Building Energy Performance Simulation in Phuentsholing Area using EnergyPlus – 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 and visual comfort for the occupants and studying overall energy usage. The analysis of the entire building was demonstrated using the DIALux and EnergyPlus software applications. The DIALux simulation results after intervention show that individual rooms have sufficient light according to the standard illuminance. It also exhibited that the energy consumption per annum values was lower than the imperative ranges. 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. Daylighting is one essential factor towards more sustainable and energy-efficient buildings. Good daylighting or well distribution of natural light improves visual comfort and helps in reducing the need for an artificial lighting system. However, it is vital to know the meteorological contrasts that influence weather visibility, indoor and outside temperature, and building cooling/heating load patterns.

Similarly, 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, OpenStudio, and DIALux software. 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. OBJECTIVES

- To explore the actual daylighting challenges and scenarios that are necessary to make the value proposition for daylighting.
- To model suitable illuminance levels in the residential building using DIALux and to calculate illumination with the lumen method.

- To produce a proposal of improved thermal performance which satisfies the thermal and visual comfort of the occupants of a residential building.
- To investigate the total electricity consumption of the residential building and the minimum requirements stipulated in the code of practice (Bhutan Green Building Design Guidelines) for energy efficiency.

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 software linked with OpenStudio or EnergyPlus to perform the thermal simulation and to check the visual performance, the building was modelled in DIALux software.

4. MODEL BUILDING

The case study was done on a residential building, the staff quarter Block – B, located 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.

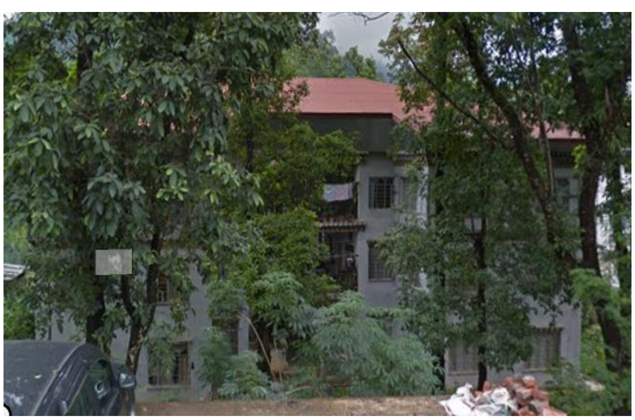

***Figure 1**: View of the Building*

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 40-watt fluorescent lamps, 9-watt LEDs, and 100-watt 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).

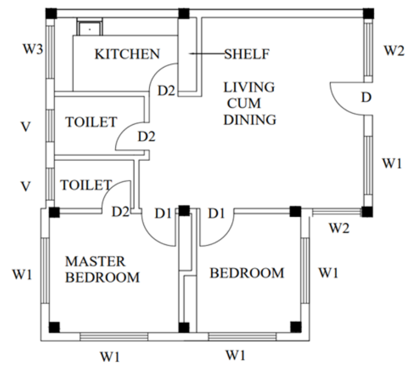

***Figure 2**: Zones in a Flat of the Building*

***Table 1**: Building Envelope Properties*

Walls	**Layers**	**Heat Cond. (W/m K)**	**Sp. Heat Cap. (J/kg K)**	**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 season, 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 no. 11 consuming the highest energy and flat 1 being the lowest.

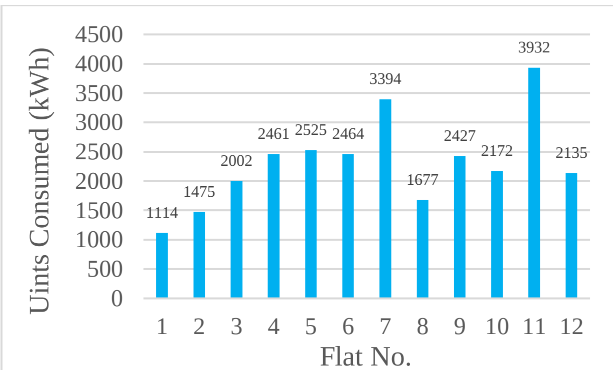

***Figure 3**: Average Energy Consumed per Flat*

5. VISUAL PERFORMANCE

Lighting strategies that are effective and efficient, including natural daylighting, can provide adequate illumination while lowering costs and also, energy consumption keeping in mind that poor lighting can cause a variety of issues, including eye strain. Lighting loads are the energy used to power the house. Lighting fixtures already installed in the building include the incandescent bulb, LED bulb, and compact fluorescent tube of different ratings used for the certain time duration provided in the survey form.

5.1 Results and Discussions

a. Existing Fixtures

The manual calculation of the lighting design using the lumen method which provides an idea about the approximate calculation for the planning of interior lighting systems was considered for the arrangement of lightings for simulation in the DIALux software. Upon simulation, the following was observed:

1. It is noticeable from figure 4 that the illumination level is not uniformly achieved on the floor. Maximum illumination is achieved in the first isoline (small circle) and the illumination strength gradually decreases as it moves away towards the corner. This indicates that the corners of the room will be dully lit whereas, the centres will be brightly lit.
2. From table 2, it can be seen that although the consumption value is within the range of the target value, the simulated value of illumination is less than the target value which indicates that the required illumination is not achieved in any room.

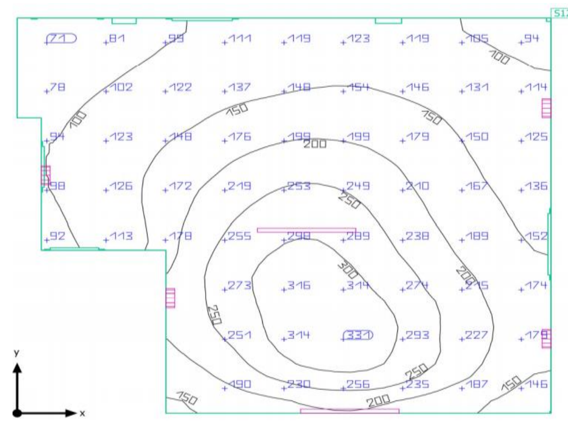

***Figure 4:** Isolines of the Living Room – Existing*

***Table 2:** Overall Simulated Result of One Flat in Ground Floor*

Sl. No.	Room	Illuminance			Consumption Values			Lighting Power Density
		Calculated (lx)	Target (lx)	Check	Calculated (kwh/a)	Target (kwh/a)	Check	Calculated (W/m²)
1	Living Room	182	≥ 300	⊗	950-1100	Max. 1200	✓	16.72
2	Kitchen	185	≥ 300	⊗	540-710	Max. 350	⊗	19.22
3	Master Bedroom	130	≥ 200	⊗	150-240	Max. 550	✓	12.49
4	Bedroom	147	≥ 200	⊗	150-240	Max. 450	✓	15.36
5	Master Toilet	57.3	≥ 150	⊗	120-190	Max. 150	⊗	28.61
6	Common Toilet	50.9	≥ 150	⊗	120-190	Max. 200	✓	20.96
7	Stairway	48.4	≥ 100	⊗	990	Max. 2600	✓	12.23

Hence, it can be concluded that the simulated value of lux is not as per the standard values as mentioned in the Electrical Engineering data book of Bhutan.

b. Proposed Fixtures

Since the calculation of illumination is not as per the standard undertaken for an existing residential building, there is a need to retrofit it to achieve the required standards. Therefore, a recommendation for lighting fixtures is proposed based on the manual calculation done using the lumen method with the luminaires selected to maintain the illumination level of each room in the building.

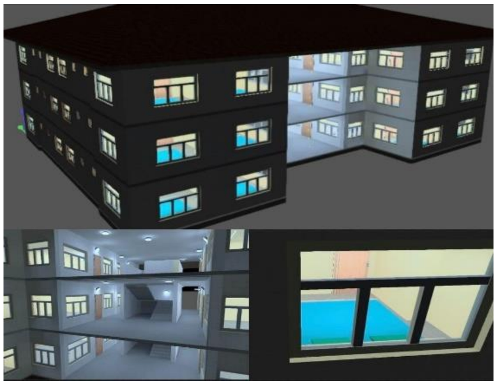

Figure 5: *View of the Building after Simulation*

Here, the illumination is distributed almost equally on the floor and the calculated illuminance is as per the target value. Figure 6 present the isoline results of the living room on the ground floor to show the required lux levels in the illuminated space

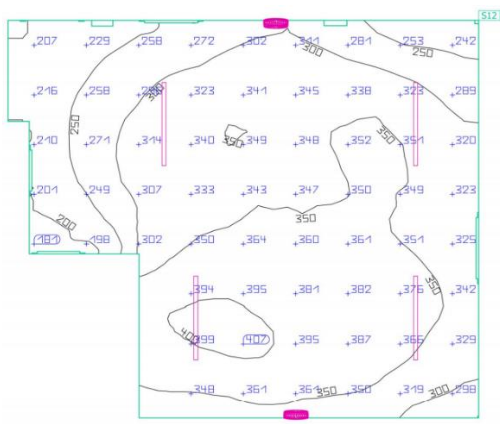

Figure 6*: Isolines of the Living Room - Proposed*

Table 3*: Illuminance Level and Energy Consumption Values of Proposed Fixtures*

Sl. No.	Room	Illuminance			Consumption Values			Lighting Power Density
		Calculated (lx)	Target (lx)	Check	Calculated (kWh/a)	Target (kWh/a)	Check	Calculated (W/m^2)
1.	Living Room	324	≥ 300	✓	580 – 690	Max. 1250	✓	10.59
2.	Kitchen	315	≥ 300	✓	200 – 270	Max. 350	✓	12.9
3.	Master Bedroom	245	≥ 200	✓	140 – 240	Max. 450	✓	12.25
4.	Bedroom	253	≥ 200	✓	140 – 240	Max. 450	✓	15.07
5.	Master Toilet	181	≥ 150	✓	53 – 85	Max. 150	✓	12.59
6.	Common Toilet	151	≥ 150	✓	53 – 85	Max. 200	✓	9.22
7.	Stairway	110	≥ 100	✓	1500	Max. 2600	✓	18.27

After simulation, the results for illuminance and energy consumptions were achieved as shown in table 3 that is, the results obtained were as per the standard values.

6. THERMAL PERFORMANCE

The thermal performance of a building is a means to find the efficiency 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.

6.1 Parameters for BEM

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

6.2 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 gender, physical nature, weight, education level, length of stay in the house, physical activity, time of last meal, and level of sweating (Adunola & Ajibola, 2016).

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 7 shows the indoor and outdoor temperature of the case study building for August month.

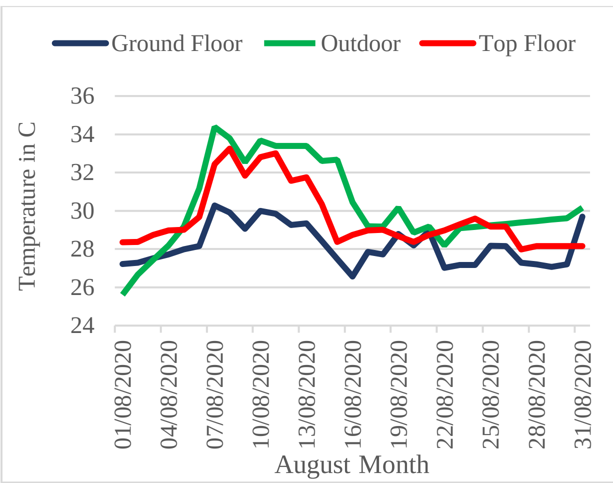

***Figure 7**: Indoor and Outdoor Temperature*

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 (Yang et al., 2017).

7. RESULT AND DISCUSSIONS

This particular section presents the blower door analysis results and modelling of a building. Modelling and simulation for the existing building were performed in the software. Finally, various ECMs were incorporated into the existing buildings. This was done mainly to conserve the energy consumption by residential buildings. Some of the ECMs incorporated are shading, daylighting controls, window glazing with low SHGC, ceiling, and roof insulation, and outdoor air ventilation. These ECMs were retrofitted to the existing building and simulated.

a. Blower Door Test Results

Table 4 represents 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 4**: 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 5 shows the results of the blower door test. It shows the airtightness of the building. Air changes per hour at 50 Pa (ACH50) of the flat is $\frac{756.15}{240} = 3.15$

***Table 5**: 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

Tables 6 and 7 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 6**: Energy Consumption of the Existing Building*

	Total Energy (MJ)	**Energy Per Total Building Area (kJ/ m²)**	**Energy per Unconditioned Building Area (kJ/m²)**
Total Site Energy	184,580	169,740	169,740
Total Source Energy	342,330	314,810	314,810

***Table 7**: Energy Consumption of the Proposed Building*

	Total Energy (MJ)	**Energy Per Total Building Area (kJ/ m²)**	**Energy per Unconditioned Building Area (kJ/m²)**
Total Site Energy	134,380	123,580	123,580
Total Source Energy	312,200	306,250	306,250

c. Electricity Consumption

Graphs 8 and 9 show 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.

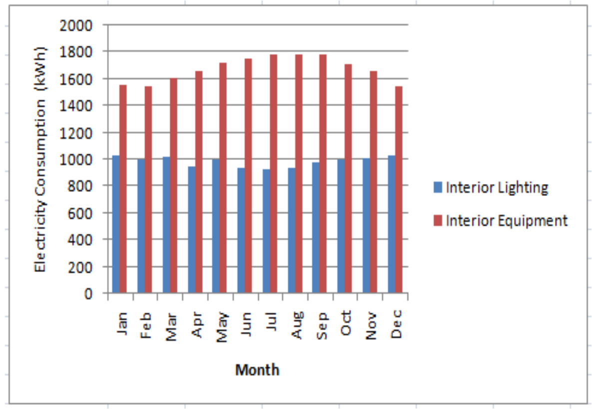

***Figure 8**: Electricity Consumption of Existing Building*

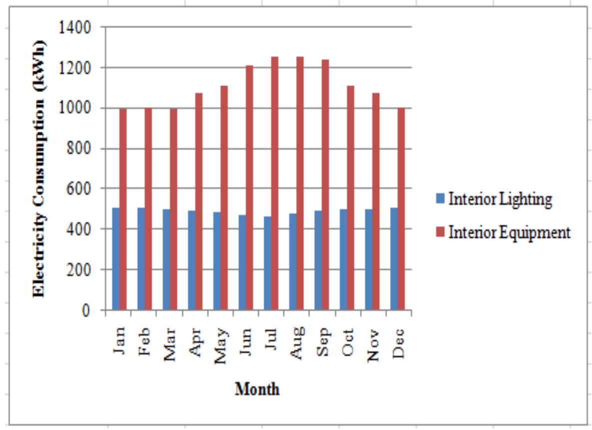

***Figure 9**: Electricity Consumption of Proposed Building*

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.

Graphs 10 and 11 represent 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 12 and 13 represent the total heating loads consumed in 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.

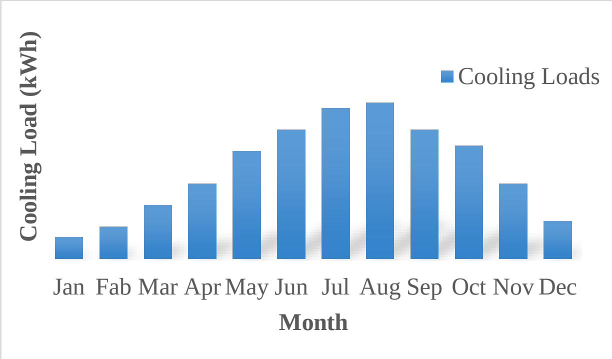

***Figure 10**: Cooling Load Demand – Existing*

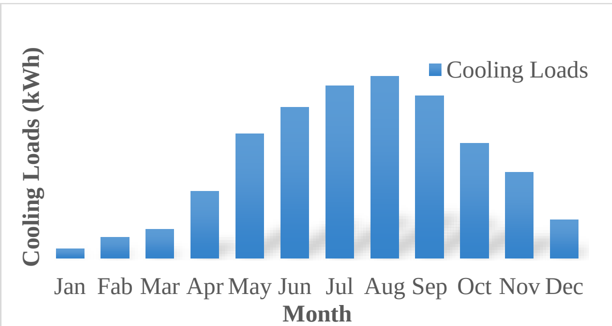

***Figure 11**: Cooling Load Demand – Proposed*

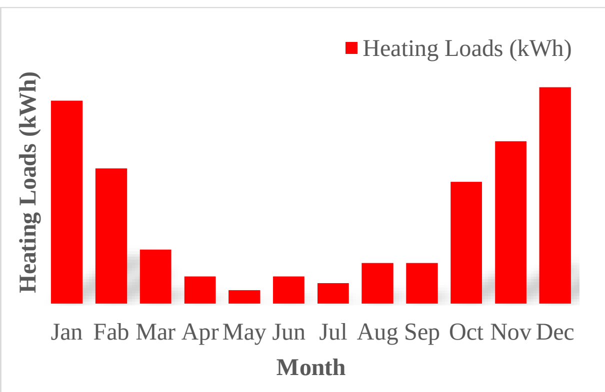

***Figure 12**: Heating Load Demand – Existing*

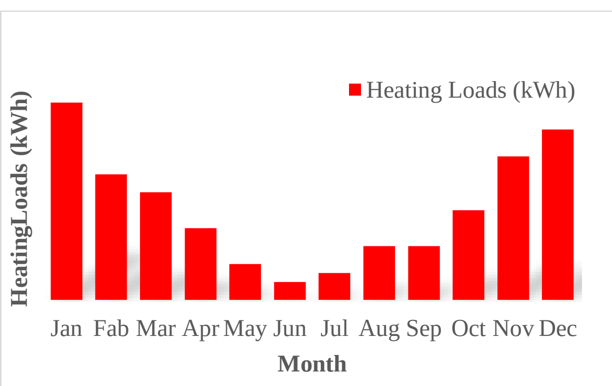

***Figure 13**: Heating Load Demand – Proposed*

Graphs 14 and 15 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.

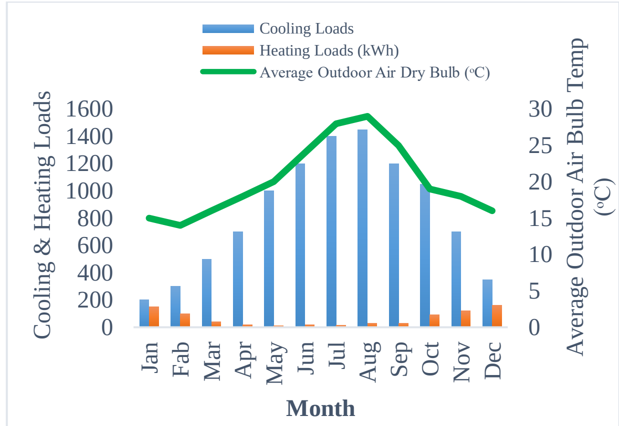

***Figure 14**: Cooling and Heating Loads with Average Outdoor Temperature – Existing*

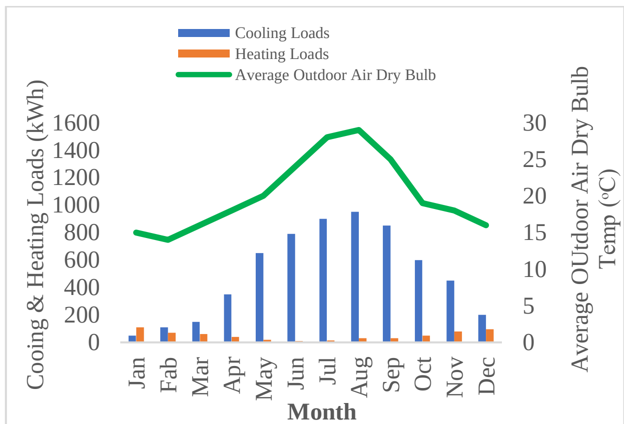

***Figure 15**: Cooling and Heating Loads with Average Outdoor Temperature – Proposed*

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.

Figures 16 and 17 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.

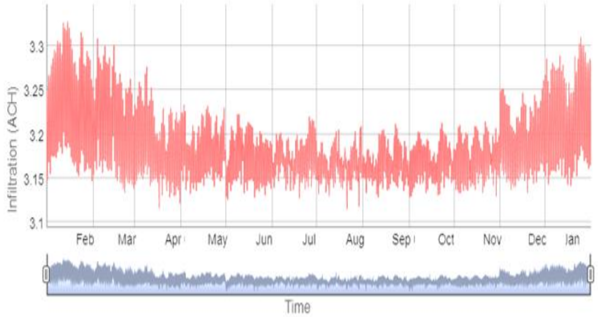

***Figure 16**: Infiltration Result Graph of the Existing Building*

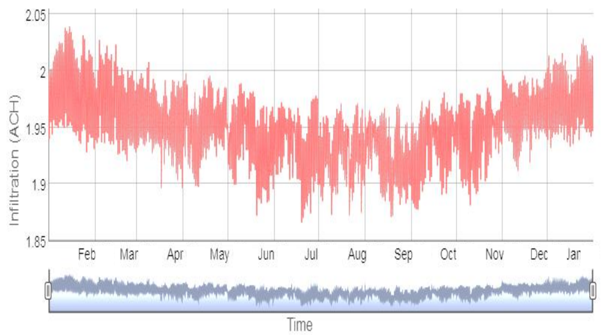

***Figure 17**: Infiltration Result Graph of the Proposed Building*

8. 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 designs to fulfil 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 and DIALux. The DIALux simulation results revealed that the pre-installed fixtures did not fulfil the required illuminance level and a fixture plan was proposed which achieved the illuminance level of the rooms.

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. 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 integrating EnergyPlus and DIALux software, as well as various energy conservation measures is critical for analyzing the residential building's energy performance.

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