ENVELOPE INSULATION AND HEAT BALANCE IN COMMERCIAL BUILDINGS

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ABSTRACT

This paper presents a methodology to evaluate the influence of different components of the annual heating and cooling load of buildings, analyzing the energy performance of building surfaces that are exposed to different weather conditions. The analysis was carried through the heat balance method by using the EnergyPlus program and weather files for Denver, in the United States and Florianopolis, in Brazil. The third floor of a building of 5-floors office building was used to analyze different optimum insulation thickness on external walls based on annual heating and cooling loads. The study reveals the possibility to analyze the heat gain and loss through the opaque elements. For Denver, the increase in the heat transfer coefficient resulted in an increase of the model total thermal load. However, for Florianopolis the increase in the wall's heat transfer coefficient provided a reduction of 14% in the thermal load value. In addition, analyzing the walls with a low value of absorptance resulted in a lower value of total thermal load.

INTRODUCTION

Many studies have shown that global warming is becoming considerably enhanced and human activities are partly responsible, according to the IPCC (2007). The main evidence of global warming is the high temperatures registered all over the world and the fast changes in temperature. The consequences of global warming on the environment and human life are numerous and varied as it is increasing the ocean levels, because the glaciers are melting, along with the growth and appearance of deserts and hurricanes. Another consequence is heat waves, which are becoming more frequent and intense. This reflects in a greater use of air conditioning systems in buildings. Such systems consume energy and increase carbon dioxide emissions to the atmosphere. Carbon dioxide emissions have a strong impact on the greenhouse effect as it forms a protecting layer that strongly absorbs infrared radiation emitted by the Sun and reflects it to the earth's surface.

According to the MME (2008), in the base year of 2006, buildings were responsible for 42% of total energy consumption in Brazil. The residential sector consumed 23%, the commercial sector 11% and the public sector 8%. In the commercial and public sector the air conditioning system consumption were responsible for 48%. According to PROCEL (2007), these figures are related to the influence of architectural projects, material characteristics and building use standards

Globally, buildings are responsible for 40% of the electrical energy consumption. A huge part of this consumption (50%) is related to the use of air conditioning systems located in public and commercial buildings. In the USA, commercial, residential and public buildings consume 65% of the electrical energy distributed and are responsible for 30% of gas emissions that contribute to the greenhouse effect.

The SSPC (Standing Standard Project Committee) revised the ASHRAE and decided that the new ASHRAE Standard 90.1 (2004) should save more energy when compared with the previous versions and the criteria in the standard will be based on cost-effectiveness for the building owner. McBride (1995) developed scalar ratios based on a multiplier factor for the energy saved related to economical factors, such as the number of years, and the costs and interest. The criteria also ensure that a balance is achieved among all the building components as each section of Standard 90.1 contributes to the building efficiency.

The material characteristics of a building are extremely important for the building thermal performance. As a result, construction companies and architects have been seeking a better understanding of the thermal interactions occurring in buildings, so that their designs save energy and are more comfortable for the users.

Chvatal et al. (2005) have analyzed the consequences of an increase in the insulation of the building envelope in the summer period through an analysis of the annual consumption of residential and commercial buildings in Portugal. The results show that increasing the wall insulation in residential buildings and using a shading factor of 75% can reduce the use of the air conditioning system by 8%. However, for commercial buildings that have higher internal loads, the increase in insulation can inhibit the dissipation of internal gains to the outside. Thus, increasing the insulation for commercial buildings is not appropriate as it increases the number of hours of use of the air conditioning system.

Melo and Lamberts (2008) analyzed two buildings in three Brazilian climates with different internal load densities, exterior absorptance, patterns of use, window to wall ratios and other parameters, to analyze their influence on the annual energy consumption. These results demonstrate that the limits of heat transfer coefficient adopted by ASHRAE Standard 90.1 can be exceeded in some cases for Brazil, depending on the case and climate analyzed.

Balaras (1996) analyzed and classified different methods that are used to calculate the cooling loads and indoor air temperatures of buildings, taking into account the effects of thermal mass. The methods were characterized according to the inputs and outputs by thermal mass effects, type of loads and method restrictions.

The thermal mass of a building is its capacity to store and liberate heat. The higher temperature variation during the day, the solar radiation and the heat gains, reflects in a higher effect of the thermal mass of a building.

This study introduces a methodology to optimize the specifications for the building envelope based on the annual heat balance method. This method uses the EnergyPlus simulation program to facilitate the procedure for obtaining the parameters involved in the heating and cooling loads.

The objective of this study is to help the simulation users in the thermal analysis of buildings and in procedures for the choice of the air conditioning capacity.

METHODOLOGY

The simulation program

The simulations of the thermal behavior of buildings were carried out in EnergyPlus 2.2 (DOE, 2007) which estimates the thermal load required to heat or cool a zone. The calculation is based on the thermal and energetic performance of the building, the weather to which the building is subjected and the values of the thermal loads.

The EnergyPlus program has many important characteristics, since it can: i) estimate the energy required to heat or cool a zone; ii) estimate the conduction of transition heat by the surfaces, iii) model thermal comfort, iv) estimate the heat balance, v) estimate the outputs related to each component of the building, and vi) analyze the influence of the components under different weather conditions.

Building

The building that the simulations are based on is a building of 5-floors, described in Figure 1. The model is a 1,000m^2 floor area, with the smallest side facing to North.

The air conditioning type is a split system with a coefficient of performance (COP) of 3.19 W/W (Watts of capacity of refrigeration for Watts of electric energy consumed) for heating and cooling, which can be considered efficient. The set point of heating and cooling is 20^{o}C and 24^{o}C, respectively.

The pattern of use adopted was 8h related to an office activity; an internal load density of 30W/m^2; a medium superficial absorptance by external walls of 50%; a solar factor of reflective glass (0.58) and window to wall ratio (WWR) of 20%. The value for the roof heat transfer coefficient is 1W/m^{2}K and the floor heat transfer coefficient is 2W/m^{2}K. The wall heat transfer will vary from 4W/m^{2}K (10cm of concrete wall without insulation) to 1W/m^{2}K (with insulation).

The front and back area of the building are conditioned and have windows in all external facades, except the central zone that is not conditioned.

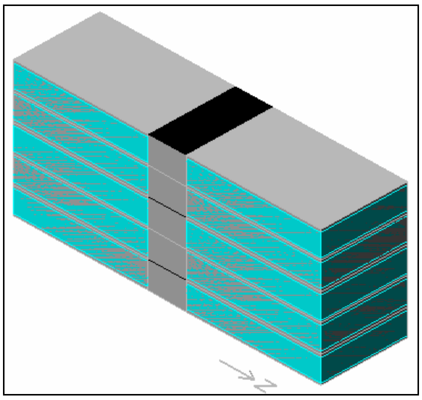

Figure 1 A representation of the building.

Heat balance

Different methods to calculate the energy consumption of buildings have been developed over many years. Some of these methods are able to estimate the heat losses of the building, and the influence of the external temperature and solar radiation on the consumption of the building, for example, PRISM (Princeton Scorekeeping Method) (Fels, 1986), SLR (Solar Ratio Method) (Balcomb et al., 1992), and H-m Method (LESO EPFL, 1985).

However, these methods are not appropriate for use in buildings whose heating and cooling loads contribute to the energy consumption. Some are so simple that do not give any indication of the building's sensitivity to solar gains. In addition, these methods do not compare different advanced control systems.

Bauer and Scartezzini (1998) proposed the Etha Method which considers the internal gains as solar gains, which can be used to estimate the heating and cooling gains.

Taylor (1991) showed that the heat balance has two possible formulations depending on whether or not the storage of energy is taken into account. Strand et al. (2001) believe that the heat balance method procedures can grow with the interest in the calculating thermal load in buildings.

The procedure for obtaining a heat balance in the EnergyPlus program applies the conduction, convection and radiation processes of surfaces inside and outside the building. The internal gains from the lighting system, air conditioning system, equipment and people are extremely important for calculating the heat balance of a building. The surfaces are involved in the heat balance since they use the air inside the zone for convection. The air heat balance considers the convection process based on internal loads and interior surfaces, the air that the air conditioning system inserts into the zone, the ventilation system and infiltration current of the zone.

The methodology of this study is based on the calculation of the heat balance through convection (Figure 2) of the indoor surface temperatures (walls, floor, roof and windows) and the zone inside temperature.

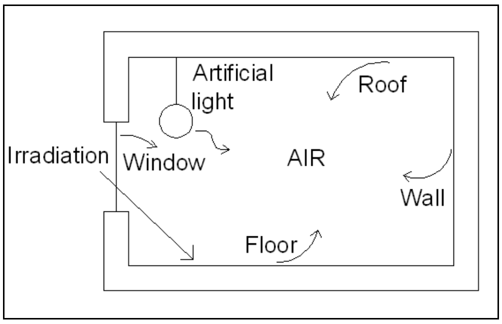

Figure 2 Heat balance representation.

Each surface area is multiplied by the difference between the temperatures of the surface and the indoor air in the zone, and by the convection coefficient related to each surface. The output in the EnergyPlus program: Surface Int Convection Heat Gain to Air, provides this result. The gain related to the lighting and equipment system, people, and the gain or loss through infiltration, are added to the sum of these multiplications.

The internal gains and the process of convection along the inside surfaces and the indoor air temperature were analyzed every hour. The sum of the hourly heat balance calculation represents the amount of heat which should be added or removed inside the zone to maintain the set-point temperature.

The thermal load is the heat which should be added or removed from the zone, per unit time, to keep the zone under the desire conditions. This load is related to the gains from radiation, convection, infiltration and air renovation; and internal gains from people, artificial lights, motors and special loads.

Therefore, the results for the air conditioning system outputs should be almost the same (in absolute value) as the results of the heat balance calculation. If the model has an ideal conditioning system (purchased air) the results should be the same. However, in this case the model has a split system that sometimes requires more capacity and energy meet the set point temperature adopted.

All the cases have the same value of internal load density (30W/m^{2}K), but it can be observed through the figures that lighting and people have different value of influence. This happens because the gains from these parameters are just used in the heat balance method when the air conditioning system needs to heat or cool the zone. If the zone temperature is between the values adopted for the set point temperature, there is no consumption related to the air conditioning system.

Parameters analyzed

The influence of different wall constructions in the building will be analyzed through the heat transfer coefficient (W/m^{2}K).

The weather files used were the Denver, in the United States and Florianopolis, in Brazil to analyzed two different climates with the same wall construction. The Denver weather has a colder winter than Florianopolis and Florianopolis has a hotter summer than Denver.

In the simulation of the models for one year, the climatic file used for Florianopolis is of the type TRY (Test Reference Year) which represents a real year of a climatic year of 30 years. For Denver, the climatic file is of the type TMY (Typical Meteorological Year) which is represented by typical months of different years.

Through the weather records for the cities of Denver and Florianopolis, the total heating and cooling degree hours were calculated by using the same temperature of set point adopted for the building: 20^{o}C for heating and 24^{o}C for cooling. The results can be observed in Table 1.

Table 1 Degree hours.

	HEATING	**COOLING**
	Degree hours Tb = 20^{o}C	Degree hours Tb = 24^{o}C
Denver	98.761	3.527
Florianopolis	12.298	4.625

On analyzing the amount of cooling degree hours for the city of Denver and Florianopolis it was observed that both weather conditions contain almost the same amount of degree hours. However, in the case of the heating degree hours, the Denver weather conditions gave a value for degree hours 8 times higher than that for Florianopolis.

Four different heat transfer coefficient (U) values for walls were analyzed: 4.0W/m^{2}K (representing a concrete wall with 10cm); 2.0W/m^{2}K (representing a concrete wall with 10cm with 0.08m of insulation); 1.5W/m^{2}K (representing a concrete wall with 10cm with 0.13m of insulation) and 1W/m^{2}K (a concrete wall with 10cm with 0.23m of insulation).

In relation to the absorptance of the external surfaces of the walls, the values of 0.20 (white surface) will be analyzed in order to evaluate the influence of this parameter in relation to the building solar gain. The analysis will be for the climate of Florianopolis, adopting a wall heat transfer of 1W/m^{2}K and 4W/m^{2}K.

The value of the integrated annual thermal load (kWh/m^2), in relation to the area of the floor of the building, will serve as a base to analyze the effect of a change in the parameters and to determine whether they influence the thermal performance of the model. The heat gains and losses of each opaque element and total thermal load will also be analyzed.

The cooling load is represented by the positives values and the heating load is represented by the negatives values. However, the infiltration load is the opposite as this load is subtracted from the total annual gain/loss.

The zone facing to North and located in the third floor of the building (Figure 3) will be used to demonstrate how to analyzed the thermal load by using the heat balance in the EnergyPlus program.

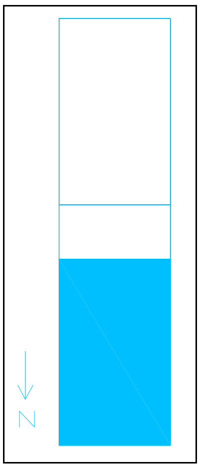

Figure 3 Zone in the third floor.

The calculation of the thermal load is obtained through the annual sum of the values related to the air conditioning system. Based on the set point temperature this system will give the total heat added to or removed from the zone, making it possible to calculate the total annual value of the cooling and heating thermal load.

The total thermal load and the peak of the air conditioning system can be analyzed through the outputs from the EnergyPlus program. These two parameters will be analyzed to find out the influence of it in the building thermal performance.

RESULTS

The values for the integrated thermal load of building for the cities of Denver and Florianopolis will be compared with the same values for the new surface constructions. The smallest part of the building was orientated to the North for the simulation of both Denver and Florianopolis.

The changes in the wall's heat transfer coefficient and walls absorptance of building were analyzed. The wall heat transfer was simulated with values of 1.00W/m^{2}K; 1.50W/m^{2}K 2.00W/m^{2}K and 4.00W/m^{2}K. The roof and floor heat transfers coefficient was maintained with the same initial value.

Denver

The influence of heat transfer coefficient for the city of Denver can be observed in Figure 4, Figure 5, Figure 6 and Figure 7.

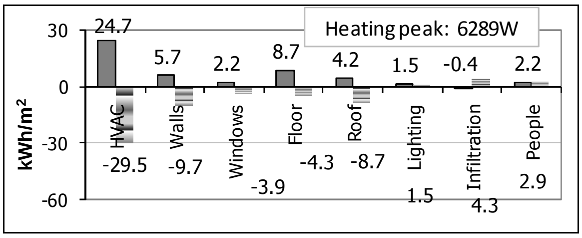

Figure 4 Wall heat transfer coefficient (1W/m^{2}K)

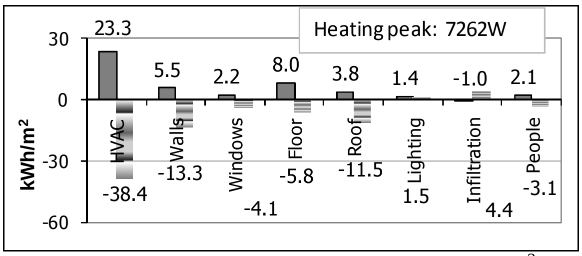

Figure 5 Wall heat transfer coefficient (1.5W/m^{2}K)

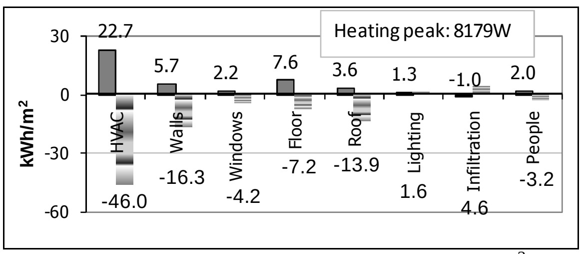

Figure 6 Wall heat transfer coefficient (2W/m^{2}K)

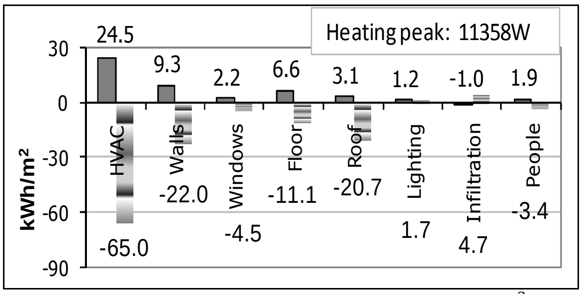

Figure 7 Wall heat transfer coefficient (4W/m²K)

The increase in the heat transfer coefficient resulted in an increase of the model total thermal load for the city of Denver. In the Denver weather conditions, an increase in the wall's heat transfer coefficient of 1W/m²K to 4.0W/m²K it can be observed that the thermal load for heating is approximately 2.5 times higher.

The Denver conditions require the air conditioning system more for heating during the year, since there are hard winters and mild summers. Thus, an increase in the wall's heat transfer coefficient in this type of climate will reflect in an increase in the thermal load value, as the inside temperature should remain within the set-point limits.

Analyzing the surfaces, it can be observed that the walls are the most responsible for the heat loss. Using a wall with 1W/m²k in the building the heat loss is 9.7kWh/m². But, adopting a construction of 4W/m²K the wall total heat loss is 22.0kWh/m², representing an increase of 56%.

The influence of the heat transfers coefficient in the peak of the air conditioning system was analyzed. The peak of the air conditioning in the wall with 1W/m²K has a heating peak of 6289W, but increasing the heat transfer coefficient to 4W/m²K the heating peak is 11358W. The thermal load for heating increase 2.5 more and the heating peak increase less than 2.0.

The increase in the wall heat transfer resulted in a peak 45% higher. For the walls with heat transfer coefficient of 1.5W/m²K and 2W/m²K the peak of the air conditioning system resulted in 7262W and 8179W, respectively.

Although it can be observed that, the thermal load for cooling is almost the same, the cooling peak increase 34% (1612W) when comparing the wall with 1W/m²K and the wall with 4W/m²K.

The total thermal load and the heating peak increase with the change of the wall heat transfer material. The wall without insulation (4W/m²K) reflects in the heating peak as Denver weather requests a more insulated wall to maintain the zone set point temperature.

Florianopolis

In the simulations for the city of Florianopolis, it was noted that the thermal load decreased with an increase in wall heat transfer coefficient as it shows in Figure 8; Figure 9; Figure 10 and Figure 11.

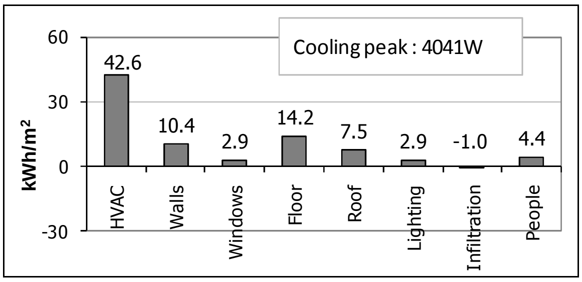

Figure 8 Wall heat transfer coefficient (1W/m²K)

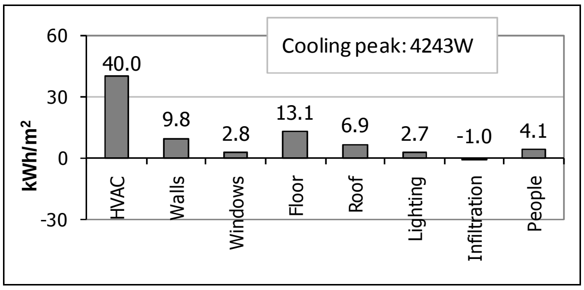

Figure 9 Wall heat transfer coefficient (1.5W/m²K)

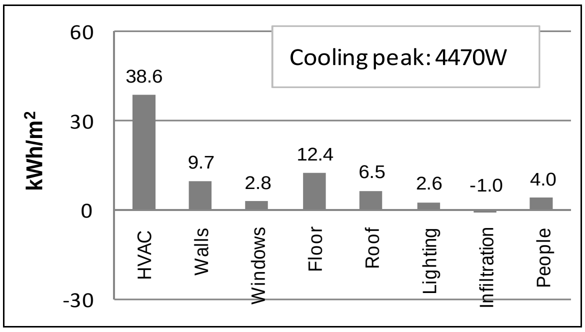

Figure 10 Wall heat transfer coefficient (2W/m²K)

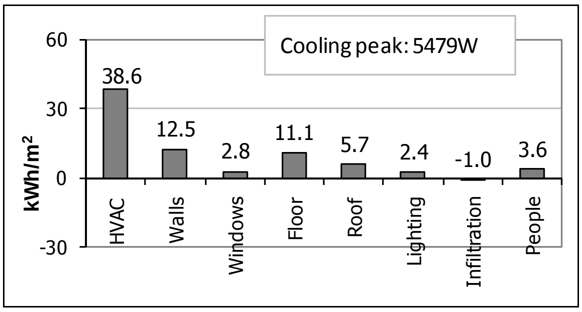

Figure 11 Wall heat transfer coefficient (4W/m²K)

Also, an increase in the wall's heat transfer coefficient of 1W/m²K to 4.0W/m²K provided a reduction of 10% (4kWh/m²) in the thermal load value. When simulated with the weather conditions of Florianopolis, the model shows that the cooling system is used and that no heating system is used since there are mild winters and hot summers.

Thus, making use of high thickness of insulation in the walls of this model, will not allow the dissipation of internal loads and window gains to the external atmosphere. Thus, the increase in wall's heat transfer coefficient allowed the internal heat to dissipate to external atmosphere easier, resulting in a reduction of thermal load.

For both weather conditions, the floor of building represents a huge part of the heat gaining, as it gains heat by irradiation from the windows. For the weather of Florianopolis the total heat gain from the floor is responsible for a significant part of the total valour of the thermal load.

For the climate of Florianopolis, the increase in the wall heat transfer coefficient resulted in an increase of the peak cooling load for the air conditioning system. The wall with $1W/m^2K$ resulted in a peak cooling of 4041W and increasing the heat transfer for $4W/m^2K$ resulted in a peak of 5479W. The annual total thermal load reduce 10%, but the cooling peak increase 26%.

The case with heat transfer of $1.5W/m^2K$ and $2.0W/m^2K$ resulted in a peak of 4243W and 4470W, respectively.

The change in the absorptance for the wall with heat transfer of $1W/m^2K$ and $4W/m^2K$ can be observed through Figure 12 and Figure 13.

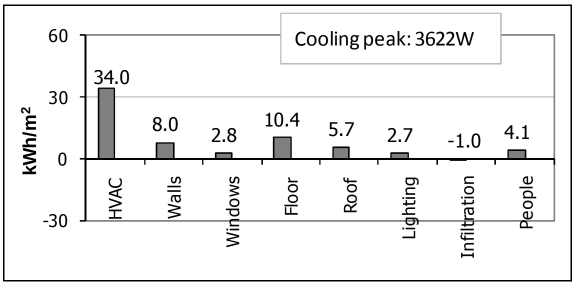

Figure 12 Absorptance of 0.2 in the wall heat transfer of $1W/m^2K$.

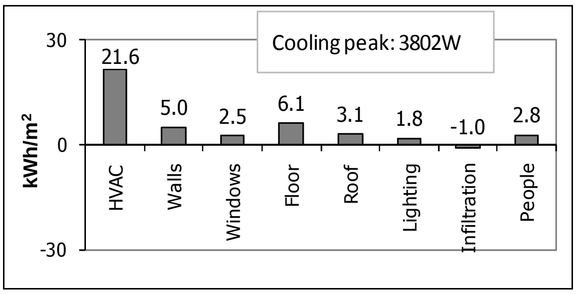

Figure 13 Absorptance of 0.2 2in the wall heat transfer of $4W/m^2K$.

The decrease in the absorptance resulted in a decrease of the model total thermal load for the city of Florianopolis for both walls. A decrease in the absorptance of wall's heat transfer coefficient of $1W/m^2K$ reduced the total thermal load in $8.6kWh/m^2$ (20%). It also can be observed that the change in the absorptance for the wall with a value of $4W/m^2K$ reduced the total thermal load in $17kWh/m^2$ (44%). These results demonstrate that for the climate of Florianopolis the surface absoptance is a parameter that can high influence in the building performance.

Comparing the cases with different absorptance values and wall heat transfers of $1W/m^2K$ it can be observed that in the case with low absorptance the heat gain from the walls decrease $2.4kWh/m^2$. Also, comparing the walls with a value of $4W/m^2K$ it can be noticed that the wall with absoptance of 0.2 reduced the heat gain in $7.5kWh/m^2$.

Analyzing the peak of the air conditioning system it can be noticed that for both cases the peak value was reduced. The new peak cooling for wall with $1W/m^2K$ is 3622W and for the wall with $4W/m^2K$ is 3802W. Comparing the wall with $1W/m^2K$ and absorptance of 0.5 with the same wall but with a abosptance value of 0.2 it can be observed that the peak value was reduced in 419W (10%). In addition, adopting a absorptance value of 0.2 in the wall with $4W/m^2K$ the value of peak cooling was reduced in 1677W (31%).

Analyzing the figures for Florianopolis can be noticed that the total thermal load decrease with the increase of the wall heat transfer coefficient, however, the cooling peak increase with the increase of the wall heat transfer coefficient. It occurs for a result of the increase of the heat transfer coefficient as the wall with $4W/m^2K$ lets the building gain more heat than the wall with $1W/m^2K$. As consequence, the heat peak inside the zone is higher when the wall is $4W/m^2K$ resulting is a higher cooling peak to bring the temperature between the set point value. But, analyzing the annual thermal load, it is noticed that the wall without insulation is better for the climate of Florianopolis.

CONCLUSION

A method for the analysis of the annual thermal performance of buildings has been exposed in this paper. The heat balance method by using the EnergyPlus program allows the user to analyze the annual heat gain and loss through the opaque elements.

The heat balance method by using the EnergyPlus program can help the users to have a quicker and better result when analyzing the parameters related in the buildings. The zone heat balance updates the zone conditions and determines the heating/cooling loads at all time step.

The user can observe and analyze which surface is losing or gaining more heat and how it influences on the building total thermal load. In addition, the user can observe the influence of each surface and system separately knowing where it is possible to chance to help in the building thermal performance. Also, the user can examine a strategy to reduce the thermal load in the building.

The buildings which are located in a climate with rigorous winters should use insulating material in the building walls and roof since this makes the inside temperature more comfortable for a longer period, keeping the internal gains reflecting in a reduction in the electricity consumption.

However, this study demonstrates that depending on which weather conditions the building is subjected to the use of insulating material can increase the integrated annual thermal load. Buildings that are located in climates that have mild and long summers should not have very insulated surfaces as this inhibits the dissipation of the internal solar gains to the exterior environment. In addition, a high value of heat transfer coefficient in this type of climate contributes to an increase in the use of the air conditioning system, as it is responsible for an elevation in the indoor air temperature.

For the weather of Denver, the annual thermal load and the heating peak increase with the increase in the wall heat transfer. Although, for the weather of Florianopolis the annual thermal load decrease and the cooling peak increase with the increase in the wall heat transfer.

The orientation of the main facade is important for enhancing the building thermal performance because, depending on the period of the year, some walls receive a higher solar incidence than other walls of the building. This influences the total thermal load that is transferred for the interior of the building. So, the incident thermal load in a building can be reduced if an appropriate orientation is used.

But, the energy saved depends on the weather, the building size and shape, glazed areas, the internal loads, the material characteristics used in the building, and also the type and efficiency of the air conditioning system.

This method can be used to optimize the envelope variables using a combination of the internal loads, envelope gains and internal gains in different climates and volumetric.

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