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GREEN ROOF BUILDING ANALYSIS AND SIMULATION OF THERMOENERGY BEHAVIOR

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Abstract. The construction technique known as Green Roof is a sustainable solution for buildings, consisting in the application of substrate and vegetation in an airtight extension on the constructions surface. This study explores the impact of Green Roofs on building thermo-energy performance using the building energy simulation program EnergyPlus and compares the consumption of electricity from a conventional roof and a green roof. The results showed that Green Roofs with thicker and denser soil is a good option to reduce energy consumption due to air conditioning. The ideal scenario proposed achieved a 21% reduction in total energy consumption in air conditioning.

Keywords: Green Roof. Thermal-Energy Simulation. EnergyPlus.

1. INTRODUCTION

The societies nowadays are large energy consumers. Almost any and all man-made processes use some kind of energy resource, including transportation, lighting, air conditioning and motor movement. Recent demand spikes and high construction rates awaken the need of to increase energy efficiency, as the installed systems will consume energy today and in the years that will come. The rational use of energy is considered as the "First Fuel", because it reduces the costs and impacts of power generation and also reduces the need for new transmission facilities (ALMEIDA and TEIXEIRA, 2014). In Brazil, the role of public policies in overcoming barriers and implementing programs that promote the rational use of energy is essential. Therefore, there is a need for strategic insight into the performance of the energy sector. Currently, the PBE Edifica (in Portuguese) program is used as a tool to reduce consumption and evaluate the operational energy performance of buildings in the use phase (PROCEL, 2016).

According to Rothschild (2007), the green roof should be a fundamental part of a country's energy and environmental strategy, where it is showed as carbon reduction example, in which, for every million square meters of green roofs planted, can be eliminated about 600 thousand tons of CO_2 per year. A well-cultivated green roof absorbs solar radiation and CO_2, reduces excess rainwater and reduces heating and cooling costs (THOMAZELLI, 2013). Then, it is intended to explain a way of reducing energy consumption through the natural conditioning techniques and components used in the building, specifically green roofs. Begins the study with the basic principles of energy transfer and the evaluated of energy behavior through thermo-energy simulation, in the same way the evaluated of building conditions.

In this way, this work aims to understand and analyze the green roofs influences on building energy consumption. As specifics objectives stands out the techniques analysis in which a green roof consists and the observation of how they affect the thermo-energetic building behavior. Also the understand of the heat transfer dynamics in the building and how it affects the thermal load of the building, and use the EnergyPlus as a tool to model the heat transfer in the building.

2. METHODOLOGY

2.1 Green Roof

Green roofs have existed for thousands years, being historically known since the Suspended Gardens of Babylon, built in the sixth century BC. The old green technology starts to be diffused by modern architecture after the architect Le Corbusier, when he talked about the "Five Points of Modern Architecture", where terraced gardens became a necessity facing the lack of green areas in the cities in the twenties (VALADAS, 2014). In Germany, the first green roofs were developed and marketed in large scale in the early 1970s. The next big step was the development of

extensive green roofs in the late eighties. The goal was to create lighter and cheaper systems that could be used on large flat roofs. These extensive roofs have gained importance and it was started the study of their additional benefits, such as reducing energy consumption for heating and cooling, storm water retention and mitigation of heat islands in large cities. (GRT, 2012).

The basic structure of a Green Roof can present variations according to the structure of the developed project. The structure is developed with the intention of ensuring the mechanical reinforcement of the vegetated part and to secure a space for de development of the plants, without, however, interferes in the structure of the building, according to TASSI et al (2014):

a)   Slab: part of building construction, the priority times is constituted by flat concrete, responsible by receive other layers of roof;

b)   Waterproof blanket: this is the first layer above slab. This is a layer responsible to the structure protection, specially to regards with infiltration;

c)   Drainage blanket: the drainage layer exist to storm the excess of rains waters;

d)   Filter: normally is made by geotextile; the filter layer separates the drainage layer to the substrate;

e)   Substrate: it is composed by the layer of ground, responsible for the vegetation support, providing water and nutrients by the vegetation development;

f)   Vegetation: superior layer of green roof adapted of local weather conditions.

2.2 Software EnergyPlus

The EnergyPlus it is official thermal-energy simulation software by the United Stated government and can be used by fee way, because the download is available. The program is a collection of integrated modules that are used to calculate the amount of energy required for the conditioning building, mixing the typologies of the system used and the sources of energy. The simulation is done by exposing the building to different climatic conditions and submitting it to the various operating scenarios (ENERGYPLUS ENGINEERING REFERENCE, 2013).

The fundamental principle is the equation of the thermal balance, seeking out the balance of the fundamental energy transfers. It is, however, a simplified tool to simulate the many combinations of systems, heat transfer, arrangements and places (ENERGYPLUS ENGINEERING REFERENCE, 2013). The development of this paper happened with the use of three free different programs available on the internet. For the building design was used Google SketchUp 2015, version 15.3.33, along with OpenStudio version 1.0.13, the latter being the plugin available for Google SketchUp. The National Renewable Energy Laboratory (NREL) for the United States Department of Energy to facilitate the transfer of data between Google SketchUp and EnergyPlus developed the plugin and for simulation; the EnergyPlus version 8.3.0 is used. In the software is carried out the data entry of the materials properties, the constructive elements used in the building, occupation schedule, location and characterization of heating and cooling. The simulations are carried out from a standard project and, as a result of the answers presented by the program, changes are proposed in the input variables.

2.3 Simulation

The simulations were done considering the standard project and, shared in two different scenarios of edifications, characterized in different types of green roofs and these respective changes:

a) Scenario 1: Conventional Roof Edification;
b) Scenario 2: Green Roof Edification.

The scenarios considered differ from each other by the coverage, and their evaluation is made, especially, about the energy consumption. For better evaluation, the building parts are treated as independent thermal zones, allowing identifying the amount of energy demanded by each sector. The details of the air-conditioned and non-air-conditioned areas and volumes can be seen in Table 1 presented in the results. In addition to the declaration of thermal zones, it is necessary to evaluate the heat gain from people, lights and equipment. The occupation expressed after the simulation is the average occupancy taking into account the schedules, the lights and equipment. The activity in the residence on weekdays (from Monday to Friday) is considered to start at 6:00 AM and is in operation until 8:00 AM, when the structure is empty, returning from 5:00 PM. On weekends and holidays, the activity in the residence starts from 8:00 AM, keeping in operation until midday. After that, activities happen between 5:00 PM and 8:00 PM for these days. In

this simulation is considered that all lamps used are LED and the equipment per zone analyzed are, 42-inch Led TVs for both rooms, 42-inch Led TV and video game for Living Room. In the kitchen are evaluated, refrigerator, freezer and microwave and, in the bathroom, electric shower and hairdryer.

In order to determine the energy consumption of the building, is used the climate archive of Porto Alegre - RS, developed by UFSC / LABEEE. Porto Alegre climate is classified as subtropical humid, showing significant variations through the year. The city has an average temperature of 19.5 °C, and the warmest month that is January, has an average temperature of 24.8 °C. The schedules mentioned above are also used to size the air conditioning systems, expecting that the temperature vary between 22 °C and 25 ° C, the set point temperatures for winter and summer. Auto size is used for sizing, and then the program must run the simulation for the design day to establish the nominal capacity of the air conditioning system. The project day creates parameters to establish the 24 hour profile used in the sizing and is represented by the 31st December, corresponding to a typical day of Monday. In addition, the wet bulb temperature that qualifies the design day is 70 °C and the dry bulb temperature is 40 °C. EnergyPlus is able to scale HVAC components based on building configurations and external design conditions, following the methodology specified by ASHRAE 62.1 -2010.

3. RESULTS AND DISCUSSION

The input data described above were synthesized in Table 1 and relate to the standard design. The changes regarding the simulations of different scenarios do not cause any alteration in the detail of the thermal zones, because the internal loads and the design do not change.

Table 1. Detailing of Thermal Zones.

Zones	Area (m^2)	Conditioned	Volume (m^3)	Outside Total area (m^2)	Window area (m^2)	Lighting (W/m^2)	People (m^2/people)
Bedroom 1	16.00	Yes	48.00	24.00	2.21	0.75	8.00
Bathroom	4.00	No	12.00	6.00	1.03	0.75	4.00
Bedroom 2	16.00	Yes	48.00	24.00	2.61	0.75	8.00
Living Room	24.00	Yes	72.00	30.00	2.32	15.00	6.00
Kitchen	24.00	No	72.00	30.00	2.25	20.00	6.00
Hall	16.00	No	48.00	6.00	0.00	0.75	4.00
Total	100.00		300.00	120.00	10.43	12.30	5.88
Total conditioned area	80.00		240.00	108.00	9.40	13.50	6.67
Total non-conditioned area	20.00		60.00	12.00	1.03	0.75	4.00

As can be seen, the total analyzed area of the building was divided into 6 thermal zones, which covers conditioned and unconditioned zones. The total built area is 100 m^2 and of these, 80 m^2 are conditioned and 20 m^2 are non-conditioned. The total external area refers to the external walls, considered a height of 3 m of right foot. The floor in direct contact with the ground and the walls dividing environments in which both are air-conditioned are defined as adiabatic.

To compare, it is used the average consumption electric power data per residence for the state of Rio Grande do Sul, because the climatic file used was from the city of Porto Alegre. According to notice (EPE, 2015), for a family of four, the average residential consumption is approximately 245.86 kWh per month. In the standard simulation, described by scenario 1 below, the value found was 295.88 kWh

The scenario 1 simulation presents an average monthly consumption of Electric Energy, about 295.88 kWh, according to Table 2. The value found is close to estimate (20% higher), and the fact of increasing can be the energy the use of air conditioning in all rooms, a situation that is not usually common to all residences.

Table 2. Electric Energy Consumption.

Electric Energy Year Consumption (kWh)	Electric Energy Month Average Consumption (kWh)	Specific Consumption (kWh/m^{2}mês)
3550.55	295.88	2.96

This total energy consumption is subdivided into HVAC, Lighting and Equipment and is quantified according to Table 3 below.

Table 3. Consumption by type of use.

Uses	Electricity (kWh/year)	Electricity (kWh/month)	Specific Consumption (kWh/m^2)
HVAC	1443.25	120.27	1.20
Lighting	176.39	14.70	0.15
Household Equipment	1930.91	160.91	1.61
Total	3550.55	295.88	2.96

At the moment the percentage of electricity consumption is divided (Figure 1), it can be identified that the highest expenditure corresponds to the domestic equipment of the building, which represents 54% of the total consumption. The consumption with air conditioning represents 41% and the consumption with lighting approximately 5% of the total consumed. The low consumption of lighting corresponds to the use, already proposed in the first scenario, of LED lamps in detriment of other technologies still commonly used, such as fluorescent lamps.
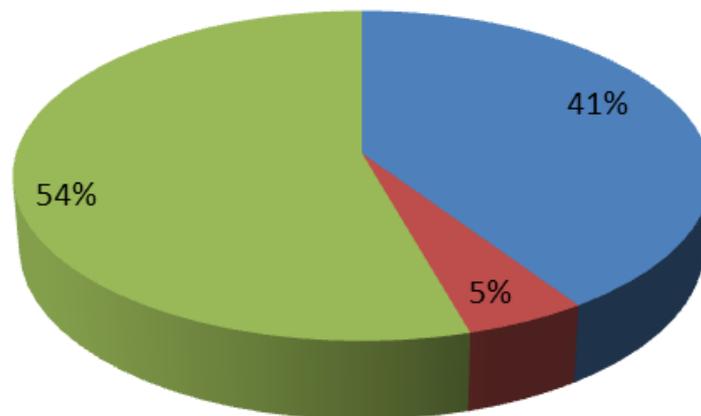

Figure 1. Chart of Energy Consumption by type of use

The chart represented by Figure 2 illustrates the total electric energy consumption per month of analysis. Consumption peaks occur between the summer months (December to March), showing a sharp drop in consumption between the winter months.
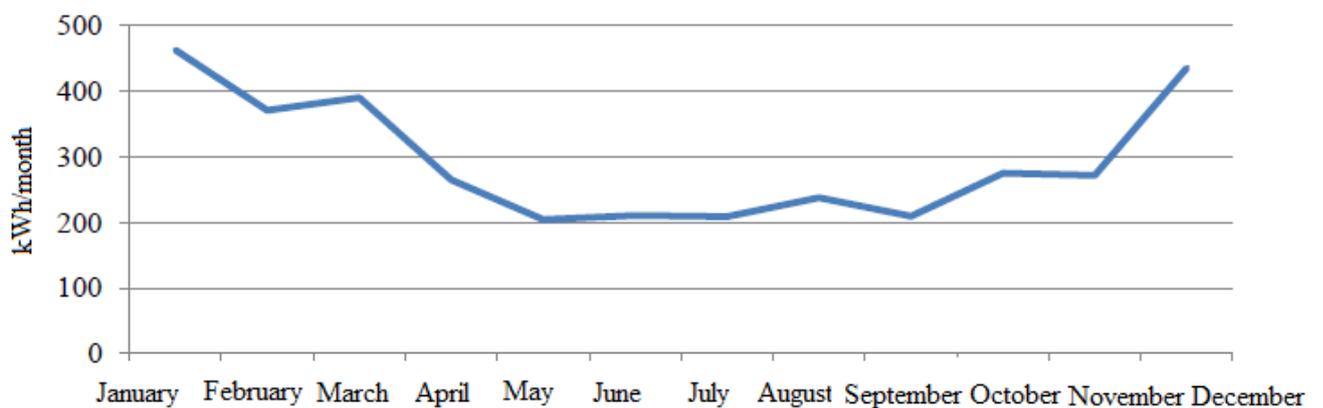

Figure 2. Chart of Energy Consumption per month

In terms of air conditioning, the temperature parameters specified as input data (variation between 22 °C and 25 °C) were met in 100% of the simulation hours (8760h) for both heating and cooling. As expected, in the warmer months (summer and spring), cooling expenditure has a higher representative, where the heating expenditure is zero. Likewise, in the colder months (winter and autumn), the expenses with air conditioning are much lower and the load is basically heating, as can be observed in Figure 3.
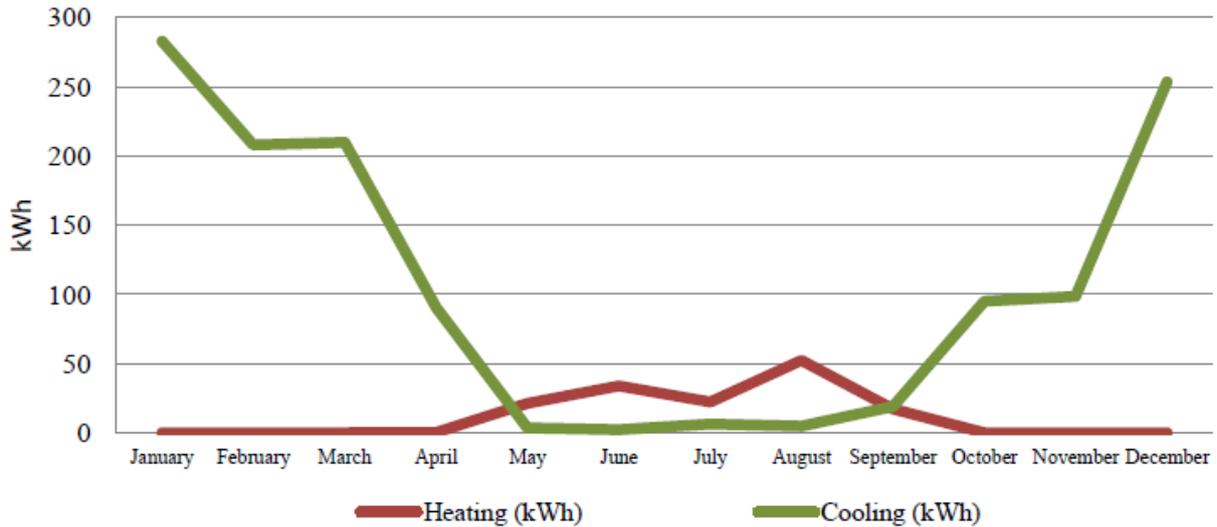
Figure 3. Monthly Electricity Spending Chart in Air Conditioning (kWh)

The best scenario of the Green Roof simulation was considered the one that presented a greater reduction of the thermal load of air conditioning, that is, the greater reduction of energy consumption in HVAC. When analyzing the reduction of the energy expenditure with air conditioning (heating and cooling), compared to scenario 1 presented previously, in the ideal scenario was obtained a total reduction of 21.1%, with a consumption of 1122.83 kWh; 102.54 kWh corresponding to the heating and 1020.29 kWh to the cooling.

The summary of the thermal load reductions compared to the baseline scenario by the results of the ideal simulation is presented in Table 4. In percentage, the reduction of the heating load is more significant, 30.6%, however, considering that its representative in the total load is lower, the total reduction is also lower.

Table 3. Thermal Load Reduction of Green Roof.

Air conditionig	Standard (kWh)	Green Roof (kWh)	Reduction
Heating	147.69	102.54	30.60%
Cooling	1275.60	1020.29	20.00%
Total	1423.29	1122.83	21.10%

4. CONCLUSION

In this work was proposed to analyze the influence of energy consumption in air conditioning systems with the use of Green Roof in a building. It was characterized the construction system, the different types of coverage, as well the environmental, economic and social impact. It is understood in this way that the described constructive technique presents numerous advantages, going beyond the thermo-energetic performance. With regard to the Green Roof, it is verified that consumptions more significantly reduced occur in thicknesses of superior substrates. This is because, the ground works as a thermal insulation that, the greater its thickness, the more it will insulate the building from the external environment. In comparison to the proposed in baseline scenario, a 21.1% reduction in energy expenditure in air conditioning was obtained in the ideal scenario, and approximately 16% in the real scenario, considering the Extensive Green Roof typology.

In order to observe the reductions of the energy expenditure in other constructive elements, it can be observed that when dealing with glasses, the increase of the thickness will be more advantageous in regions of cold climates, this because it reduces the expense on heating, however increasing the energy demand for refrigeration. For the thickness of the walls, the amount of gypsum and light cement was doubled, reaching a total of 38 mm and 200 mm, respectively. In both cases, the value of the reduction approached 2.0%. The results presented in this work indicate that there is energy saving in the air conditioning system with the use of Green Roof. In addition to simulating its effects on building, the basis for future studies of this theme is presented. It is therefore suggested that an economic analysis be carried out which contemplates the costs of investment and maintenance of the Green Roof and the time of investment return. In addition, it is suggested to evaluate the thermo-energetic performance in a real building, in the construction commonly used in Brazil. Knowing that the climate of Porto Alegre is not representative of the whole country and in order to know the behavior of the Green Roof on a national scale, it is indicated the simulation and comparison in other cities of the country that reach different climatic zones.

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6. RESPONSIBILITY NOTICE

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