GREEN BUILDING CERTIFICATION - A CORE & SHELL CASE

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Abstract. *This work is developed to analyze thermal performance of a building targeting Green Building certified in LEED category Core and Shell. It is a kind of speculative building in the city of Curitiba, composed by twenty one floors for commercial use. The building must be simulated to calculate his annual energy consumption. The Proposed Building should spend at least 10% less annual energy with respect to the Baseline Building, which has compliance to ASHRAE Standard 90.1. In the case of Core and Shell, is not possible to change the air conditioning system, the power of lighting and equipment, if they will not be provided by the constructor. It is possible to make changes only in the Proposed Building envelope and systems provided by constructor (e.g. air conditioning).*

Keywords*: Green building, LEED certification, Core & Shell, EnergyPlus*

1. INTRODUCTION

This work is developed to analyze the thermal performance of a building targeting Green Building certified in LEED category Core and Shell. It is a kind of speculative building in the city of Curitiba, composed by twenty one floors (21) for corporative use.

The LEED protocol defines that the certification should be done using the ASHRAE Standard 90.1 (2007), which in its Appendix G defines the reference building called Baseline Building. This building must have areas and heights equal to the Proposed Building, with definitions in the Standard for the construction of walls, floors and roofs, that should be insulated, definitions on windows, which has limitation in its area in relation to area of the walls, in his heat conduction coefficient, in his transmission of solar radiation, and in the artificial illumination's power. The Baseline Building may not have external shading devices.

The Baseline Building air conditioning system shall be Variable Air Volume (VAV) with motorized boxes, electric reheat, fan-coils with variable air volume fans, primary chilled water pumps with constant flow and secondary pumps with variable flow, chillers with screw compressors with staggered power, condenser water pumps with constant flow and cooling towers with two speeds fans.

The Baseline Building must be simulated to calculate his annual energy consumption. To neutralize the effect of solar orientation, the building must be simulated first with the orientation of the proposed building and then should be simulated three more times, each time rotated 90 °. The annual consumption is the average of these four solar orientations.

The Proposed Building should spend at least 10% less annual energy with respect to the Baseline Building annual consumption. In the case of Core and Shell, is not possible to change the air conditioning system, the power of lighting and equipment, as they will not be provided by the constructor. It is possible to make changes only in the Proposed Building envelope and those systems provided by constructor (e.g. air conditioning), in order to spend a minimum of 10% less energy mentioned above.

2. BUILDING SIMULATION PARAMETERS

The simulation was made with EnergyPlus (2010a), a collection of many program modules that work together to calculate the energy required for heating and cooling a building using a variety of systems and energy sources. It does this by simulating the building and associated energy systems when they are exposed to different environmental and operating conditions. The core of the simulation is a model of the building that is based on fundamental heat balance principles. Since it is relatively meaningless to state "based on fundamental heat balance principles", the model will be described in his basic constitution in next sections.

2.1. Zone and Air System Integration

The basis for the zone and air system integration is to formulate energy and moisture balances for the zone air and solve the resulting ordinary differential equations using a predictor-corrector approach. The formulation of the solution scheme starts with a heat balance on the zone air (EnergyPlus 2010b).

$$C_z \frac{dT_z}{dt} = \sum_{i=1}^{Ncl} \dot{Q}_i + \sum_{i=1}^{Ns} h_i A_i (T_{si} - T_z) + \sum_{i=1}^{Nz} \dot{m}_i c_p (T_{zi} - T_z) + \dot{m}_{inf} c_p (T_\infty - T_z) + \dot{m}_{sys} c_p (T_{sup} - T_z) \quad (1)$$

where $C_z \frac{dT_z}{dt}$ is energy stored in zone air, $\sum_{i=1}^{Ncl} \dot{Q}_i$ is sum of the convective internal loads, $\sum_{i=1}^{Ns} h_i A_i (T_{si} - T_z)$ is convective heat transfer from the zone surfaces (see section 2.2), $\sum_{i=1}^{Nz} \dot{m}_i c_p (T_{zi} - T_z)$ is heat transfer due to interzone air mixing, $\dot{m}_{inf} c_p (T_\infty - T_z)$ is heat transfer due to infiltration of outside air and $\dot{m}_{sys} c_p (T_{sup} - T_z)$ is air systems output.

The sum of zone loads and air system output now equals the change in energy stored in the zone. Typically, the capacitance C_Z would be that of the zone air only. However, thermal masses (like furniture) assumed to be in equilibrium with the zone air could be included in this term.

EnergyPlus provides three different solution algorithms to solve the zone air energy and moisture balance equations: 3rdOrderBackwardDifference, EulerMethod or AnalyticalSolution.

The timestep object specifies the basic timestep for the simulation, in this case 15 min. This is used in the above Zone Heat Balance Model calculation as the driving timestep for heat transfer and load calculations. The Loads Convergence Tolerance Value represents the number at which the loads values must agree before convergence is reached, equal 0,04 W. The Temperature Convergence Tolerance Value represents the number at which the zone air temperatures must agree (from previous iteration) before convergence is reached, in this case 0,4 °C.

2.2. Surfaces Heat Balance

The heat balance on the outside and inside faces of a surface can be done as follows (EnergyPlus 2010b):

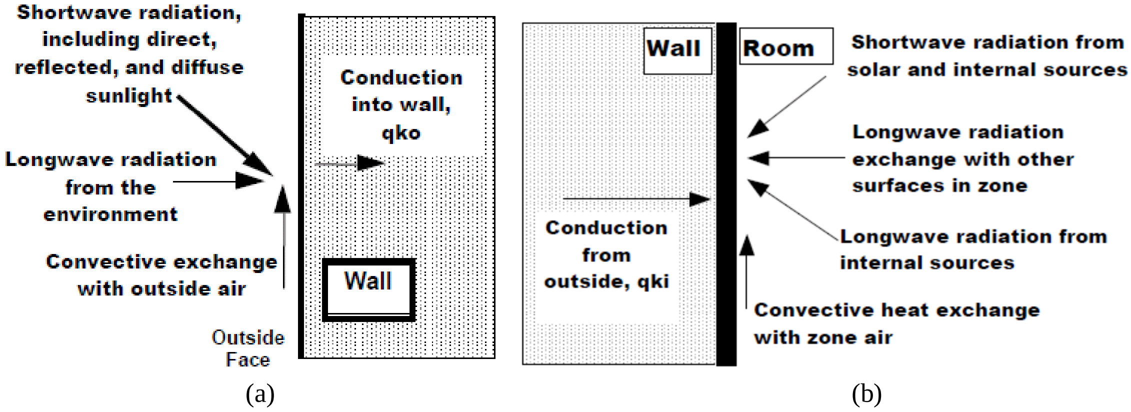

Figure 1. Outside (a) and Inside (b) Heat Balance Control Volume Diagram (EnergyPlus 2010b)

The heat balance on the outside face is:

$$q''_{\alpha sol} + q''_{lwr} + q''_{conv} - q''_{ko} = 0 \tag{2}$$

where $q''_{\alpha sol}$ is absorbed direct, reflected and diffuse solar radiation heat flux, q''_{lwr} is net longwave radiation flux exchange with the air and surroundings, q''_{conv} is convective flux exchange with outside air and q''_{ko} is conduction heat flux into the wall.

The heat balance on the inside face can be written as follows:

$$q''_{swr} + q''_{lwrz} + q''_{lwri} + q''_{conv} + q''_{ki} = 0 \tag{3}$$

where q''_{swr} is shortwave radiation flux to surface from solar and lights, q''_{lwrz} is long wave radiant exchange flux between zone surfaces, q''_{lwri} is long wave radiation flux from people and equipment in zone, q''_{conv} is convective heat flux to zone air (see section 2.1) and q''_{ki} is conduction flux through the wall.

Heat transfer due to exterior convection is modeled using the classical formulation with h_c , the exterior convection coefficient, obtained with equation (LBL 1994).

$$h_c = h_n + R_f \left[\sqrt{h_n^2 + (aV_z^b)^2} - h_n \right] \tag{4}$$

where h_c is the forced convective heat transfer coefficient, h_n is the natural convective heat transfer coefficient, R_f is surface roughness multiplier, a and b are constants and V_z is local wind speed calculated at the height above ground of the surface centroid.

For the natural coefficient an enhanced convection correlation is used:

$$h_n = \frac{c(\Delta T)^{1/3}}{d - (cos\Sigma)} \tag{5}$$

where *c* and *d* are constants, ΔT = Air Temperature - Surface Temperature and Σ is the surface tilt angle.

For interior convection, it is used the detailed natural convection model, that correlates the convective heat transfer coefficient to the surface orientation and the difference between the surface and zone air temperatures, equation (5) above.

Conduction through the walls is done with Conduction Transfer Function (CTF). The most basic time series solution is the response factor equation which relates the flux at one surface of an element to an infinite series of temperature and heat flux histories at both sides as shown by equations (6) and (7) (EnergyPlus 2010b):

For the inside heat flux

$$q''_{ki}(t) = -Z_0 T_{i,t} - \sum_{j=1}^{nz} Z_j T_{i,t-j\delta} + Y_0 T_{0,t} + \sum_{j=1}^{nz} Y_j T_{0,t-j\delta} + \sum_{j=1}^{nq} \Phi_j\, q''_{ki,t-j\delta} \tag{6}$$

and for the outside heat flux

$$q''_{ko}(t) = -Y_0 T_{i,t} - \sum_{j=1}^{nz} Y_j T_{i,t-j\delta} + X_0 T_{0,t} + \sum_{j=1}^{nz} X_j T_{0,t-j\delta} + \sum_{j=1}^{nq} \Phi_j\, q''_{ko,t-j\delta} \tag{7}$$

where q_k'' is conduction heat flux, T is temperature, i signifies the inside of the building element, o signifies the outside of the building element, t represents the current time step, Xj is outside CTF coefficient, j= 0,1,...nz, Yj is cross CTF coefficient, j= 0,1,...nz, Zj is inside CTF coefficient, j= 0,1,...nz, Φj is flux CTF coefficient, j = 1,2,...nq and δ is time step.

The basic method used in EnergyPlus for CTF calculations is known as the state space method (Ouyang and Haghighat 1991). Another common, older method used Laplace transformations to reach the solution; the Laplace method was used in BLAST (Hittle & Bishop, 1983).

2.3. Glazing System Properties

The optical properties of a glazing system consisting of N glass layers separated by nonabsorbing gas layers (Figure 2) are determined by solving the following recursion relations for $T_{i,j}$, the transmittance through layers i to j; $R^f_{i,j}$ and $R^b_{i,j}$, the front (*f*) and back (*b*) reflectance, respectively, from layers i to j; and A_j , the absorption in layer j. Here layer 1 is the outermost layer and layer N is the innermost layer. These relations account for multiple internal reflections within the glazing system. Each of the variables is a function of wavelength (EnergyPlus 2010b).

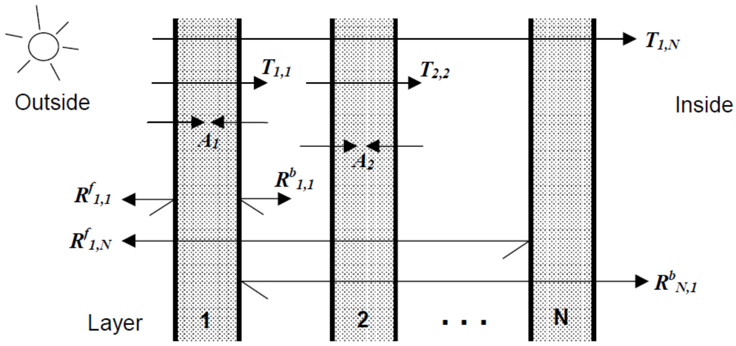

Figure 2. Schematic of Transmission, Reflection and Absorption of Solar Radiation within a Multi-layer Glazing System (EnergyPlus 2010b)

The relations are:

$$T_{i,j} = \frac{T_{i,j-1} T_{j,j}}{1 - R^f_{j,j} R^b_{j-1,i}} \tag{8}$$

$$R^f_{i,j} = R^f_{i,j-1} + \frac{T^2_{i,j-1} R^f_{j,j}}{1 - R^f_{j,j} R^b_{j-1,i}} \qquad R^b_{j,i} = R^b_{j,j} + \frac{T^2_{j,j} R^b_{j-1,i}}{1 - R^b_{j-1,i} R^f_{j,j}} \tag{9a, 9b}$$

$$A^f_j = \frac{T_{1,j-1}\left(1 - T_{j,j} - R^f_{j,j}\right)}{1 - R^f_{j,N} R^b_{j-1,1}} + \frac{T_{1,j} R^f_{j+1,N}\left(1 - T_{j,j} - R^b_{j,j}\right)}{1 - R^f_{j,N} R^b_{j-1,1}} \tag{10}$$

The spectral data include the transmittance, *T*, and the reflectance, *R*. For uncoated glass the reflectance is the same for the front and back surfaces. For angle of incidence, φ, the transmittance and reflectance are related to the transmissivity, τ, and reflectivity, ρ, by relationships.

The Solar Distribution Setting determines how EnergyPlus treats beam solar radiation and reflectances from exterior surfaces that strike the building and, ultimately, enter the zone. In the used FullExterior case, shadow patterns on exterior surfaces caused by detached shading, wings, overhangs, and exterior surfaces of all zones are computed. Also shadowing by window and door reveals is also calculated. All beam solar radiation entering the zone is assumed to fall on the floor, where it is absorbed according to the floor's solar absorptance. Any reflected by the floor is added to the transmitted diffuse radiation, which is assumed to be uniformly distributed on all interior surfaces. If no floor is present in the zone, the incident beam solar radiation is absorbed on all interior surfaces according to their absorptances. The zone heat balance is then applied at each surface and on the zone's air with the absorbed radiation being treated as a flux on the surface (EnergyPlus 2010c).

3. ENERGYPLUS WEATHER FILE

A generalized weather data format for use by energy simulation programs has been developed and adopted by EnergyPlus. Anticipating the need for data at time steps less than one hour, the format includes a minute field to facilitate the use of sub hourly data. The data include basic location identifiers such as location name, data source, latitude, longitude, time zone, elevation, peak design conditions, holidays, daylight saving period, typical and extreme periods, ground temperatures, period(s) covered by the data and space for descriptive comments. The time step data include dry bulb and dew point temperature, relative humidity, station pressure, solar radiation (global, extraterrestrial, horizontal infrared, direct, and diffuse), illuminance, wind direction and speed, sky cover, and current weather. It is based on the data available within the TMY2 weather format but has been rearranged to facilitate visual inspection of the data.

Dry bulb temperature evolution for Curitiba over a year can be seeing in figure 3, with tendency curve. The file was <BRA_Curitiba-Afonso.Pen.838400_SWERA.epw>, find in EnergyPlus homepage (EnergyPlus 2010a).

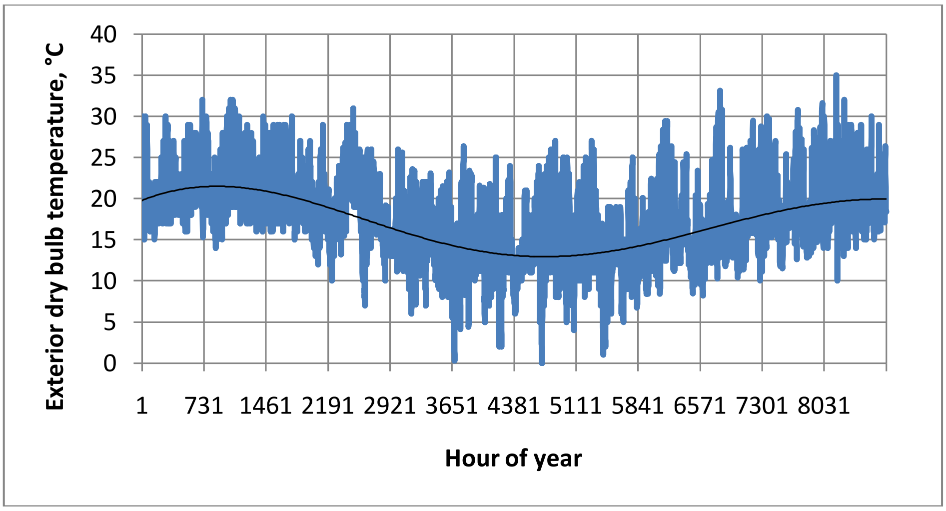

Figure 3. Exterior Annual Dry Bulb Temperature for Curitiba

4. SCHEDULES

This object allows the user to influence scheduling of many items (such as occupancy density, lighting, thermostatic controls, occupancy activity, air conditioning). EnergyPlus schedules consist of three pieces: a day description, a week description, and an annual description. The day description is a name and the values that span the 24 hours in a day to be associated with that name. The week description also has an identifier and twelve additional names corresponding to previously defined day descriptions. There are names for each individual day of the week plus holiday, summer design day and winter design day. Finally, the annual schedule contains an identifier and names and dates of the week schedules associate with this annual schedule. Schedule used in this simulation can be seeing in figure 4, for weekdays, Saturday and Sunday/Holyday.

5. SURFACE CONSTRUCTION ELEMENTS

This group of objects describes the physical properties and configuration for the building envelope and interior elements. That is, the walls, roofs, floors, windows and doors for the building.

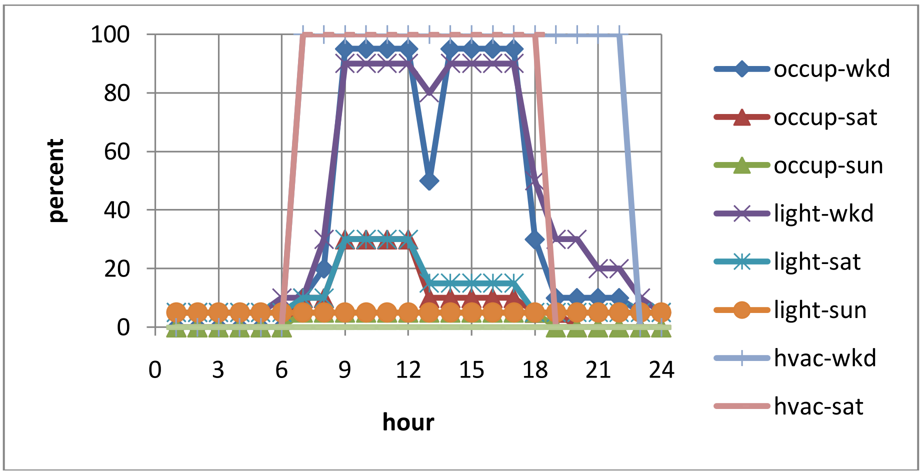

Figure 4. Schedules for Offices

5.1 Opaque Material

This definition should be used with materials roughness and thickness, and the four main thermal properties, i.e. conductivity, density, and specific heat of the material. Also three radiation properties are necessary, i.e., thermal (long infra red), solar and visible absorptances.

5.2 Glazing

In the following, for exterior windows, front side is the side of the glass closest to the outside air and back side is the side closest to the zone the window is defined in. Necessary properties from glazing materials are thickness, solar transmittance at normal incidence, front and back side solar reflectance at normal incidence, visible transmittance at normal incidence, front and back side visible reflectance at normal incidence, infrared transmittance at normal incidence, front and back side infrared hemispherical emissivity, and thermal conductivity.

5.3 Construction

For walls, roofs, floors, windows, and doors, constructions are built from the included materials. Each layer of the construction is a material name listed in order from outside to inside. Outside is the layer furthest away from the Zone air (not necessarily the outside environment). Inside is the layer next to the Zone air.

6. BASELINE BUILDING ENVELOPE

For the appropriate climate, space-conditioning category and class of construction, the Baseline Building envelope shall comply with Section 5 - Building Envelope - from ASHRAE Standard 90.1 - Energy Standard for Building Except Low-Rise Residential Buildings (ASHRAE 2007).

6.1 Opaque Areas

For opaque surfaces compliance shall be demonstrated by observing maximum U-factor. U-factor is the heat transmission in unit time through unit area of a construction and the boundary air films, induced by unit temperature difference between the environments on each side. For Curitiba, climate zone 2 (A,B):

Table 1. Building Envelope Requirements - Opaque Elements

Opaque Elements	Max. U-factor, W/m².K
Roofs, Insulation Entirely above Deck	0.273
Walls, Steel-Framed	0.705
Interior Floors, Steel-Joist	0.390
Slab-on-Grade Floors	1.264

6.2 Fenestration

Compliance with U-factor and SHGC (Solar Heat Gain Coefficient) shall be demonstrated for the overall fenestration product. SHGC is the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. The total vertical fenestration area shall be less than 40 % of the gross wall area. Fenestration shall have a U-factor and SHGC not greater than that specified in Table below. For Curitiba (Zone 2):

Table 2. Building Envelope Requirements - Fenestration

Fenestration	Max. U-factor, W/m².K	Max. SHGC
Vertical Glazing, Metal Framing	4.26	0.25

7. PROPOSED BUILDING ENVELOPE

All components of the building envelope in the proposed building shall be modeled as shown on architectural drawings or as built for existing building envelopes. The exterior wall simulated was composed by alucobond 3 mm, 70 mm air space, 20 mm stucco, brick - fired clay/1120 kg/m3 - 190 mm, 100 mm air space and 20 mm gypsum board. The exterior window construction was SKN clear 4 mm glass, air space 8 mm and float clear 4 mm glass.

8. BASELINE LIGHTING

The installed interior lighting power shall include all power used by the luminaries, including lamps, ballasts, transformers and control devices. The installed interior lighting power shall not exceed the interior lighting power allowance developed in accordance with Lighting Power Densities (LPD) using Space-by-Space Method in next table.

Table 3. Lighting Power Densities using Space-by-Space Method

Space Types	LPD, W/m²	Space Types	LPD, W/m²
Office	12	Atrium	6
Stairs	6	Electrical/Mechanical	16
Parking Garage	2		

9. PROPOSED LIGHTING

Lighting power in the proposed design shall be determined as in designed lighting system.

10. INTERIOR EQUIPMENT

The computers, printers, copiers, etc., heat gains was calculated with the following general guidelines. The load density considered was medium/heavy, and assumes 9.3 m²/workstation (11 workstations per 100 m²) with computer and monitor at each plus printer and fax. Computer and monitor diversity was 0.75 and printer and fax diversity was 0.50, and the result was a load factor of 16.1 W/m², used in both buildings.

11. BASELINE HEATING, VENTILATING AND AIR CONDITIONING (HVAC)

The HVAC system in the baseline building design shall be with Variable Air Volume (VAV) with Parallel VAV Fan-Powered Boxes (PFP Boxes) with reheat, chilled water and electric resistance. The baseline building design's chiller plant shall be modeled with 2 water-cooled screw chillers sized equally. Chilled-water system shall be modeled as primary/secondary systems with variable-speed drives on the secondary pumping loop. The heat rejection device shall be an axial fan cooling tower with two-speed fans.

12. PROPOSED HEATING, VENTILATING AND AIR CONDITIONING (HVAC)

The HVAC system type and all related performance parameters in the proposed design shall be consistent with HVAC system design documents. In this case de system was Variable Refrigerant Volume (VRV) or Variable Refrigerant Flow (VRF) with heat pump heating system.

13. BASELINE BUILDING

Figure 5 show isometrics views of one of the 21 floor of the simulated building, made with Google SketchUp and using the plugin OpenStudio, which generates a file that EnergyPlus simulates with annual weather data. It can be seen that the areas of windows are limited to 40% of the area of the walls, with no external shading.

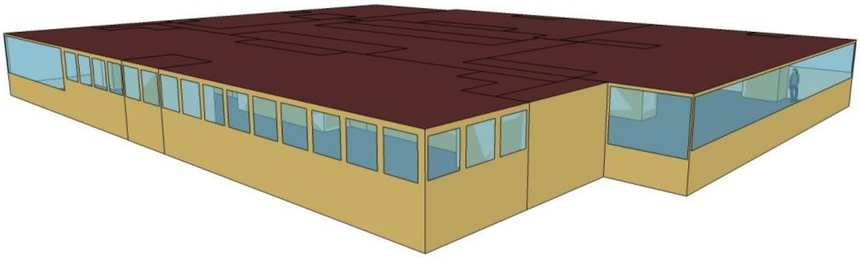

Figure 5 - Baseline Building Facades

This building was simulated in annual scale, and the figure 6 show monthly energy consumption of the building.

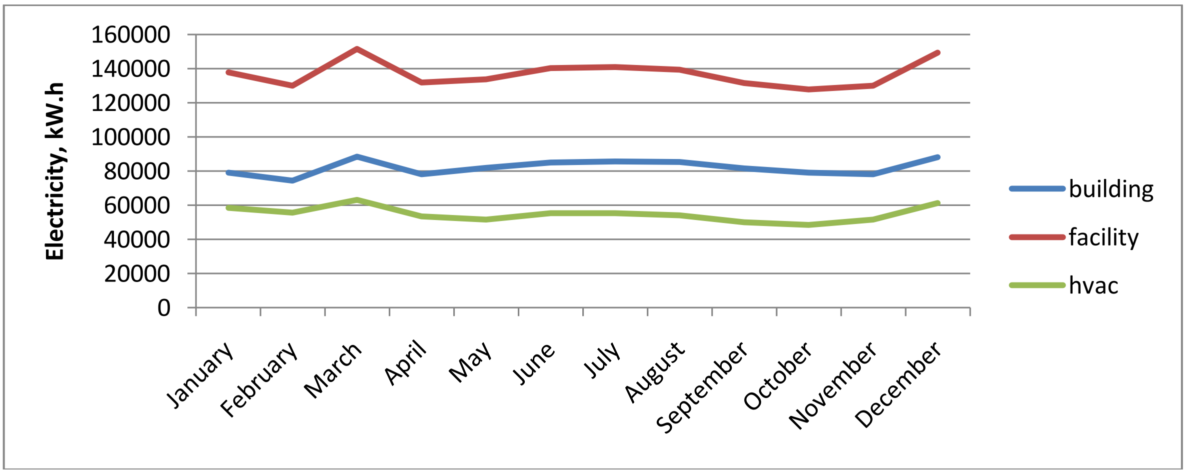

Figure 6 - Basic Monthly Consumption of Baseline Building

It can be seen that the Facility uses about 140,000 kW.h/month, the Building uses about 80,000 kW.h/month and HVAC energy uses about 55,000 kW.h/month. The calculated consumptions are:

Facility = Building + HVAC (11)
Building = Equipment + Lights (12)
HVAC = Cooling + Fans + Tower + Heating + Pumps (13)

The sum of the monthly consumption of the Facility gives 1,644,057 kW.h/year, and the Proposed Building should spend at least 10% less on this value, or 1,479,651 kW.h per year. The Building use 985,205 kW.h/year (59.9 % of total energy) and HVAC use 658,852 kW.h/year (40.1 %). These energies in the form of a chart on annual scale could be seeing on figure 7.

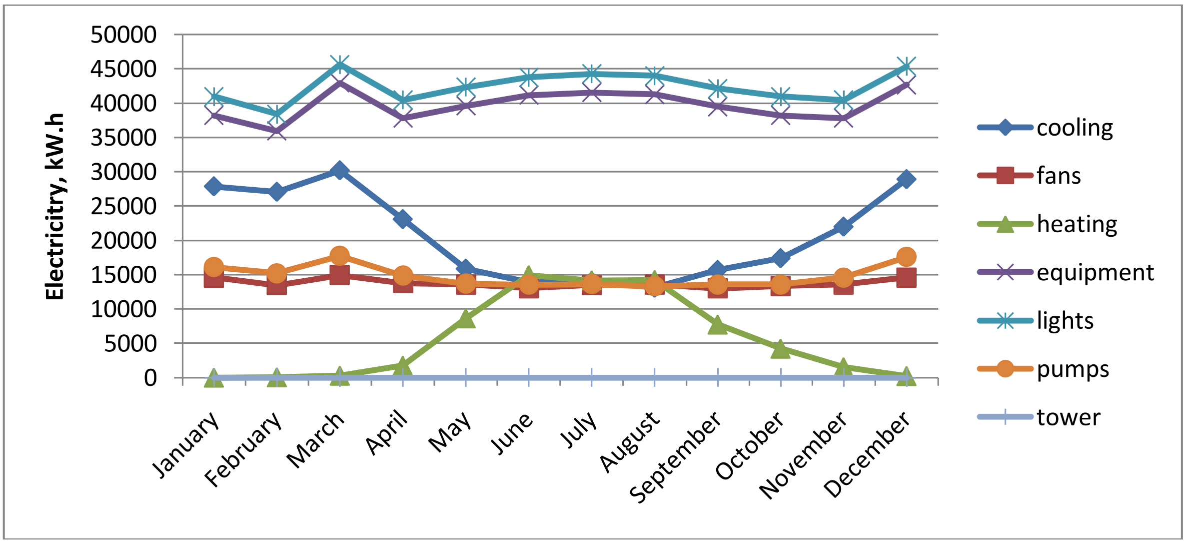

Figure 7 - Monthly Consumptions of Baseline Building

It can be seen that consumption by Lights and Equipment are greatest, and similar throughout the year, with charges averaging around 40,000 kW.h/month. The Cooling is great in summer and Heating in winter. Cooling is fairly great in winter because windows have no shade. Heating is great on winter, even with no shade device, because use electric resistance. Fans and Pumps are similar. Tower consumption is negligible. Annual consumptions could be seen in figure 8.

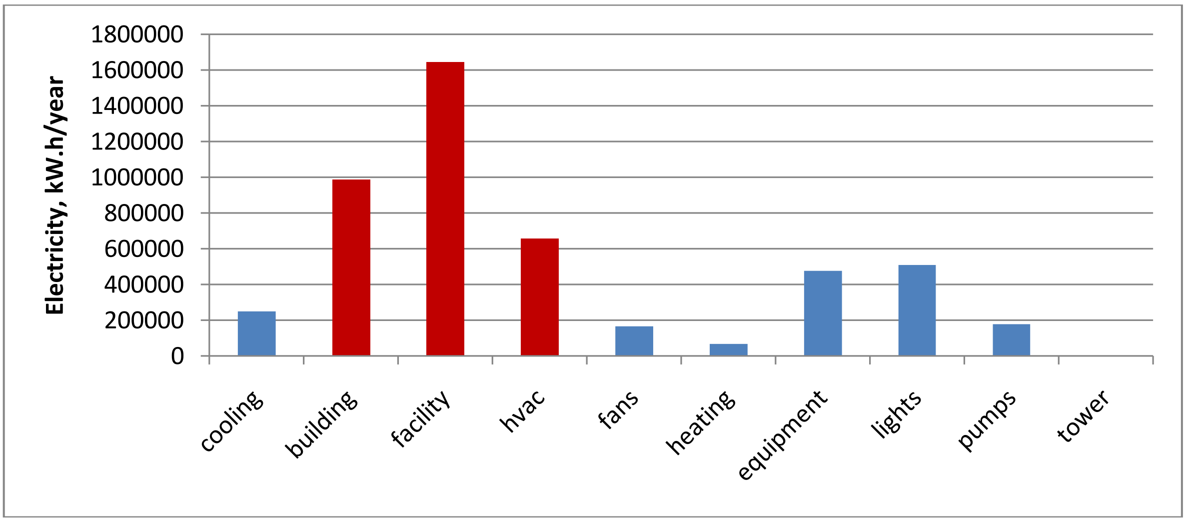

Figure 8 - Energy Consumption thought the Year for Baseline Building

14. PROPOSED BUILDING

To reduce the consumption of the building it was tried to diminish some individual consumption, changing the envelope of the building and the air conditioning system.

To decrease solar heat gain, the building facades was covered with external shading devices like multiple overhangs in front of glass on quadrant north, because the sun passes high above the horizon on these fronts, and multiple fins in front of glass on quadrant facades in the southern quadrant, as the sun goes down on these fronts.

To decrease air conditioning energy consumption was used Variable Refrigerant Volume (VRV) or Variable Refrigerant Flow (VRF) system.

The facades can be seen in figure 9.

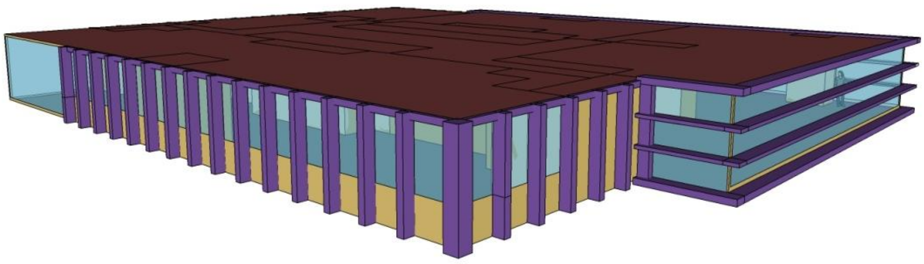

Figure 9 - Proposed Building Facades

Proposed Building was then simulated in annual scale yielding the results on figure 10.

It can be seen that the Facility develop most of the time below 120,000 kW.h/month. Observing the evolution of HVAC, can also be seen low consumption in winter.

The total annual consumption was 1,390,530 kW.h, or 15.4% less than the Baseline Building, larger than the 10% required by the LEED Protocol. The Building use 974,138 kW.h/year (70.1 % of total energy) and HVAC use 416,392 kW.h/year (29.9 %).

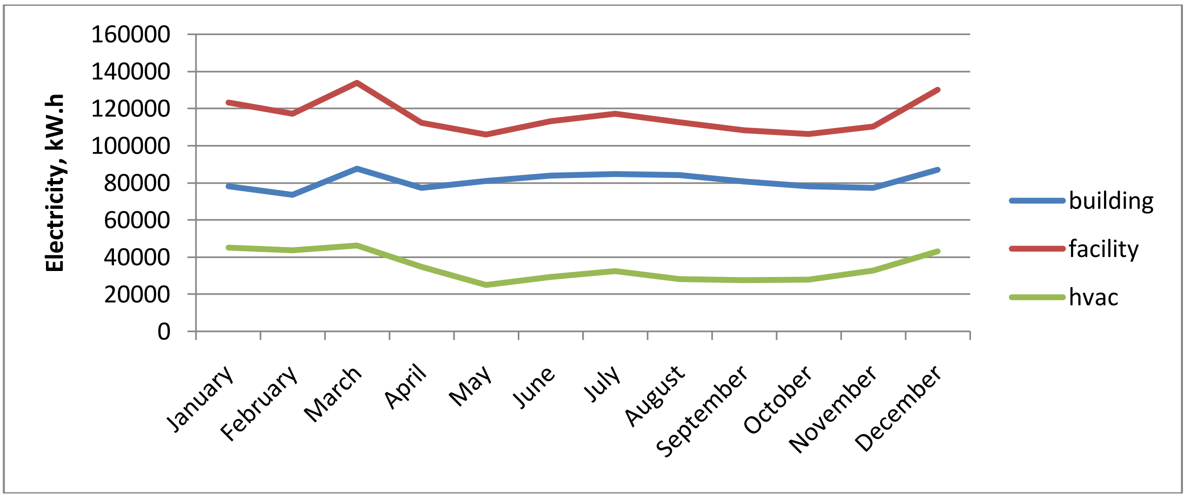

Figure 10 - Proposed Building Annual Monthly Consumption

Individual loads could be seeing in figure 11.

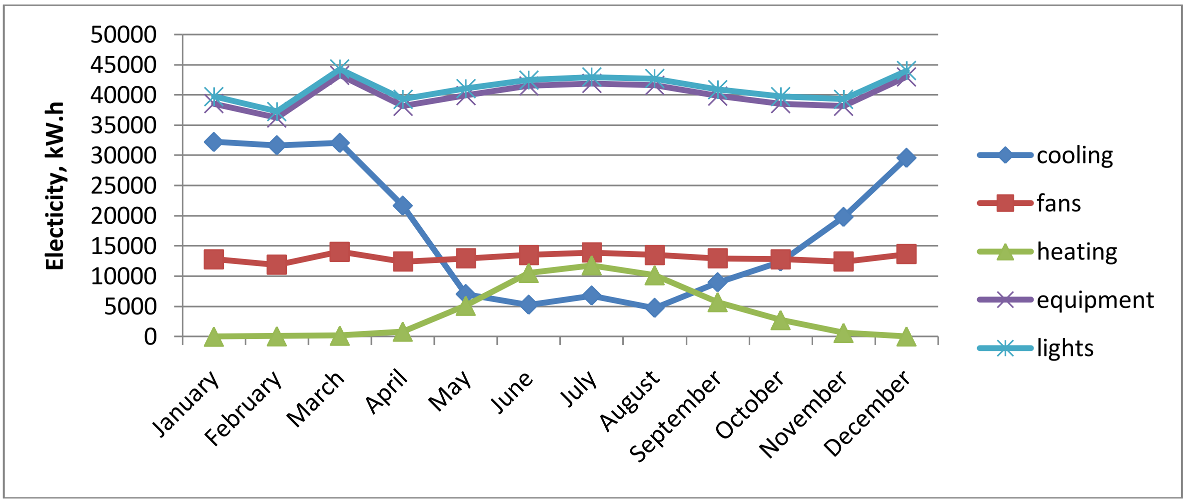

Figure 11 - Proposed Building Primary Consumptions

It can be seen that the external shading devices decreased quite a load of Cooling, shading the windows, properly chosen in their horizontal and vertical orientations. The shading also decrease indoor solar radiation on winter, but the heating energy decreases because proposed building use heat pump system, and baseline building use electric resistance system for heating. Each annual load could be seeing in figure 12.

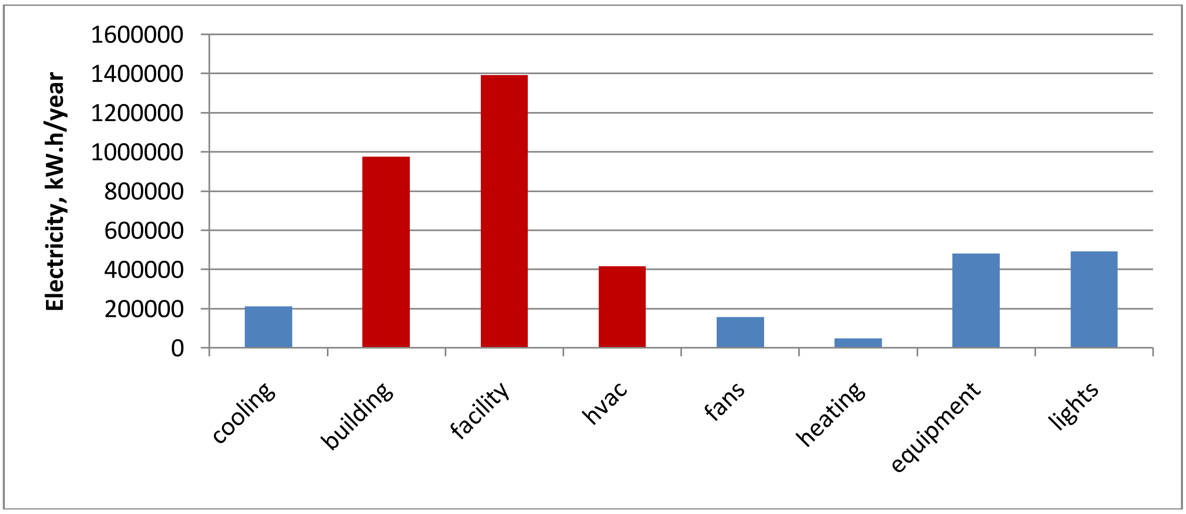

Figure 12. Annual Energy Consumption for proposed Building

15. PROPOSED VERSUS BASELINE BUILDING

Comparing the loads between the two buildings one have the figure 13.

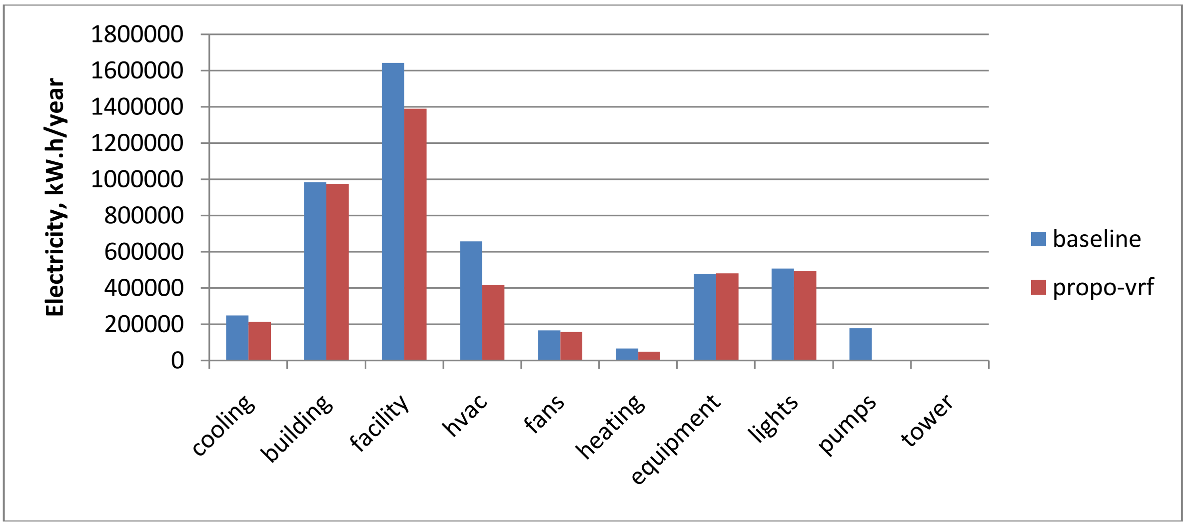

Figure 13 - Comparison between Baseline and Proposed Building

It can be seen that occur an energy gain by don't using Pumps. Also there is an energy saving in Cooling, Fans and Heating. And so, there is an energy economy of 15.4 %, from Proposed Building in contrast to Baseline Building.

16. CONCLUSIONS

The software's Google SketchUp, plugin OpenStudio and EnergyPlus offer a very good association to simulate buildings energy consumption.

The USGBC-LEED protocols give a complete set of information to guide the Green Building certification.

The ASHRAE Standard 90.1 - Energy Standard for Buildings except Low-Rise Residential Buildings provide minimum requirements for the energy-efficient design of buildings and its energy systems.

Externals shading devices on buildings may be a good solution for energy saving.

Pumps in chilled water air conditioning systems use a lot of energy.

Variable Refrigerant Volume (VRV) or Variable Refrigerant Flow (VRF) is air conditioning system with good efficiency.

17. REFERENCES

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18. RESPONSIBILITY NOTICE

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