Evaluation of the Design and Energy Simulation to Implement the Sustainable Project of a Building for LEED Certification in Lima, Peru

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***Abstract*—Applying sustainable strategies and energy simulation through software for mechanical, electrical, lighting and automation systems, the design of a building project was oriented in order to obtain LEED (Leadership in Energy and Environmental Design) certification. The work was done as part of the project to build a ten-story tower for use in offices and commercial areas in Lima, Peru.**

***Keywords*—Environment, sustainability, energy saving, air conditioning, efficiency.**

I. Introduction

Faced with the need to preserve the environment and the efficient use of energy, different technical institutions have appeared in charge of developing recommendations, guides and certifications in the building projects sector, to obtain efficiency and sustainability; For this, design supervision and energy simulation must be performed. There are different entities, some shown in Fig. 1.

Fig. 1. Diagram of guidelines for the Base and Proposed Model.

In this work, the analysis was made for a ten-story building in the city of Lima, Peru. The certification was sought *LEED* [1], which is a type of certification in sustainable construction considered one of the most important in the world. This certification evaluates all climatic and energy aspects that impact the environment, considering criteria of, sustainability of the place, water saving, energy saving, sustainability of materials and indoor environmental.

II. Calculations and Obtaining Results

A. Energy modeling

Work following the activity flow diagram shown in Fig. 2, we observe the procedure to evaluate two alternatives to select and refine the energy model with the needs and investment possibilities.

The reference regarding the goals was a *building with similar characteristics* that achieved LEED Gold certification, with an energy saving in modeling of 18.23%, which is above 10%, the minimum required by LEED.

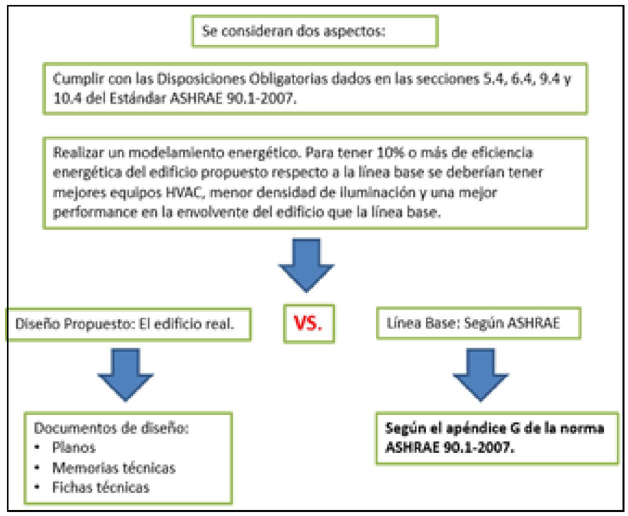

Fig. 2. Diagram of guidelines for the Base and Proposed Model.

Fig. 3 shows the flow chart for energy modeling. The input information is to the DesignBuilder, then it is exported to the EnergyPlus simulation engine, then an annual consumption report is obtained [2].

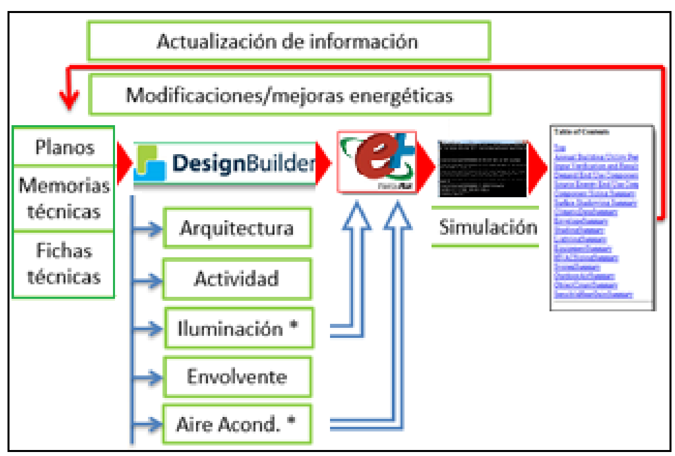

Fig. 3. Flow diagram for energy modeling.

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B. *Bioclimatic Study*

It focuses on energy conservation, which requires analyzing the temperature, radiation, orientation and location of the project. This allows to analyze the architectural design, the feasibility of natural ventilation and natural lighting.

Table I shows the monthly and annual average temperature of the city of Lima. ASHRAE comfort temperatures of 21 ° C for heating and 24 ° C for cooling are considered as the cooling and heating set points to stay in the comfort zone [3].

TABLE I. RELATIVE TEMPERATURES AND HUMIDITIES OF LIMA [4]

Mes	Ene.	Feb.	Mar.	Abr.	May.	Jun.	Jul.	Ago.	Sep.	Oct.	Nov.	Dic.	Anual
T máx. abs. (°C)	31	31	32	31	30	28	30	26	26	26	27	31	32
T máx. media (°C)	26	26	26	24	22	20	19	18	19	20	22	24	22
Temp. media (°C)	23	23	23	21	20	18	17	17	17	18	20	21	20
T mín. media (°C)	20	20	20	18	17	16	15	15	15	16	17	18	17
T mín. abs. (°C)	16	17	16	13	12	11	10	10	10	10	8	10	8
Lluvias (mm)	1	1	0	0	1	2	3	3	3	2	2	0	16
D lluvia (≥ 1 mm)	4	2	3	2	5	11	12	15	13	7	5	3	82
Horas de sol	179.1	169	139.2	184	116.4	50.6	28.6	32.3	37.3	65.3	89	139.2	1284
Hum relativa (%)	85	80	80	85	85	85	85	85	85	85	85	85	84.2

The ASHRAE standard requires that in the climate zone type 2A in which Peru is located, SHGC values lower than 0.25 (25%) of the heat radiation from the sun.

Solar impact according to percentage of glaze: The lateral faces are semi-oriented towards the path of the sun, for this reason they must have greater solar protection. Fig. 4 shows the solar transit throughout the year.

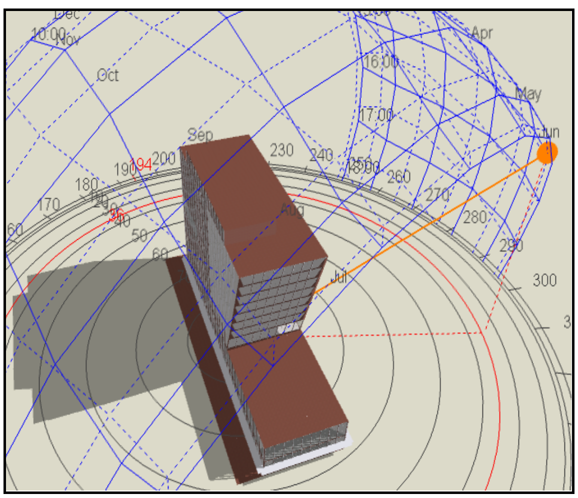

Fig. 4. Solar impact on the building project.

The percentage of glass is important for the design of air conditioning systems, in this case it is 94.5%, this value indicates the impact of glass selection. The roof material receives perpendicular radiation that generates a heat island. A reflectance greater than 0.30 is required.

Natural ventilation and natural lighting: You must take advantage of natural lighting, previously the light transmittance and consider heat rejection factors at the same time.

Two simulations were carried out modifying the variable of the SHGC value of the glass; the first with a percentage of the glazed area of 94.5% and considering a SHGC of 0.35 (commercial glass) and a U value of 3.97 W / m^2-K. The second with the SHGC value of 0.22 (glass recommended by ASHRAE) and a U value of 3.97W / m^2-K. A 30% saving in heat rejection was obtained, just by varying the SHGC values of the glass.

C. *Energy and automation*

system The HVAC system has been divided into 6 systems, taking into account the requirements of LEED and ASHRAE.

Monoxide extraction system: Frequency variators were chosen for the extraction, jet fan and injection equipment, taking into account the level of carbon monoxide.

Kitchen hood ventilation system: It was based on an air extraction and injection system for the kitchens.

Mechanical extraction system: It was placed in the organic garbage room, this affects the quality of the space and also in the design of the energy model.

Fresh air injection system: fresh air a monitoring system has been established to check the correct operation of the air injection equipment.

Air conditioning system: The efficiency value was increased and it was decided to use a COP of 5 for the final design. The efficiency of each VRV unit was taken.

Condensation water system: Closed cooling towers were considered to avoid placing a double pumping system due to the plate exchanger that separates the two water circuits and thus obtain energy savings. The use of secondary variable speed pumps was chosen.

D. *Electrical and lighting system*

It was proposed to measure the electrical consumption of the VRV condensing units, using an independent HVAC panel for the total consumption of the condensers.

For the lighting system, it was taken into account that the equipment does not exceed the power of 12 W / m^2 and 18 W / m^2 for the commercial premises on the first floor, which is an ASHRAE requirement for an office space and area Retail. To achieve an energy saving of 30% it can be restricted to 9W / m^2 in offices and 15 W / m^2 in commercial premises. An energy saving of 29% was calculated, see Table II.

TABLE II. ENERGY SAVINGS IN THE FINAL LIGHTING SYSTEM

	DISEÑO (PROPUESTO)	ASHRAE (BASE)
Iluminación AREAS COMUNES(GLOBAL ACCESS)	46047	81731.10
Iluminación AREAS LOCATARIOS	146840	190689.10
TOTAL	192887	272420.20
Ahorro de iluminación **considerando** contrato inquilinos	**29.20%**	

Another proposal is daylight sensors, to contribute to energy savings. This includes presence sensors for parking lots. This proposal allows a saving of up to 10% additional in the consumption of the comparative line for parking in basements.

E. Automation

The system is made up of autonomous controllers connected to the electrical system, capable of executing independent control from other controllers on the network. There is a record and control of system operations, considering the generator set, transformers, UPS's, capacitor banks and medium voltage cells.

The lighting system connects through the Bacnet IP protocol; In addition, it must be displayed on a screen and must deliver a report of hours of operation, consumption and demand of the lighting equipment.

An electrical metering system for the HVAC system and logging of loads in real time. In addition, differential pressure sensors interconnected with the BMS to communicate if the air injection equipment has a fault. Carbon dioxide sensors, to monitor the quality of oxygenation in densely occupied environments.

F. Modeling and simulation based

The following requirements were followed:

- The base and proposed modeling must use the same simulation program (DesignBuilder)
- The same climate data and same energy costs.

The Design Builder, which has an EnergyPlus as a calculation engine, was used [5]. With the following characteristics:

- Duration of the simulation is 8760 hours per year.
- Hours of operation for lighting, thermostats, and HVAC systems must be the same for the base and proposed modeling.
- Have 10 or more thermal zones. Consider efficiency curves at partial load.

The energy modeling is divided into three parts:

- The 3D survey of the project that involves materials of the envelope, glass and orientation.
- The allocation of schedules, activity ratios and lighting in each type of environment.
- Modeling of the air conditioning system and air renewal, for the base or proposal.

G. Activity allocation, schedules and lighting ratios

Considering the same schedules and types of activity as the actual or proposed building. The schedules and type of activity should be able to represent the variations in occupancy, lighting power, outlet loads, thermostat set point, and HVAC operating hours between different types of environments.

In Table III, if the operating power fraction ratios are added multiplying by the hours, it can be deduced that at 6 am the system operated at 25% of its power for 1 hour, then at 7 am it increased to 50% for an hour and so it was varying during the day, with which a global of 3 hours at full power per day is obtained. The lighting system was designed with a 29% overall energy saving.

TABLE III. POWER FRACTION AND HOURS OF THE EXTRACTION SYSTEM

Hourly Operation of Exhaust Fans					
Model : Proposed case					
Type: Fraction					
Mdnt-1 am	0 ratio	8-9 am	0.25 ratio	4-5 pm	0.25 ratio
1-2 am	0 ratio	9-10 am	0.1 ratio	5-6 pm	0.5 ratio
2-3 am	0 ratio	10-11 am	0.1 ratio	6-7 pm	0.25 ratio
3-4 am	0 ratio	11- noon	0.1 ratio	7-8 pm	0 ratio
4-5 am	0 ratio	noon-1 pm	0.25 ratio	8-9 pm	0 ratio
5-6 am	0 ratio	1-2 pm	0.25 ratio	9-10 pm	0 ratio
6-7 am	0.25 ratio	2-3 pm	0.1 ratio	10-11 pm	0 ratio
7-8 am	0.5 ratio	3-4 pm	0.1 ratio	11- Mdnt	0 ratio

The energy consumption *for each environment is calculated using the DesignBuilder*, as shown in Fig. 5.

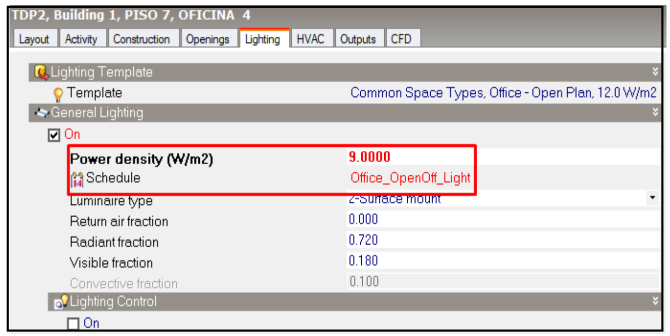

Fig. 5. Daylight sensors in the cafeteria.

In DesignBuilder, the pumping systems were simulated, Fig. 6.

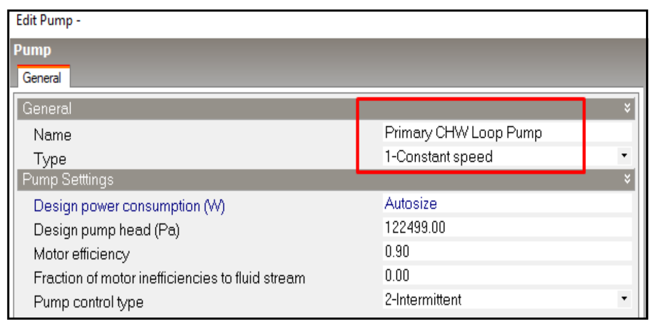

Fig. 6. Daylight sensors in the cafeteria.

Table IV shows part of the information considered for the VRV systems modeled in the proposed building.

TABLE IV. VRV CONDENSERS OF THE PROPOSED BUILDING

TABLA DE CAPACIDADES DE UNIDADES CONDENSADORAS VRV						
Cod.	Cap.	Mod.	Dem.Ele.	Peso	S.E.	COP
UC S1-01	191,100	MOD 1	11.20	420	380/60/3	5.73
UC S1-02	210,600	MOD 1	6.46	254	380/60/3	5.4
		MOD 2	5.09			
UC 1-01	745,300	MOD 1	11.20	560	380/60/3	5.44
		MOD 2	11.20			
		MOD 3	11.20			
		MOD 4	9.69			
UC M-01	210,600	MOD 1	6.46	254	380/60/3	5.73
		MOD 2	5.09			
UC M-02	248,500	MOD 1	7.84	254	380/60/3	5.49
		MOD 2	6.46			
UC M-03	172,000	MOD 1	9.69	420	380/60/3	5.6
UC 2-01	554,200	MOD 1	11.20	420	380/60/3	5.46
		MOD 2	11.20			

Where: Cod. = Code Cap. = Capacity (BTU / h)
Mod. = Modules Dem.Ele. = Electric Demand (kW)
Weight = Weight (Kg) SE = Electric Supply

III. RESULTS OF THE MODELING OF THE REAL BUILDING

For the proposed model, as well as the baseline, the results shown in Table V.

TABLE V. ANNUAL ENERGY CONSUMPTION FOR THE PROPOSED MODE

	Ele.[kWh]	NG	AF	DC	DH	W[m^3]
Heating	5630.12	0.00	0.00	0.00	0.00	0.00
Cooling	186634.99	0.00	0.00	0.00	0.00	0.00
Interior Lighting	632303.43	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	914768.42	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	175504.97	0.00	0.00	0.00	0.00	0.00
Fans	40168.83	0.00	0.00	0.00	0.00	0.00
Pumps	177981.85	0.00	0.00	0.00	0.00	0.00
Heat Rejection	1286.36	0.00	0.00	0.00	0.00	2426.41
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	2134278.96	0.00	0.00	0.00	0.00	2426.41

Where: Ele. = Electricity [kWh] NG = Natural gas [kWh]
AF = Additional fuel [kWh] DC = District Cooling [kWh]
DH = District Heating [kWh] W = Water [m^3]

The energy consumption of the demand throughout the year of the condensers of the VRV system is shown in Table VI.

TABLE VI. CAPACITIES OF VRV CONDENSERS IN THE MODELED REPORT FOR THE PROPOSED MODEL

Air conditioning: Variable Refreigerant Flow	F1	F2	F3	F4	F5	F6	F7
VRF OUTDOOR UNIT UC S1 - 01	12336.09	61720.00	61720.00	61720.00	7.04	263.30	0.002965
VRF OUTDOOR UNIT UC1 - 01 UCM - 02 03	165812.73	341660.00	341660.00	341660.00	38.95	1457.52	0.016416
VRF OUTDOOR UNIT UCM - 01	16378.49	61720.00	61720.00	61720.00	7.04	263.30	0.002965
VRF OUTDOOR UNIT UC2 - 02	111186.56	179242.00	179242.00	179242.00	20.43	764.65	0.008612
VRF OUTDOOR UNIT UC2 - 01	102766.44	162420.00	162420.00	162420.00	18.52	692.88	0.007804
VRF OUTDOOR UNIT UC10 - 01 02	170843.43	280029.00	280029.00	280029.00	31.92	1194.60	0.013455
VRF OUTDOOR UNIT UC9 - 01 02	145020.71	207259.00	207259.00	207259.00	23.63	884.17	0.009958

Where:
Air conditioning: Variable Refreigerant Flow
F1 = Design size Total nominal cooling capacity (gross) [W]
F2 = Total cooling Nominal User Specified Capacity (Gross) [W]
F3 = Design Size Total Heating Capacity Nominal [W]
F4 = Design Size Resistive Defrost Heater Capacity
F5 = Design Size Evaporative Condenser Air Flow Rate [m^3/ s]
F6 = Design size Nominal power of the evaporative condenser pump Consumption [W]
F7 = Water flow of the designated condenser [m^3/ s]

Table VII shows the energy consumption for different environments.

TABLE VII. EXTRACT OF THE ENERGY CONSUMPTION IN KWH FOR EACH TYPE OF ENVIRONMENT IN THE REPORT OF THE PROPOSED MODEL.

	Subcategory	Electricity [kWh]
Heating	General	5630.12
Cooling	General	186634.99
Interior Lighting	ELECTRIC EQUIPMENT#SOTANO1:CTOEXTRACC#GeneralLights	10.29
	ELECTRIC EQUIPMENT#SOTANO1:CTOPRESURI1#GeneralLights	5.97
	ELECTRIC EQUIPMENT#SOTANO1:SSHHEMPLEADOSH#GeneralLights	490.50
	ELECTRIC EQUIPMENT#SOTANO1:CORREDOREMPLEADOS#GeneralLights	209.17
	ELECTRIC EQUIPMENT#SOTANO1:COMEDOREMPLEADOS#GeneralLights	381.63
	ELECTRIC EQUIPMENT#SOTANO1:ESTACIONAMIENTO#GeneralLights	12927.84
	ELECTRIC EQUIPMENT#SOTANO1:DEP1#GeneralLights	325.96
	ELECTRIC EQUIPMENT#SOTANO1:CTOPRESURI#GeneralLights	6.29
	ELECTRIC EQUIPMENT#SOTANO1:DEP2#GeneralLights	3275.56
	ELECTRIC EQUIPMENT#SOTANO1:BOTADERO1#GeneralLights	95.40
	ELECTRIC EQUIPMENT#SOTANO1:SSHHEMPLEADOSM#GeneralLights	311.34

The maximum power consumed per year can be broken down for each type of system as shown in Table VIII.

TABLE VIII. MAXIMUM DEMAND OF THE PROPOSED MODELING

	Elec. [W]	NG [W]	P [W]	DC [W]	S [W]	W [m^3/s]
Heating	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	183866.78	0.00	0.00	0.00	0.00	0.00
Interior Lighting	205694.01	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	244147.95	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	228522.10	0.00	0.00	0.00	0.00	0.00
Fans	13947.17	0.00	0.00	0.00	0.00	0.00
Pumps	87662.50	0.00	0.00	0.00	0.00	0.00
Heat Rejection	1145.32	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	964985.85	0.00	0.00	0.00	0.00	0.00

Where:

Elec. [W] = Electricity [W] NG [W] = Natural gas [W]
P [W] = Propane [W] DC [W] = District cooling [W]
S [W] = Steam [W] W [m^3/ s] = Water [m^3/ s]

The maximum demand is practically 964 kW, with this information on the power consumed on the day of greatest demand, the number of minimum hours of operation for each can be estimated *subsystem*. From Table VIII can be highlighted:

- Annual hours of operation in *Interior Lighting*, since they are practically on for half a day.
- Annual hours of operation in *Interior Equipment*, hours in which computers and equipment.
- Annual hours of operation at *Exterior Equipment*, considering operation with frequency inverters.
- Annual operating hours in *Fans*, which represent the operating time of VRV indoor units.
- Annual Operating Hours at *Pumps*, which are the operating hours of all primary condensing pumps.
- Annual hours of operation *heat rejection* of two-speed cooling tower fans.

Table IX shows the hours of non-compliance with the thermal comfort range, which should be less than 300 hours per year in order to consider a correct air conditioning design in the proposed mode.

TABLE IX. NUMBER OF HOURS THAT THE THERMAL COMFORT OF THE SET POINTS IS NOT REACHED IN COOLING AND HEATING MODE

	Data
Number of hours heating loads not met	0.00
Number of hours cooling loads not met	10.000000
Number of hours not met	10.000000

As in the baseline modeling, it is only outside the set point established in 10 hours per year, which guarantees correct thermal comfort in the project.

IV. DISCUSSION OF RESULTS

Fig. 7 shows the energy expenditure of the source that provides the energy for both the baseline and the proposed mode.

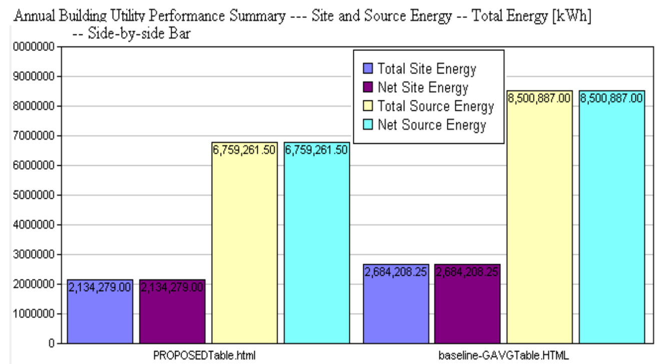

Fig. 7. Graph of on-site energy and energy source for baseline and proposed consumption.

Fig. 8 shows the amount of conditioned area of the project and the unconditioned area.

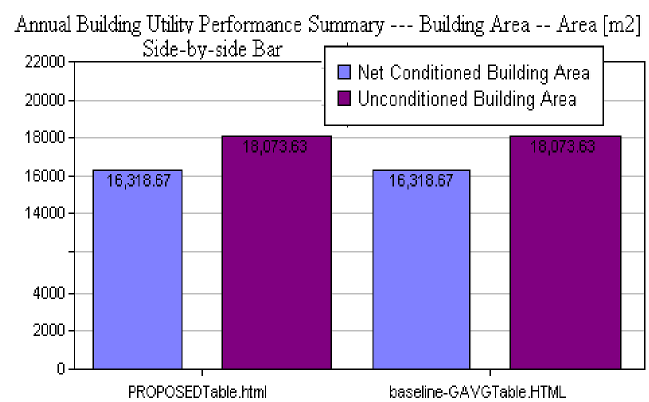

Fig. 8. Amount of conditioned area and unconditioned area of the project.

Amount of annual energy consumption for each type of system for the baseline and proposed model, Fig. 9.

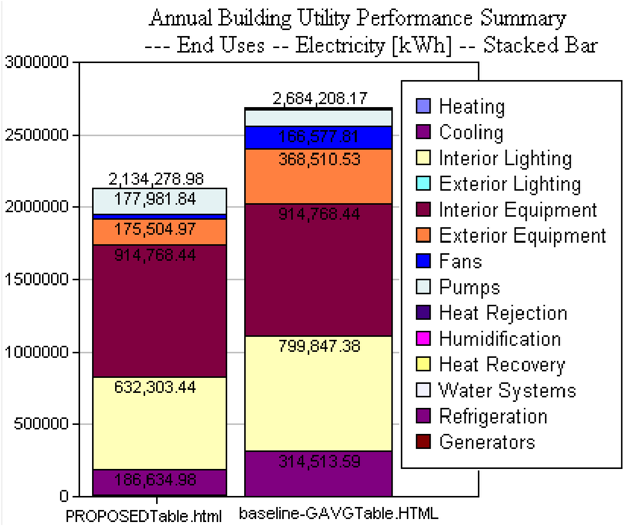

Fig. 9. Energy consumption of the main final use of the project.

It is observed that the project consumes the highest amount of energy in the system corresponding to *the Interior Equipment*, which corresponds to the outlets and is the same in the baseline and proposed. The second major consumption is for *interior lighting,* which represents interior lighting, which is very efficient in the proposed model and allows significant consumption to be saved. The third important consumption is the *outdoor equipment*, the consumption of the *basement fans* and in which significant energy consumption is saved due to the use *of frequency inverters*.

Another useful graph to estimate consumption in future projects of similar application would be the energy consumption per m^2, which indicates the estimated consumption per unit area of a project made up of offices as shown in Fig. 10.

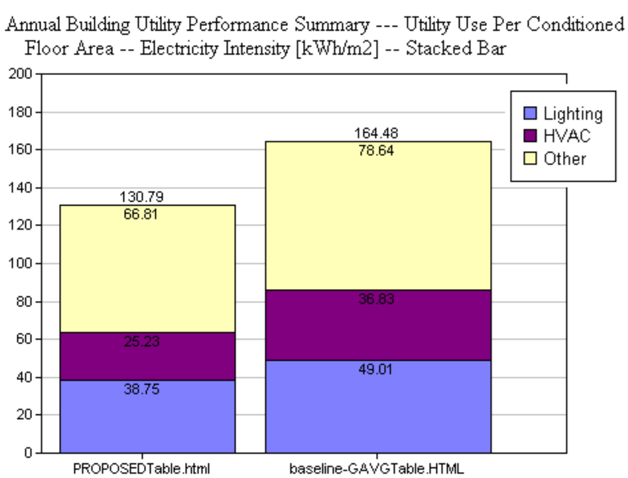

Fig. 10. Annual energy consumption by project area unit.

In addition to obtaining information on energy consumption, information on the maximum demand was also obtained and the comparison of the maximum demands of the baseline and proposed could be detailed as shown in Fig. 11.

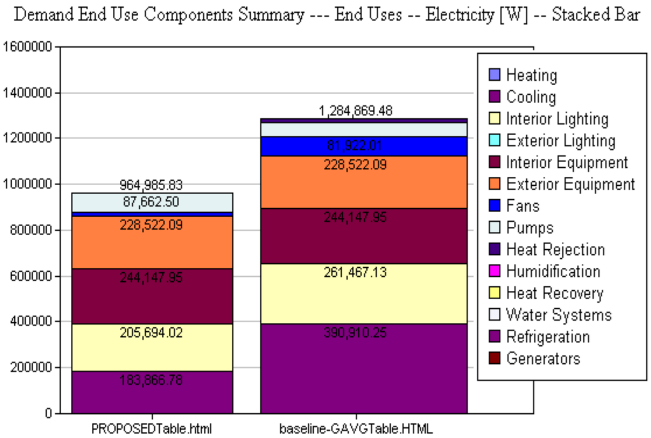

Fig. 11. Maximum power demand of the baseline and proposed.

The maximum demand difference of both can be observed, *baseline modeling* approximately *1,284 kW* unlike the *models proposed model 964 kW*. Considerable energy savings can be deducted. The results obtained in consumption are shown in Table X.

TABLE X. BASELINE ENERGY CONSUMPTION AND PROPOSAL

	Edificio Linea Base		Edificio Propuesto
Heating	0	Heating	5,630.12
Cooling	314,513.6	Cooling	186,634.99
Interior Lighting	799,847.35	Interior Lighting	632,303.43
Interior Equipment	914,768.42	Interior Equipment	914,768.42
Exterior Lighting	0	Exterior Lighting	0
Exterior Equipment	368,510.54	Exterior Equipment	175,504.97
Fans	166,577.81	Fans	40,168.83
Pumps	114,471.66	Pumps	177,981.85
Heat Rejection	5,518.76	Heat Rejection	1,286.36
Total End Uses	2,684,208.25	Total End Uses	2,134,279

It is observed, a saving of 20.48% complies with the LEED certification in the EA category for New Constructions, and also achieves 7 EAc2 credit points: Optimize energy performance as estimated to be achieved so that the project can qualify for LEED Gold certification. with a high score in energy performance as can be seen in Table XI.

TABLE XI. CREDIT SCORE OPTIMIZATION OF ENERGY PERFORMANCE OF THE LEED CERTIFICATION [6]

New Buildings	Existing Building Renovations	Points
12%	8%	1
20%	16%	5
22%	18%	6
38%	34%	14

CONCLUSIONS

1) A review was sent for the LEED Gold v3 Core & Shell certification with 63 points of which 5 points correspond to the energy simulation and 5 more points correspond to the intake decisions that are implemented in each energy system.
2) Tangible energy savings were achieved above the 10% minimum required for LEED v3 Core & Shell certification.
3) The use of the VRV air conditioning system (approximate COP of 5) which on average is much more efficient than the simulated chillers for the baseline (COP (Full Load) = 4.9 and IPLV = 5.6) and the use of frequency inverters in Basement fans greatly reduce energy consumption.
4) The thermal comfort of the project was achieved, evidenced in the energy simulation, which requires that 300 hours per year not be exceeded outside of the estimated temperature set points.
5) The bioclimatic study was carried out in which the impact of the environment on the project could be observed by evaluating its envelope (97% of glazed area, SHGC <0.25) and its orientation with respect to the sun and how it affects the calculation of air conditioning consumption.

RECOMMENDATIONS

1) Further energy optimization strategies can be considered to increase the score required for LEED certification, such as installing solar panels and contributing a significant percentage of at least 5% of project demand.
2) Increase the IEER value up to 9 in the VRV condensers, since increasing the efficiency at partial loads is of great impact because the project usually works at partial loads most of the year.
3) Consider frequency inverters for all the pumps of the condensation system and the fans of the increment towers to increase the overall savings.
4) Placement of the lattices to be able to help reject the impact of the sun around the project envelope.

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