *O método do balance térmico através de simulação computacional no programa EnergyPlus* (in Portuguese), Labeee – Energy Efficiency in Buildings Laboratory, Florianópolis, 20 p.

Melo, A.P., Lamberts, R., 2009, Envelope insulation and heat balance in commercial buildings, *Proceedings of Building Simulation 2009:11th Conference of International Building Performance Simulation,* IBPSA: p. 2243-2250.

SIMLAB - Sensitivity Analysis, 2011. Available at http://simlab.jrc.ec.europa.eu/

Tsilingiris, P.T., 2004, On the thermal time constant of structural walls, *Applied Thermal Engineering*, v. 24, p. 743-757.

Vose, D., 2000, *Risk analysis: a quantitative guide*, Ed. Wiley, Chichester, 752 p.