Building Energy Performance Simulation in Phuentsholing Area using Energy Plus - A Case Study of Residential Building at College of Science and Technology (CST)

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Abstract: ***Energy consumption in residential building is considered to be one of the biggest areas which consume maximum energy which is a major concern currently due to unparalleled demand. Thus, this report analyses the energy performance of one of the residential buildings at CST. The study was performed on both the existing and proposed buildings, and a comparative analysis was done to accomplish the project's objectives of proposing thermal comfort for the occupants and studying overall energy usage. The analysis of the entire building was demonstrated using the EnergyPlus software applications. Likewise, the blower door test study result pointed that the building was partially exposed to the wind. Thus, by sealing the gaps, the infiltration was reduced. Furthermore, simulation of the real-time building found its energy use to be around 184,580 MJ which, by implementing the energy conservation measures such as shading and double-glazed windows with low SHGC, energy usage was reduced.***

Keywords: Building Energy Performance, Residential Building, EnergyPlus, Simulation

1. Introduction

Nowadays, environmental and energy problems are a major concern. Therefore, people have no choice but to diminish energy consumption. It is vital to know the meteorological contrasts that influence weather visibility, indoor and outside temperature, and building cooling/heating load patterns.

Addressing the airtightness of building envelope, energy consumption patterns, building retrofitting, ceiling and roof insulation, and improved ventilation system are some of the key factors to achieve thermal comfort, good ventilation system, and minimize energy usage.

Therefore, various energy simulation software was built to enhance the performance of building and achieve zero net building. Learning various software such as EnergyPlus, OpenStudio, TRNSYS, Radiance, and DIALux can help one to increase the buildings' energy efficiency. The usage of software helps in determining and investigating energy usage and load patterns, as well as designing and proposing a new energy-efficient house. Furthermore, basic procedures such as light bulb replacement (LED over incandescent), energy auditing, and light switch ON/OFF can help to increase energy conservation.

This study primarily presents the building energy performance simulation of the residential buildings at the College of Science and Technology located in Phuentsholing. The project incorporates the study of the use of EnergyPlus and OpenStudiosoftware. It encourages future researchers and designers to enhance the knowledge of energy-efficient buildings and urge people to use the various energy simulation software.

2. Literature Review

It is vital to comprehend the baseline concept of energy efficiency, building envelopes, properties of thermal performance, energy conservation measures, various tests and methods to model and simulate the building in EnergyPlus software for conducting a case study on building energy performance simulation.

A building retrofitted with low thermal performance and high energy demand for heating is a dynamic process. Using the transient simulation software and measured data, a residential apartment in Thimphu, Bhutan was simulated and it was observed that attic insulation is the first and most effective way for retrofitting a poorly performing structure. Also, the simulation resulted in the reduction of heating load demand by 64% when the attics and walls were insulated. When it comes to implementing such measures in place, the type of insulation, the thickness of the insulation, the insulation method, and the investment must all be taken into account. As a result, when such methods of thermal insulation are applied, the building's thermal comfort is improved. [4].

3. Methodology

A thorough literature review was done to figure out the parameter requirements necessary for this project. Basic data of the buildings were either measured or identified through research. A survey form was circulated to a family member of each unit to obtain information regarding the occupants, their schedules, and the various electrical loads used in each flat which could directly or indirectly affect the outcomes of this project. The building was then modelled in EnergyPlus software to perform the thermal simulation.

4. Model Building

The case study was done on a residential building, the staff quarterlocated at College of Science and Technology (CST), Phuentsholing. The region was particularly selected as it is under the subtropical zone. The three-storied building shown in figure 1 is situated at 26.84977°N and 89.39657°E at approximately 420 m above sea level. With a floor-to-floor height of 3 m, the building consists of four units per storey totalling twelve units with a floor area of 79.71 m^2 of each unit.

Figure 1: View of the Building

4.1 Building Envelope

The building has no air conditioning system pre-installed however, two tenants have an air conditioning system installed that is rarely used. Natural ventilation along with ceiling fans is used to keep the building cool. The building's lighting system is primarily comprised of standard 40W fluorescent lamps, 9W LEDs,and 100W incandescent lamps.

Figure 2 represents the thermal zones of one flat of the building considered in this case study. The zones include Living Room (LR), Kitchen (K), Common Toilet (CT), Master Toilet (MT), Master Bedroom (MB), and Bedroom (CB).

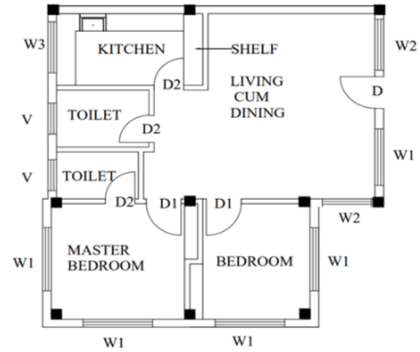

Figure 2: Zones in a Flat of the Building

Table 1: Building Envelope Properties

Walls	Layers	Heat Cond. (W/mK)	Sp. Heat Cap. (J/kgK)	Density (kg/m^3)	Thickness (mm)
Floor	Cement Mortar	0.58	840	2100	2
	RCC	0.19	837	580	100
	Cement Plaster	0.72	800	1860	20
Ceiling	Plywood	0.15	2500	560	3
Exterior wall	Cement Mortar	0.58	840	2100	2
	Red Bricks	0.65	920	1760	110
	Cement Mortar	0.58	840	2100	2
Interior wall	Cement Mortar	0.58	840	2100	2
	Red Bricks	0.65	920	1760	110
	Cement Mortar	0.58	840	2100	2
Roof	Corrugated Iron	0.75	810	1400	0.8

4.2 Building Energy Consumption

At the case study location, summertime sees a rise in the use of electric power as the constant use of ceiling fans or air conditioners (in few households) for cooling increases energy consumption throughout the season. During the winter, energy consumption is lower since extensive heating or cooling is not needed as the temperature remains moderate. The average energy consumed per annum of each household in the building is shown in figure 3 with the flat 11 consuming the highest energy and flat 1 consuming the lowest.

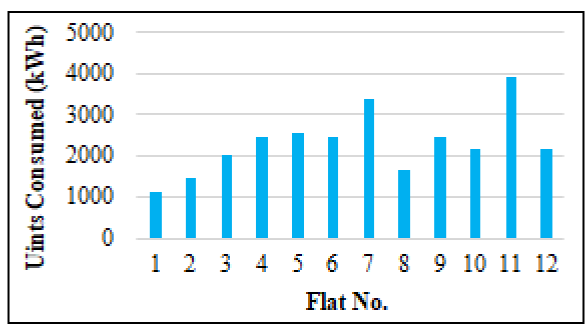

Figure 3: Average Energy Consumed per Flat

5. Thermal Performance

The thermal performance of a building is a means to find the ezfficiency of a building. It ensures the proper thermal level of a building. Further, it provides thermal comfort to the occupants.

Building Energy Modelling (BEM) is mainly carried out using the software EnergyPlus platform to analyse the building energy performance. It also gives the thermal performance of a building. Physical parameters of the building are counted in the software for modelling. Then the simulation is done to obtain the outputs.

5.1 Parameters for BEM

- Weather files
- Building geometry
- Constructional materials
- Occupancy and electrical equipment schedule
- Assignment of thermal zones

5.2 Factor affecting the Thermal Performance of a Building

a) Behaviour of the Occupants

The behaviour of the occupants would also affect the thermal performance of the building. If there are many occupants in a building, it is obvious that the energy generated would be also more than the building with fewer occupants. Even the personal characteristics of occupants would determine the thermal performance of a building. Some of the relevant variables among the personal characteristics are sex, physical nature, weight, education level, length of stay in the house, physical activity, time of last meal, and level of sweating[2].

b) Location of Building

The building station in different climate zones would have different thermal characteristics. For instance, a building in a cold place would require more thermal insulation than a building in a hot and humid place to regulate the thermal performance of a building. Moreover, the surrounding of the building will also affect the thermal performance.

c) Indoor Temperature

For the load calculation of the building, the indoor temperature is essential. In summer if the indoor temperature is low, then the cooling equipment required would reduce. Conversely, in winter if the indoor temperature is high, then the heating load would reduce. It is prominent to understand how indoor temperature has an impact on the energy efficiency of a building. Proper regulation of temperature would assist in eliminating waste energy, improve thermal comfort and ultimately achieve energy conservation.Figure 4 shows the indoor and outdoor temperature of the case study building for August month which experienced a major heat wave globally.

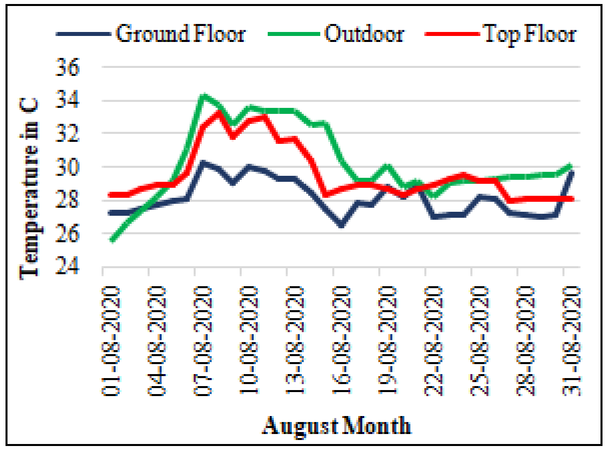

Figure 4: Indoor and Outdoor Temperature

d) Building Design

Some of the factors on which the building design depends are density, layout and height of the building, and climatic condition. The larger size of the building would cast an enlarged shadow and reduce the incident solar rays which would decrease the temperature. But huge building density would affect the ventilation of the area and prolong the cooling of the heat, which would augment the temperature and decreases human comfort [8].

6. Result and Discussions

Modelling and simulation for the existing building were performed in the software. Various ECMs such as shading, daylighting controls, window glazing with low SHGC, ceiling, and roof insulation, and outdoor air ventilationwere incorporated into the existing buildings. This was done mainly to conserve the energy consumption by residential buildings.These ECMs were retrofitted to the existing building and simulated.

a) Blower Door Test Results

Table 2represents the building information along with the test information. Some of the test information are building envelope volume and area, building height from ground to top, exposure of building to wind, and accuracy of measurement.

Table 2: Building and Test Information

Test File Name	EN13829-2021-02122 1348
Building Envelope (m^3)	240
Envelope Area (m^2)	137.3
Floor Area (m^2)	32
Building Height from Ground to Top (m)	9.5
Building Exposed to Wind	Partially Protected Building
Accuracy of Measurements	10 %

Table 3 shows the results of the blower door test. It shows the airtightness of the building. Air changes per hour at 50 Pa of the flat is $\frac{756.15}{240}$ = 3.15ACH50

Table 3: Blower Door Test Result

Airflow at 50 Pa, [m^3/h]	756.15
Air Changes at 50 Pa, [h]	3.15
Flow per envelope area at 50 Pa, [m^3/ h/ m^2]	5.506
Flow per floor area at 50 Pa, [m^3/ h/ m^2]	23.644
Effective leakage area at 50 Pa, [cm^2]	230.5
Equivalent leakage area at 50 Pa, [cm^2]	378.0
Leakage per envelope area at 50 Pa, [cm^2/cm^2]	1.6782
Leakage per floor area at 50 Pa, cm^2/cm^2]	7.21

b) Building Energy Consumption

Tables4 and 5 explain the total site energy and source energy used by the existing and proposed design of the residential building. Site energy is defined as the energy that is consumed by electrical equipment and lighting which are reflected in utility bills. It is a comprehensive means to measure a building's energy consumption in a given period. The main limitation is that site energy does not account for energy loss. The energy would be lost during generation, transmission, and generation. Whereas source energy is the total raw energy that is used or required for the operation of the residential building. It includes all energy consumed by the building such as fuel or natural gas consumption and electrical energy purchased from the distribution company.

Table 4: Energy Consumption of the Existing Building

	Total Energy (MJ)	*Energy Per Total Building Area (kJ/ m^2)*	*Energy per Unconditioned Building Area (kJ/m^2)*
Total Site Energy	184,580	169,740	169,740
Total Source Energy	342,330	314,810	314,810

Table 5: Energy Consumption of the Proposed Building

	Total Energy (MJ)	Energy Per Total Building Area (kJ/ m^2)	Energy per Unconditioned Building Area (kJ/m^2)
Total Site Energy	134,380	123,580	123,580
Total Source Energy	312,200	306,250	306,250

c) Electricity Consumption

Graphs5 and 6show the electricity consumption by interior lighting and equipment for the existing and proposed design. From the graphs, it is evident that interior equipment consumes more energy than interior lighting.The electricity consumption of interior equipment is maximum in summer. This includes June, July, and August.The energy consumption by interior lighting and interior equipment has been reduced in the proposed design. This is because of the incorporation of ECMs. The use of daylighting controls, installing transparent sheets in areas that are frequently visited, and turning off light could greatly contribute to conserving energy.

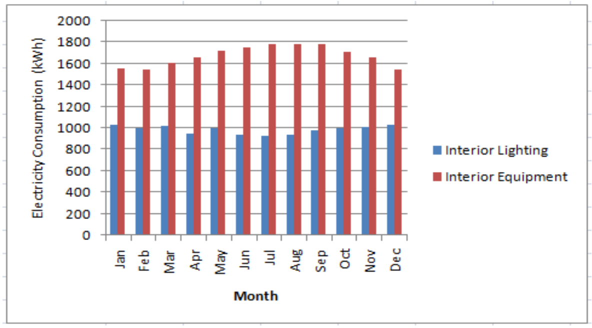

Figure 5: Electricity Consumption of Existing Building

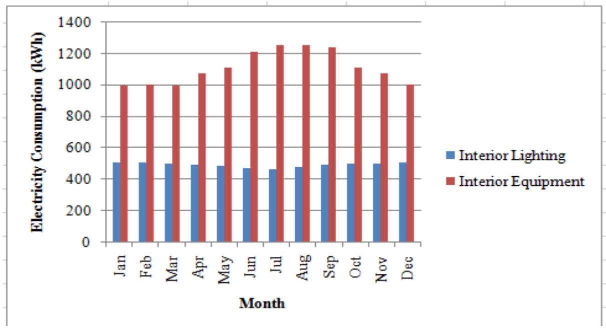

Figure 6: Electricity Consumption of Proposed Building

d) Cooling and Heating Loads

Since the building lies in the sub-tropical zone of the country, the cooling loads are comparatively higher than the heating loads. Some of the cooling loads include air-conditioning and fans. Similarly, heating loads include heater, boiler, geyser, etc.

Graphs7 and 8represent the energy usage by cooling loads throughout the year by the residential building and the proposed building. The energy consumption is more in the monsoon season.The highest energy consumption is observed in August in both cases.

Graphs 9 and 10 represent the total heating loads consumedin a year by the whole building and the proposed design.In the sub-tropical climatic zone, heating equipment is used mostly in winter. The energy consumption is also more during these winter months.Compared to the cooling load, the energy consumed by the heating load is much less.

From the graphs, it is found that the energy consumption by both the cooling and heating loads is reduced due to the implementation of ECMs.

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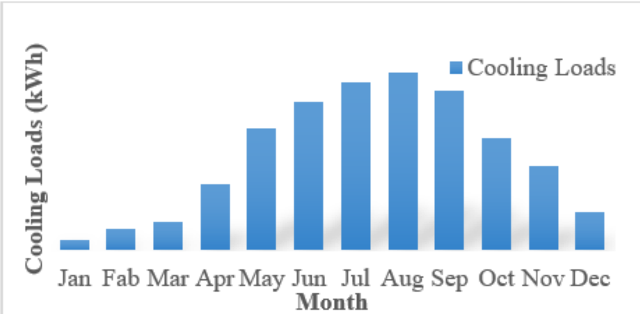

Figure 7: Cooling Load Demand – Existing

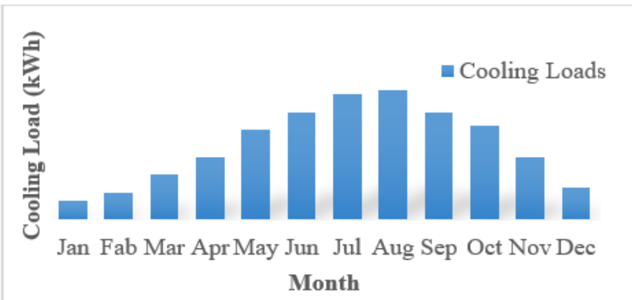

Figure 8: Cooling Load Demand – Proposed

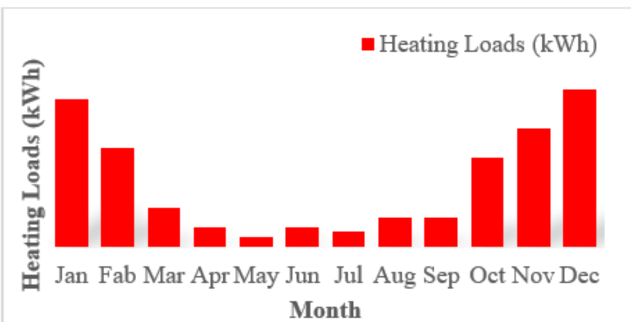

Figure 9: Heating Load Demand– Existing

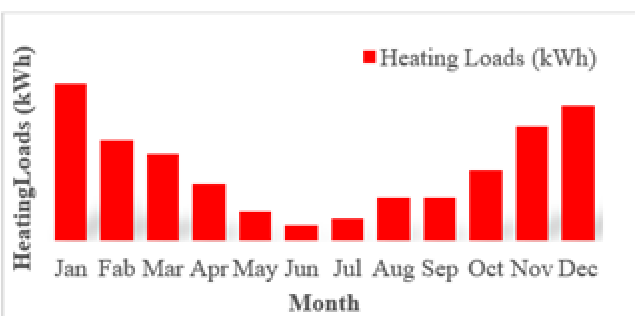

Figure 10: Heating Load Demand– Proposed

Graphs11 and 12 is the comparison between the cooling and heating loads. It is graphically displayed along with the outdoor temperature. This is in view of the fact that the outdoor temperature would also affect the energy consumption pattern.

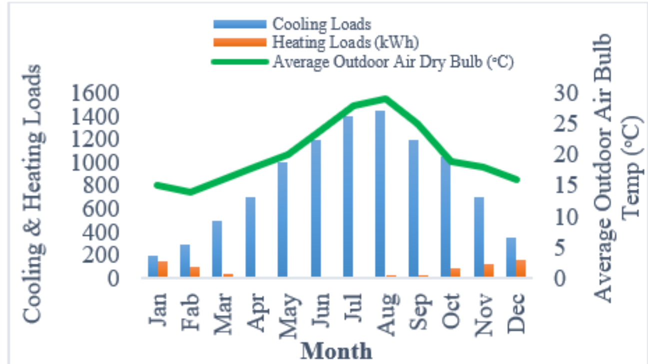

Figure 11: Cooling and Heating Loads with Average Outdoor Temperature – Existing

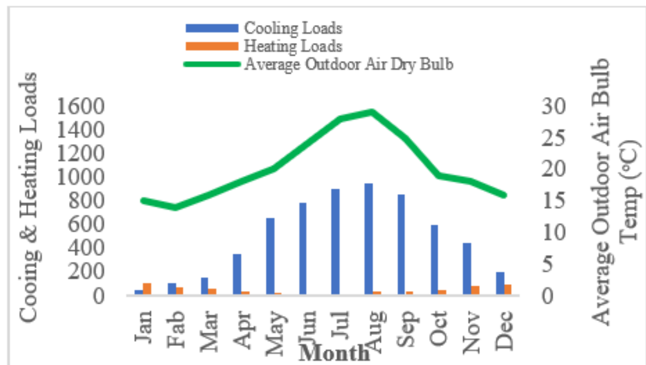

Figure 12: Cooling and Heating Loads with Average Outdoor Temperature – Proposed

e) Infiltration Rate

Infiltration is the unwanted air entered from the open spaces of the building. If the building surfaces have too many cracks and leaked areas from the windows and doors, the building would have a high infiltration rate. Conversely, building without leakages would have a low infiltration rate. The infiltration rate is detrimental to the thermal performance of the building. A blower door test is usually performed to determine the infiltration rate. It is measured in ACH.

Figures13 and 14 graphically represent the results for infiltration of the existing and the proposed building respectively. Comparing to the existing building, the infiltration rate is lower in the proposed building.

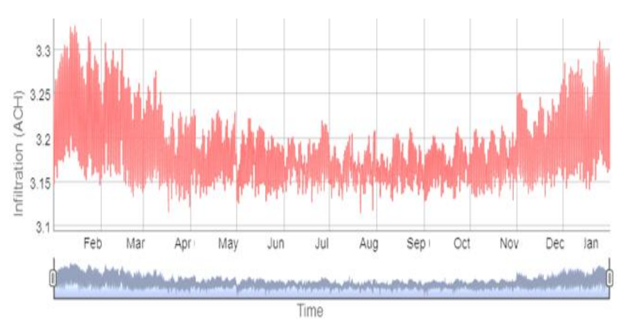

Figure 13: Infiltration Result Graph of the Existing Building

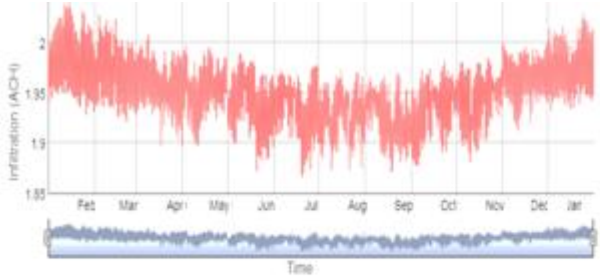

Figure 14: Infiltration Result Graph of the Proposed Building

7. Conclusion

Building energy performance simulation is a good way to assess a building's energy efficiency. It is critical and has become a serious concern to implement specific energy-saving measures to reduce energy usage. This study was conducted to enhance the energy performance of a residential building in the Phuentsholing area. Comparative analysis was done on both the existing and proposed building designsto fulfill the project's goals.

All the necessary information is gathered from the real-time building to analyse the building's performance under various scenarios into the energy simulation tools EnergyPlus.

The analysis of the infiltration result (through blower door test) showed that the flat was partially exposed to the wind, and the infiltration result was determined to be 3.15 ACH. By sealing the gaps, the flat's ACH was reduced. Also, the real-time building's energy use was observed to be higher, at roughly 184,580 MJ. The energy demand is reduced by integrating ECMs, which resulted in less than 134,380 MJ energy use.

In general, the study found that using EnergyPlussoftware, as well as integrating various energy conservation measures is critical for analyzing the residential building's energy performance.

References

[1] ‘ECBC Envelope for Warm & Humid Climate’.
[2] A. O. Adunola and K. Ajibola, ‘Factors Significant to Thermal Comfort Within Residential Neighborhoods of Ibadan Metropolis and Preferences in Adult Residents’ Use of Spaces’, *SAGE Open*, vol. 6, no. 1, 2016, doi: 10.1177/2158244015624949.
[3] N. Brown, M. S. Ubbelohde, G. Loisos, and S. Philip, ‘Quick design analysis for improving building energy performances’, *Energy Procedia*, vol. 57, pp. 1868–1877, 2014, doi: 10.1016/j.egypro.2014.10.051.
[4] T. Lhendup and T. Powdel, ‘Analysis of Thermal Performance Improvement of Residential Building: A Case Study in an Urban Bhutan’, *J. Educ. Pract.*, pp. 1–11, 2020, doi: 10.7176/jep/11-27-14.
[5] Z. O’Neill, X. Pang, M. Shashanka, P. Haves, and T. Bailey, ‘Model-based real-time whole building energy performance monitoring and diagnostics’, *J. Build. Perform. Simul.*, vol. 7, no. 2, pp. 83–99, 2014, doi: 10.1080/19401493.2013.777118.
[6] M. M. Saad, ‘Designing with Daylight in Residential Buildings A Case Study in New Cairo’, *Proc. SBE 2016, Sustain. Built Environ. Conf. Cairo, Egypt*, November 2016.
[7] P. Shiel, S. Tarantino, and M. Fischer, ‘Parametric analysis of design stage building energy performance simulation models’, *Energy Build.*, vol. 172, pp. 78–93, 2018, doi: 10.1016/j.enbuild.2018.04.045.
[8] Y. Yang *et al.*, ‘Effects of building design elements on residential thermal environment’, *Sustain.*, vol. 10, no. 1, pp. 1–15, 2017, doi: 10.3390/su10010057.