

# Thermal performance and energy consumption analysis of retail buildings through daylighting: A numerical model with experimental validation

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## ABSTRACT

The simultaneous impact of a building's electricity consumption and thermal performance is analyzed in this paper by taking a thermal model of a retail building located in Ranchi, India. A Baseline design of retail building having a rectangular footprint area is compared with four buildings with different footprint areas (Rectangular, T, L, H and U), in the South-West orientation. The thermal models for lighting of retail building are developed using eQuest software, and results obtained were validated experimentally. Intensity of light is reduced by 35% in baseline building corresponding to the amount of energy saved by upgrading to a T8 fluorescent fixture from a T12 fluorescent fixture. Average daylight factor of retail building in hot summer was found to be 34.80% experimentally and 28.98% through simulation. Based on energy consumption it is found that, for temperate buildings with rectangular footprints, buildings with L footprints, and buildings with H footprints are preferable when targeting net-zero energy status. The results encourage architects and engineers to work out an effective framework to enhance the use of natural illumination energy and suitable lighting according to buildings layout.

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## 1. Introduction

A significant increase in energy consumption in buildings has been observed over the past decades due to development and living standard. The constructed infrastructure in India was 21 billion sq ft. in 2005, and that figure is expected to grow to approximately 104 billion sq. ft. by 2030, which predicts an increase of approximately 395% in 25 year [1]. Majority of building construction occurs for residential and commercial sectors and very few for historical. By 2030, cities are expected to consume about 73% of the total energy production [1]. Moreover, residential apartment uses about 30% of total electricity and this figure is increasing by 8% every year [2]. Energy consumption caused by heating and cooling load is 20–50% for residential buildings [3]. About 80% of total electricity consumption in retail commercial building happens in following area i.e. lighting, airing out, and central air conditioning [3–5]. However electricity consumption in buildings is a major

concern for the government and entrepreneur. In retail commercial buildings, some amount of electricity were used to decorative lightning to attract more customers into the malls, such lightning can be minimized to save energy [6–8].

Building energy consumption can be reduced by using thermal storage, Trombe walls and internal hollow composite walls within building envelopes. The studies were conducted on the analytical and experimental application of Trombe walls by Briga-Sá et al. [9]. It was found that there would be a temperature decrease of over 30 °C between the internal and external surfaces of the wall when equipped with an occlusion device and significant heat delay is also expected when the ventilation openings are switched off. Wang and Shi [10] created a novel exhaust air insulation wall characterized by an air-permeable porous layer. Results from the thermal performance indicated that the exfiltration process of the exhaust air flowing across the porous layer could extensively reduce the inward conductive heat flux through the wall. Furthermore, Peng et al. [11] studied the influence of diverse ventilation modes on thermal and power performance of a ventilated photovoltaic DSF. The results portrayed the ventilation design to cause

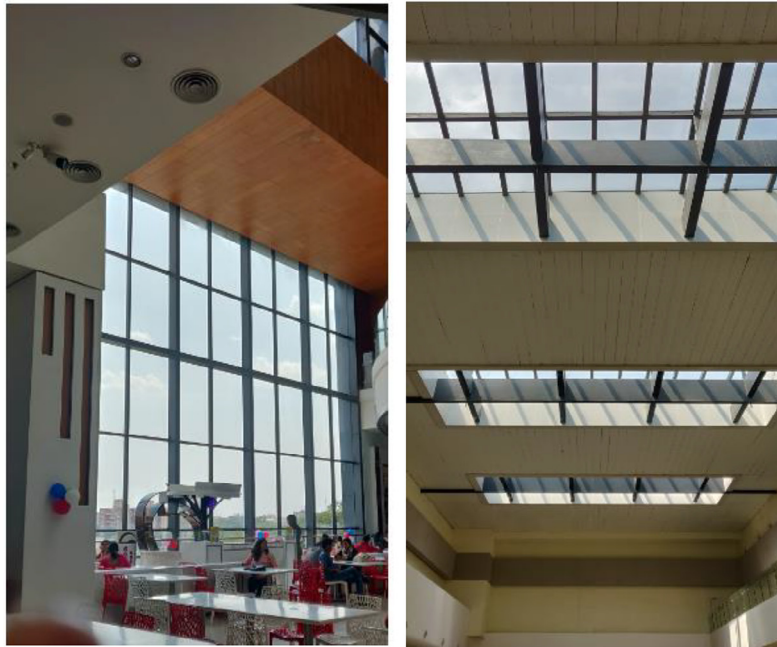
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a higher reduction of heat gain and improve energy generation. A simulation study by Peng et al. [11] was also presented to explore the overall energy performance of the building structure, proving that it could efficiently reduce solar radiation. The possible increase in dynamic thermal performance of different multi-layered walls was experimented by Leccese et al. [12], where the impact of thermal insulation was recorded against thermal performance. Also, the thermo physical characteristics, incorporation methods and application of phase change walls were studied by Huo et al. [13].

The main test for energy conservationists in buildings would be to devise a way to streamline energy use. Proper daylighting can contribute well to indoor illumination from daylight, control solar

heat gains, reduce glare and at the same time it improves thermal comfort [14]. This can be achieved by adopting and effectively using building orientation, daylight factor model and sunlight distribution analysis [15]. Good orientation plays a crucial role in minimizing the need for subsidiary heating and cooling, which curtails energy bills and greenhouse gas emissions and increases comfort and convenience [16]. This often increases satisfaction and productivity (effective and efficient use of space in energy-saving) [17]. Variations in an angle towards east and west can prove to be advantageous in hotter climates. In cold climates, however, for orientations with west-facing buildings, the south-facing side of the building obtains solar gains in the afternoon. This results in the desired comfort required in the evenings [17].



a. Front side and ceiling of Nucleus mall from the inside environment.

**Fig. 1a.** Front side and ceiling of Commercial retail building from the inside environment.



b. The ceiling of Nucleus mall in wide aperture view from the inside environment.

**Fig. 1b.** The ceiling of Commercial retail building in a wide aperture view from the inside environment.

After going through the various literature surveys, it is found that very few researches happens in energy consumption analysis of the commercial retail building in India. However, no research happens in the energy consumption analysis in humid subtropical climatic condition of India.

In this communication, there are two major sections. In the first section, five prominent baseline shape of commercial building in the humid subtropical climatic is being selected. An annual energy consumption analysis has been done for these building. Rectangular shape building found to be more energy efficient in this climatic condition. Hence a detail analysis has done on this building in the second section of manuscript. Thermal model and daylight factor has been evaluated and validated with experimental data.

2. Methodology

By considering the commercial retail building located in Ranchi capital city of Jharkhand, India as a model for performing the building energy simulation. Five different baseline shapes of the retail building has been modelled and simulated. For analysis, the climate data for the software was set to the weather details of Ranchi, which comes under the humid subtropical climatic zone. This type of climatic condition of Ranchi has summer season, which is hot and humid and very cold winters where the temperature is between 10 and 15 °C and in summer season the temperature is 30 to 35 °C. Fig. 1a and Fig. 1b show the front side and wide aperture view of the Commercial retail building from the inside environment.

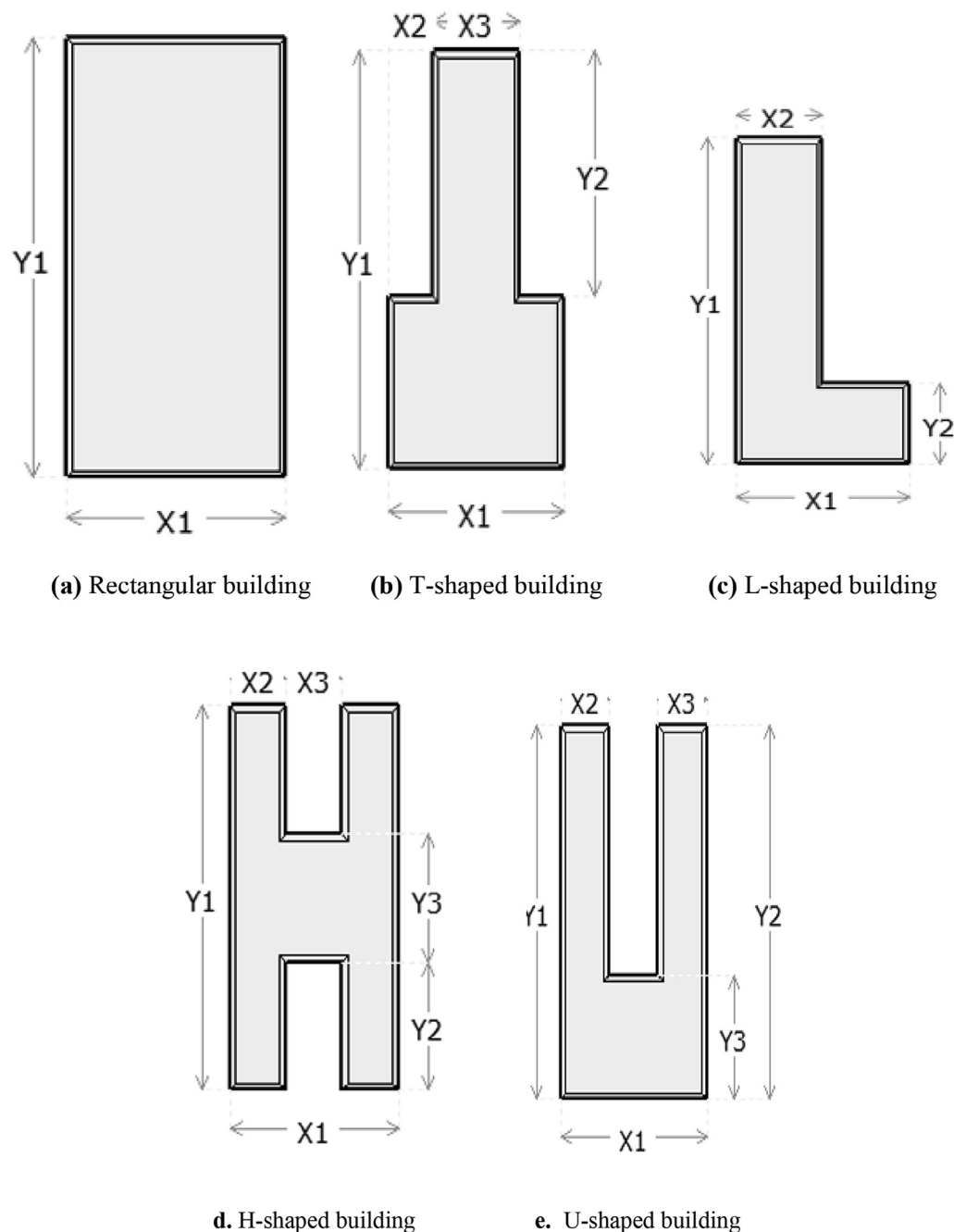


Fig. 2. Details of the building area of the baseline.

The building shape, size, annual electricity consumption, and daylight factor for different building types are designed and studied, shown in Fig. 2a–2e. The shape of the first building is a rectangle and the second building shaped in the form of a 'T'. The third, fourth and fifth buildings represent the shapes of the alphabet's 'L', 'H' and 'U' respectively. The building areas vary from 30,000 ft<sup>2</sup> to 45,000 ft<sup>2</sup>, with a perimeter zone depth of 5 ft. All the buildings were designed to be five floors, with the floor to floor height is 15 ft, and the floor to ceiling height of 11 ft. The orientation of all the buildings considered for simulation was South-West. The building footprint dimension is represented in Table 1a.

Building orientation was effectively utilized to maximize thermal comfort and to use the sun's free energy efficiently. The standard number of hours of sunlight received by any building atrium is at least two and these two hours can be in between 10 a.m. to 3p.m. during winter seasons [18]. However, implementing this in real-life situations can be very complex as there are many practical complications. This complex process can be carried out with ease by simulating it with a suitable software. An orientation to the east of the south can warm the buildings more effectively in the mornings, and the building orientation for this analysis is set at South-West.

### 2.1. Effect of wall materials on building thermal performance

Walls are considered a predominant and efficient part of the building. A building's thermal performance is determined by passively regulating the indoor environment, which depends on materials configuring the building wall. The wall materials that can thermo-regulate the building but accessible and feasible materials should be used for the economic construction of a building. The materials (with thickness) used and assembly of materials (sequence of arrangement) in this study is shown in Fig. 3. The other important factor in choosing wall material is the thermal properties, which plays a crucial role in thermal comfort and electrical energy conservation. In this research, the assembly of different (multi-layered) materials has been used.

Heat transfer through an infinite wall is given by Eq. (1):

$$\frac{q}{A} = \frac{k}{b} (T_1 - T_2) \quad (1)$$

For the (multi-layered) composite wall in series having thermal conductivities  $k_1, k_2, \dots, k_n$ , heat flux is evaluated in Eq. (2):

$$\frac{q}{A} = \frac{T_1 - T_2}{\frac{b_1}{k_1} + \frac{b_2}{k_2} + \frac{b_3}{k_3} + \dots + \frac{b_n}{k_n}} \quad (2)$$

And the overall heat transfer coefficient is given by U, as shown in Eq. (3):

$$U = \frac{q}{A(T_1 - T_2)} \quad (3)$$

Therefore, for composite walls (multi-layered materials in series) the overall heat transfer coefficient is given by Eq. (4):

$$\frac{1}{U} = \frac{b_1}{k_1} + \frac{b_2}{k_2} + \frac{b_3}{k_3} + \dots + \frac{b_n}{k_n} \quad (4)$$

## 3. Overview of energy performance analysis

### 3.1. Model verification

Ranchi's Commercial retail building has been represented as a model for the buildings' footprint details. This Mall proves to be an excellent example of a retail building in the heart of Lalpur, Ranchi City, Jharkhand, India with the coordination of 23.3772° N latitude, 85.3315° E longitude, 644 m altitude. The first shape considered in the simulation was a rectangle resembling the building in Commercial retail building; however, the four other building footprints varied in shape and area. Although the shapes may be different, the overall area of the rectangular building is the largest and the following four building variations have areas that can all fit inside that of the rectangular footprint. The red outline in Fig. 4a represents the footprint used for the rectangular variant. Side view of the proposed building is shown in Fig. 4b.

The model used in this simulation has been analyzed in the eQUEST 3–65 software. eQUEST was intended to permit a detailed comparative analysis of building designs and advances by applying modern building energy use simulation procedures. This is done by joining schematic and design improvement building creation wizards, an energy efficient measure (EEM) and graphical outcomes show module with a total state-of-the-art DOE-2 (variant 2.2) building energy simulation. This software is widely popular in countries like the USA and it is being validated by many researchers. All the buildings under consideration in this analysis are of 5 stories and have the same construction and enveloping characteristics. Thus, we aim to analyze electricity consumption by changing a building's footprint shape. For the analysis, the weather data in this simulation is set for Ranchi (23.3441° N, 85.3096° E), which comes under the humid subtropical climatic zone.

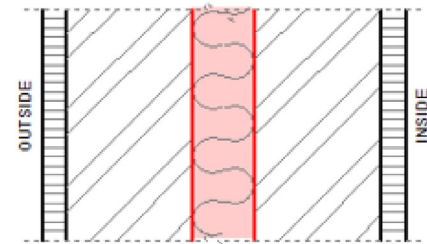
All the buildings were considered to be retail buildings and models for the buildings were fairly standard since the design of the retail building was majorly constructed based on rectangular shaped, L shaped, U shaped and H shaped. Default relevant data were used in defining the building characteristics corresponding to the prescribed climatic zone data. The building envelope construction of the above-grade walls consisted of 8 in. heavyweight. The exterior finish of the roof is the standard built-up type, whereas the exterior finish of the above-grade walls is Stucco/Granite in white colour. There is no exterior insulation in the roofs, and the ground floor exposure is over the parking garage. On the other hand, the interior ceiling finish is that of lay-in acoustic tile with vertical wall frame type, and the interior finish for the floors is ceramic or stone tile. Four revolving glass doors were described in which one revolving glass is in the North orientation and

**Table 1a**  
Building Footprint dimensions.

Shape	Building Orientation	Footprint Dimension (Meters)
Rectangle	South West	Perimeter Zone Depth – 1.524 X <sub>1</sub> – 45.72 Y <sub>1</sub> – 91.44
T-Shaped	South West	Perimeter Zone Depth – 1.524 X <sub>1</sub> – 45.72 X <sub>2</sub> – 11.58 Y <sub>1</sub> – 91.44 Y <sub>2</sub> – 53.34
L-Shaped	South West	Perimeter Zone Depth – 1.524 X <sub>1</sub> – 45.72 X <sub>2</sub> – 22.86 Y <sub>1</sub> – 91.44 Y <sub>2</sub> – 91.44
H-Shaped	South West	Perimeter Zone Depth – 1.524 X <sub>1</sub> – 45.72 X <sub>2</sub> – 15.24 X <sub>3</sub> – 15.24 Y <sub>1</sub> – 91.44 Y <sub>2</sub> – 30.48 Y <sub>3</sub> – 30.48
U-Shaped	South West	Perimeter Zone Depth – 1.524 X <sub>1</sub> – 45.72 X <sub>2</sub> – 15.24 X <sub>3</sub> – 15.24 Y <sub>1</sub> – 91.44 Y <sub>2</sub> – 91.44 Y <sub>3</sub> – 30.48



Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1. Plaster Building (Molded Dry	20.0	1250.0	1088.000	0.431	85
2. Brick Masonry Medium	100.0	2000.0	836.800	0.711	25
3. Polystyrene Foam (Low Den	50.0	38.0	1130.000	0.033	45
4. Brick Masonry Medium	100.0	2000.0	836.800	0.711	25
5. Plaster Building (Molded Dry	20.0	1250.0	1088.000	0.431	85



Layer Name	Width	Density	Sp.Heat	Conduct.	Type
1. Plaster Building (Molded Dry	20.0	1250.0	1088.000	0.431	85
2. Brick Masonry Medium	100.0	2000.0	836.800	0.711	25
3. Vacuum Insulation	50.0	186.0	800.000	0.003	45
4. Brick Masonry Medium	100.0	2000.0	836.800	0.711	25
5. Plaster Building (Molded Dry	20.0	1250.0	1088.000	0.431	85

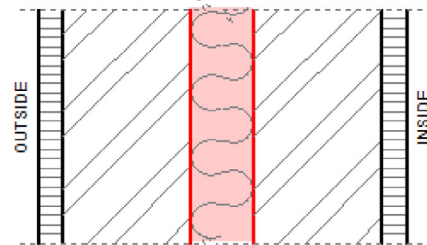


Fig. 3. Materials used in walls and their conductivity values.



a. Nucleus Mall aerial shot

Fig. 4a. Commercial retail building aerial shot.



b. Nucleus mall top view

Fig. 4b. Commercial retail building side view.

remaining three are in the South orientation while the dimensions and constructions of the doors and glasses were set to default data.

Table 1b

Ventilation rate in the building.

Occupant Category	cfm/ person	L/s person	cfm/ft <sup>2</sup>	L/s m <sup>2</sup>	1000 ft <sup>2</sup> /100 m <sup>2</sup>
Building Lobby	7.5	3.8	3.8	0.3	120
Office Space	5	2.5	0.06	0.3	25
Bathroom	5	2.5	0.12	0.6	50

The exterior windows glass category was defined as Single PPG (Pittsburgh Plate Glass), and the window width was fixed to five feet. PPG SSB 28x32 is a single strength high-quality float glass sheet that is 32 in. in length 28 in. in width, and 2.5 mm in thickness. All exterior windows were equipped with overhangs and fins with shade depths of two feet in every orientation. The areas of activity and occupied loads were allocated as per the default data. The heating, ventilation and air conditioning system's (HVAC) definitions were defined in two types. One type had chilled water coils and no heating for the cooling source and heating sources, respectively. Conversely, the second system had DX coils as their cooling source and no heating source like the first system. Both systems had a direct return air path. All the HVAC system's supply and return fans' efficiency were set to standard. The HVAC system is installed with reinforced carbon create at the roof of the building, isolated against transmission of vibrations to the building structure. The central plant HVAC system is connected to the bathroom and other kitchen based shops. The exhaust of air was done through hoods equipped with grease filters, duct network. An exhaust blower cleared out the fumes from the bathroom and other food based shops. The heater used for domestic non-residential water heating was of the instantaneous type operating on electricity as the heater fuels. The other characteristics of building components include a ventilation system the building is constructed as per the minimum standard set for ventilation rate according to CPW (Central Public Works Department, India). Table 1b represents the ventilation where CMF is cubic feet per minute and L/s m<sup>2</sup> liters per second-meter square. Table 2a and Fig. 5a shows occupancy and usage schedules of the building (i.e. how many people, time throughout the day)

### 3.2. Application of EEM wizard on internal loads

The energy efficiency measure wizard was used to optimize the internal loads, particularly focusing on the lighting power density.

**Table 2a**  
Occupancy and usage schedules of the building.

Time of the day	Occupant present
10:00 AM	37
11:00 AM	94
12:00 PM	131
1:00 PM	97
2:00 PM	73
3:00 PM	77
4:00 PM	107
5:00 PM	171
6:00 PM	209
7:00 PM	356
8:00 PM	228
9:00 PM	119
10:00 PM	58
11:00 PM	26

In this efficiency analysis, the T12 fluorescent fixtures were replaced by the T8 fixtures in specific activity areas to optimize lightings and reducing costs. Fluorescent lights as they are likewise known, are arranged by their wattage, shape and measurement. The “T” in T5 shows the bulb which is cylindrical moulded, while the “5” indicates that it is having a measurement of five eighths inch. The other basic lights are the bigger T8 (eight eighths inch = 1”) and T12 (twelve eighths inch = 1½” tubes). The average cost of T8 bulb is 350 Indian Rupees while T12 bulb average cost is 560 Indian Rupees. The activity areas considered for the fluorescent fixture upgrades were offices, corridors, lobbies and conference rooms. The areas not considered for lighting upgrade were restrooms, mechanical and electrical rooms, as their contribution to the overall building energy conservation analysis was rather insignificant because the area for these specific activities was quite minimal when compared to the other areas that were considered for the energy efficiency measure wizard. All the lighting intensities for the considered activity areas were reduced by around 35%, corresponding to the amount of energy saved by upgrading to a T8 fluorescent fixture from a T12 fluorescent fixture.

### 3.3. Daylight factor

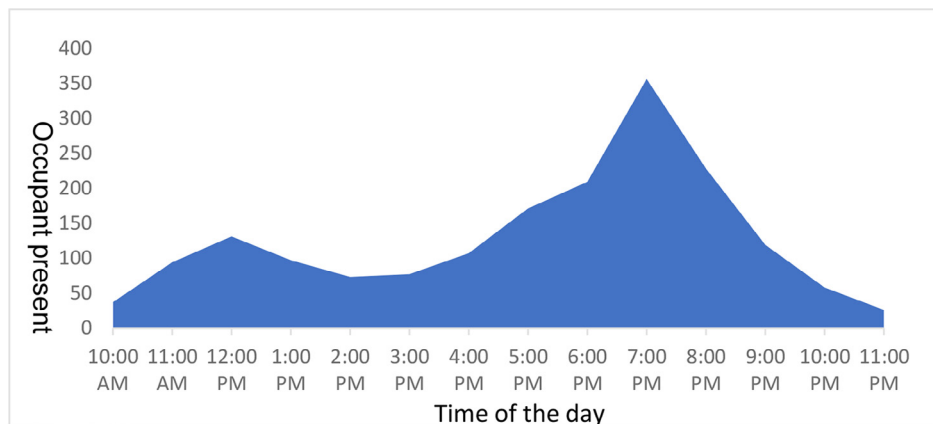
Daylight factor (DF) is the availability of natural light inside the building atrium. Architects do estimation of sufficient internal building daylighting after calculating the daylight factor of the building. Daylighting allows a more energy-efficient building

design by providing further flexible building facade design strategy, and different atrium building features make up the DF (daylight factor) [19]. These features include the atrium shape, the sun orientation, atrium roof transmittance, surface reflectivity of the atrium and the penetration of daylight into adjoining spaces. The size, position and orientation of fabrics (windows/ doors/ vents), optical phenomenon (skylight and the sky illuminance) distributions all contribute to the illuminance level received inside of a building.

The daylight factor is made of three different constituents, which are the sky component (SC), the externally reflected component (ERC), and the internally reflected component (IRC) [20]. The sky component is the light received from the sky. The externally reflected component is the part of light received from skylight reflected by a reflective impediment [21]. The internally reflected component is the constituent of the light reflected by the interior facades of the building. The addition of all these parameters results in the daylight factor [22]. Daylight received by a vertical surface is the sum of direct-beam, externally reflected components and sky-diffuse [22]. For designing a wall window in clear sky conditions, the daylight factor can be computed by considering both direct and diffuse components illuminance level on a given point in a living space. Useful daylight illuminance (UDI) is an annual occurrence of illuminance, i.e. daylight is within the range of 100–2000 lx [23]. The UDI conspire is both useful and complex. While UDI is based essentially on human factor contemplations, high estimations of UDI related to low vitality use for electric lighting and cooling. UDI does not show any correlation between electric lighting use and achieved UDI for office spaces with controlled shades [24]. The daylight factor continues as the predominant assessment metric because of its simple and realistic approach used by an organization such as LEED.

### 3.4. Building orientation

The orientation of the building is conveyed as one of the most important factors in daylighting. To achieve living comfort during both hotter and colder days, proper orientation is required. Ranchi's Commercial retail building has an orientation of South-West. As a part of this analysis, we have modelled the rectangular baseline building in different orientations. The orientation is decided upon the direction of the main entrance facing. This was done to examine the effect of varying the orientation of a building have on its electricity consumption.



a. Graphical variation of Occupancy with respect to time of day

**Fig. 5a.** Graphical variation of occupancy with respect to time of day.

U-Value (W/m <sup>2</sup> .K):	1.370
Admittance (W/m <sup>2</sup> .K):	4.770
Solar Absorption (0-1):	0.389412
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.02
Thermal Lag (hrs):	16.48
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	290.0
Weight (kg):	459.300

#### b. U- value obtained with the conventional wall material.

**Fig. 5b.** U- value obtained with the conventional wall material.

The building variation considered for this part is the rectangular baseline building. The building was modelled in six different orientations, namely, East, West, North, South East, North West and North East. No other parameter of the building was altered other than its orientation.

## 4. Results and discussion

The simulated daylight factor is validated with an experimental value measured at the different floors of the proposed building. Monthly and annual electricity consumption was recorded based on area lighting, miscellaneous equipment, pumps and auxiliaries, ventilation fans, water heating, space cooling and heat rejection. Readings were obtained in kilowatt-hours (kWh)  $\times 106$ . The five different types of buildings differed from one another by their footprint shapes. The rectangular building can be considered a baseline for all the other four buildings in terms of area. It is used as a live model of Commercial retail building Ranchi with coordinate's 23.3772° N latitude 85.3315° E longitude, 644 m altitude. The four variations of the rectangular footprint include T-shaped, L-shaped, H-shaped and U-shaped buildings. Otherwise, the number of floors, cooling systems, HVAC systems, and other building parameters are identical.

### 4.1. Effect of wall materials on building thermal performance

Heat transfers take place from higher temperatures to lower temperatures. In buildings, heat transfers were mostly from walls and roofs. Wall is a predominant part of the building, so

choosing wall material is very important to increase thermal comfort inside buildings. In this conventional research material is used, the U-value obtained is 1.37 w/m<sup>2</sup>k which is shown in Fig. 5b., then the middle layer of the wall is replaced with a new layer (vacuum insulation). From this, the U-value decreased by 2.85 times and became 0.48 w/m<sup>2</sup>k as shown in Fig. 5c. The decreased U-value increases the thermal comfort inside the building envelope. The U- values were validated physically from the given equations used in this research. The U- value decreases as the conductivity of vacuum insulation is smaller than that of polystyrene foam.

### 4.2. Simulation result

Simulated is performed to find out the electricity consumption in each building monthly and annually. Daylight factor of a retail building (Commercial retail building) of Ranchi city is compared with experimentally measured values

#### 4.2.1. Monthly electricity consumption comparison of building alternatives

The gross annual and monthly electricity consumption readings were gained from the simulation of each of the five buildings. It can be concluded by analyzing Figs. 6a–6e that May is the most electricity consuming month of the year, as the peaks of the bars are highest in May, regardless of the type of building. This is understandable as May and June are the hottest months of the year in Ranchi. The bulk of the electricity consumption, 36.4%, of the rectangular baseline building is used in space cooling for occupants' comfort in the hot summer days of June.

#### 4.2.2. Annual electricity consumption of building alternatives

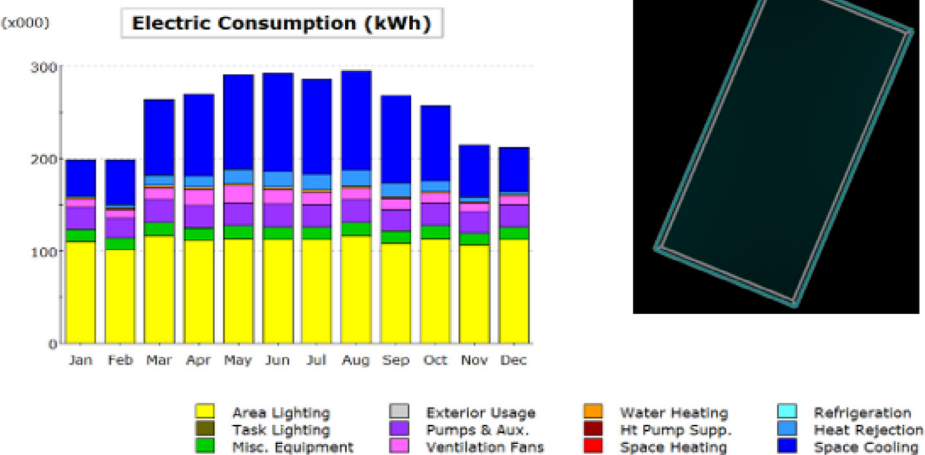
On an annual basis, electricity consumption ranged from 2.559 million kWh (L-shaped building) to 3.219 million kWh (U-shaped building). All the buildings averaged 2.869 million kWh of electricity annually. From Tables 2b–2f) and graphically shown in Figs. 7a–7e, it is evident that the U-shaped building consumes the most amount of energy. It is followed by the rectangular baseline building, T-shaped, H-shaped and L-shaped buildings as the second, third, fourth and fifth ranking respectively in consuming the most electricity. The U-shaped building consumes about 6% more electricity than the rectangular baseline building's second most electricity-consuming building.

As mentioned earlier, space cooling is the system that consumes the most amount of electricity in all the buildings, except for the rectangular alternative. Area lights consume  $1.33 \times 10^6$  kWh, which amounts to 44% of total annual electricity consumption.

U-Value (W/m <sup>2</sup> .K):	0.480
Admittance (W/m <sup>2</sup> .K):	4.720
Solar Absorption (0-1):	0.1
Visible Transmittance (0-1):	0
Thermal Decrement (0-1):	0.18
Thermal Lag (hrs):	11.12
[SBEM] CM 1:	0
[SBEM] CM 2:	0
Thickness (mm):	290.0
Weight (kg):	451.900

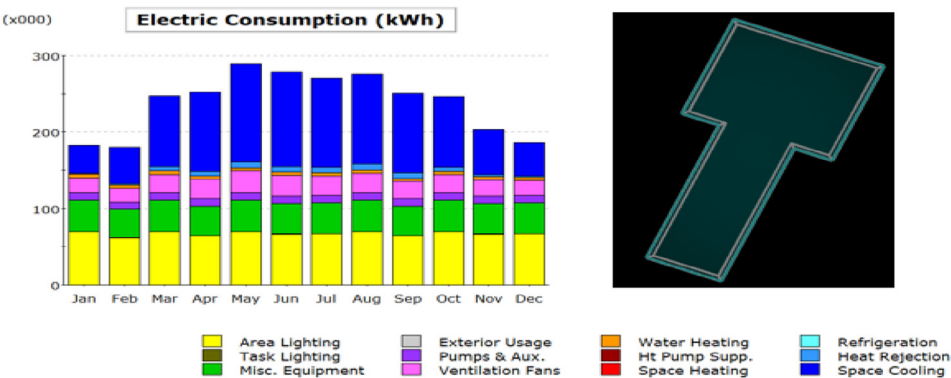
#### c. U- value obtained with innovative wall material (vacuum insulation)

**Fig. 5c.** U- value obtained with innovative wall material (vacuum insulation).



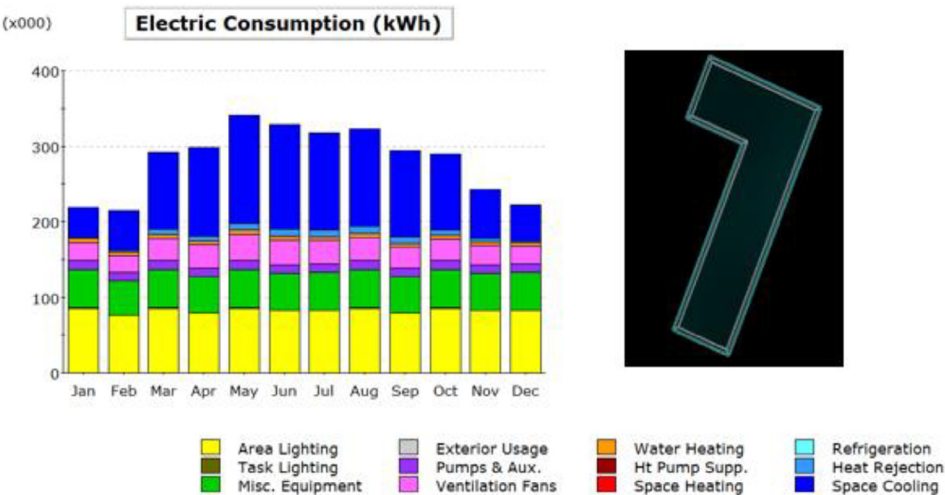
a. Rectangular building simulated footprint and monthly electric consumption data

Fig. 6a. Rectangular building simulated footprint and monthly electric consumption data.



b. T-shaped building simulated footprint and monthly electric consumption data

Fig. 6b. T-shaped building simulated footprint and monthly electric consumption data.



c. L-shaped building simulated footprint and monthly electric consumption data

Fig. 6c. L-shaped building simulated footprint and monthly electric consumption data.



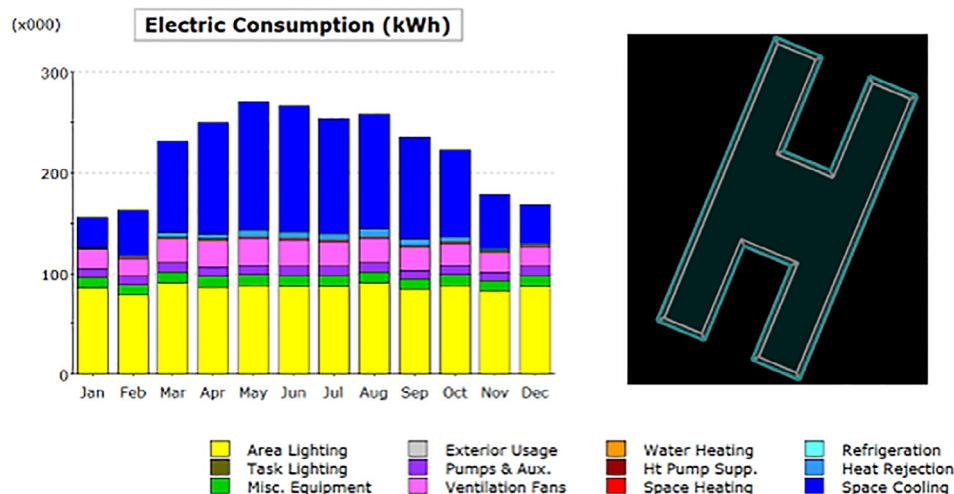


Fig. 6d. H-shaped building simulated footprint and monthly electric consumption data.

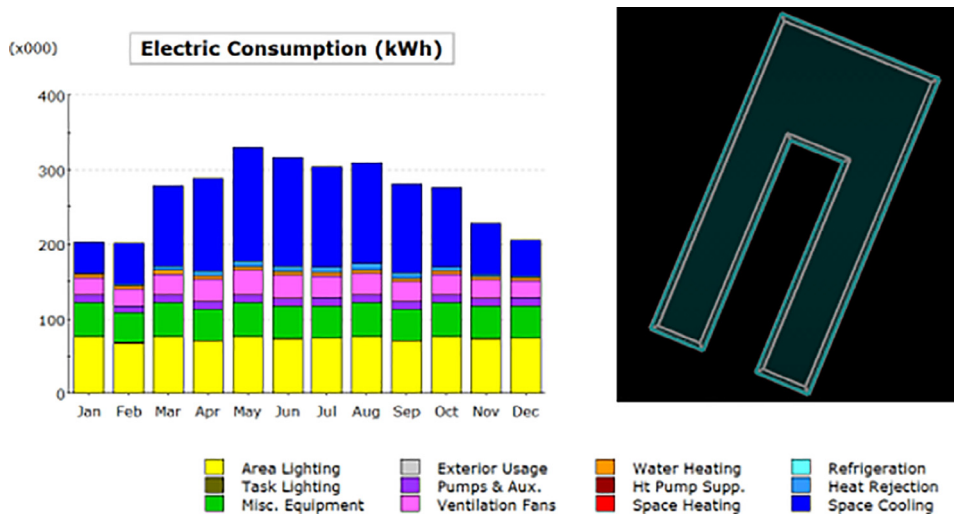


Fig. 6e. U-shaped building simulated footprint and monthly electric consumption data.

**Table 2b**  
Annual energy consumption of the rectangular building for different uses.

Electricity Use	Electricity kWh (x1000)
Space Cool	959.1
Heat Reject.	128.8
Hot Water	24
Vent. Fans	148
Pumps & Aux.	291.3
Misc. Equip.	163.1
Task Lights	0
Area Lights	1,332.70
Total	3,046.90

**Table 2c**  
Annual energy consumption of the T- shaped building for different uses.

Electricity Use	Electricity kWh (x1000)
Space Cool	1,064.30
Heat Reject.	65.8
Hot Water	49.9
Vent. Fans	277.6
Pumps & Aux.	119.9
Misc. Equip.	479.9
Task Lights	3.5
Area Lights	802
Total	2,863.00

The area lighting is followed by space cooling, which consumes about 31% of the annual electricity. Furthermore, miscellaneous equipment consumes around 5% of the annual electricity. Vent fans use 5%, and 10% is used by pumps and auxiliaries, while the remaining 5% of annual electricity is used by hot water supply and heat rejected.

It is evident from Fig. 6e that the U-shaped building consumes proportionately more electricity annually for space cooling than the other building alternatives. On the other hand, the L-shaped

building consumed the least amount of electricity annually for area lights than the other building alternatives; this can be analyzed through Figs. 6a–6d.

The annual electricity consumption for uses such as heat rejection, hot water, vent fans and pumps and auxiliaries were more or less the same for every building alternative. It is important to know that the energy efficiency measure wizard was not put into effect to calculate the annual electricity consumption of building alternatives.

**Table 2d**

Annual energy consumption of the L- shaped building for different uses.

Electricity Use	Electricity kWh (x1000)
Space Cool	968.60
Heat Reject.	56.3
Hot Water	44
Vent. Fans	253
Pumps & Aux.	103.3
Misc. Equip.	423.7
Task Lights	3.1
Area Lights	707.7
Total	2,559.80

**Table 2e**

Annual energy consumption of the H- shaped building for different uses.

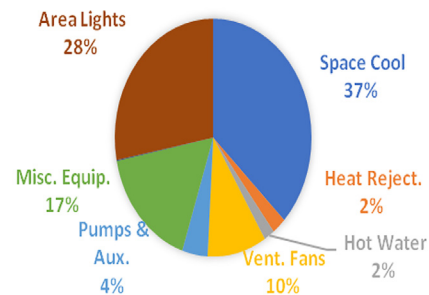
Electricity Use	Electricity kWh (x1000)
Space Cool	1,036.90
Heat Reject.	55.7
Hot Water	18.6
Vent. Fans	271.5
Pumps & Aux.	108.1
Misc. Equip.	126.9
Task Lights	0
Area Lights	1,036.50
Total	2,654.30

**Table 2f**

Annual energy consumption of the U- shaped building for different uses.

Electricity Use	Electricity kWh (x1000)
Space Cool	1,233.40
Heat Reject.	67.8
Hot Water	54.8
Vent. Fans	327
Pumps & Aux.	124.3
Misc. Equip.	527.7
Task Lights	3.9
Area Lights	880.30
Total	3,219.30

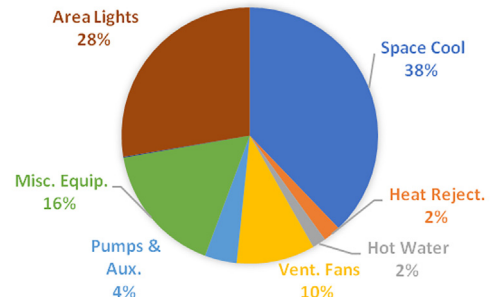
### T-SHAPED BUILDING ANNUAL ELECTRICITY CONSUMPTION



**b.** Percentage annual energy consumption of T-shaped building

**Fig. 7b.** Percentage annual energy consumption of T-shaped building.

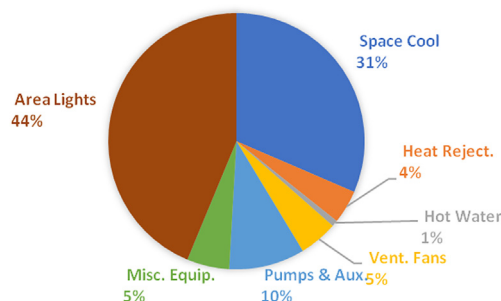
### L-SHAPED BUILDING ANNUAL ELECTRICITY CONSUMPTION



**c.** Percentage annual energy consumption of L-shaped building

**Fig. 7c.** Percentage annual energy consumption of L-shaped building.

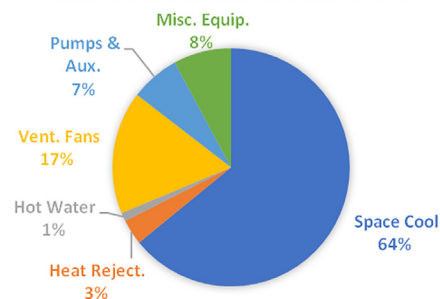
### RECTANGULAR BUILDING ANNUAL ELECTRICITY CONSUMPTION



**a.** Percentage annual energy consumption of the rectangular building

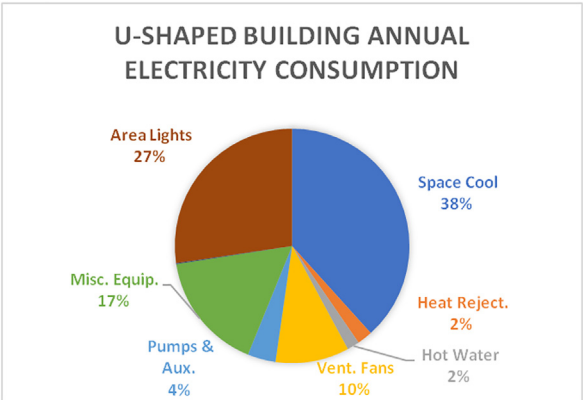
**Fig. 7a.** Percentage annual energy consumption of the rectangular building.

### H-SHAPED BUILDING ANNUAL ELECTRICITY CONSUMPTION



**d.** Percentage annual energy consumption of H-shaped building

**Fig. 7d.** Percentage annual energy consumption of H-shaped building.



e. Percentage annual energy consumption of U-shaped building

Fig. 7e. Percentage annual energy consumption of U-shaped building.

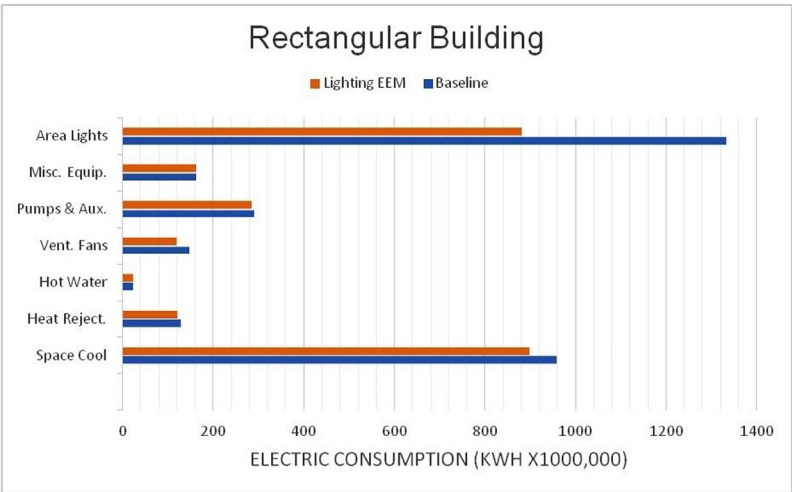
4.2.3. Effect of EEM wizard on the electricity consumption of building alternatives

The EEM wizard was applied to all the building alternatives and the results are shown in Figs. 8a–8e. After decreasing the lighting intensity of an important building area by 35%, it is seen that electricity consumption has reduced considerably, as shown by the difference in length of the blue and orange horizontal bars, representing the T12 to T8 lighting EEM results and the baseline simulation results respectively, in Figs. 8a–8e.

The area most affected by this lighting EEM analysis is the area lights, showing the highest decrement of electricity consumption, regardless of the building alternative.

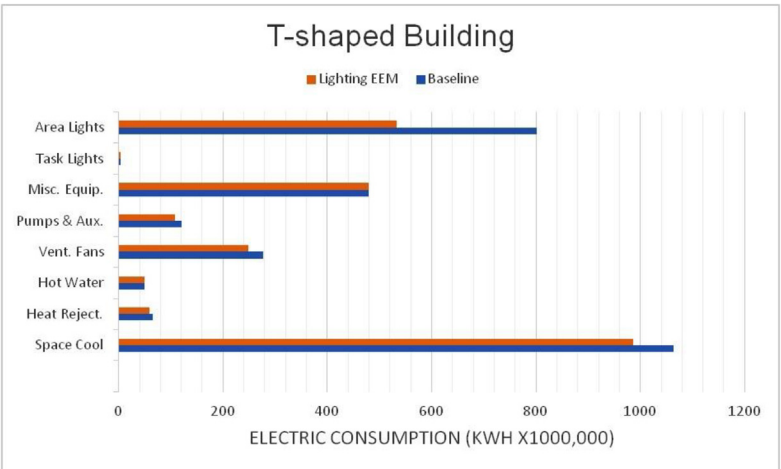
4.3. Daylight factor

The average daylight factor of the retail building was found to be 34.80% experimentally during the hot summer, as shown in Table 2a. Table 2a also represents the sunshine (in lux) from the front window and the top ceiling of the Commercial retail building.



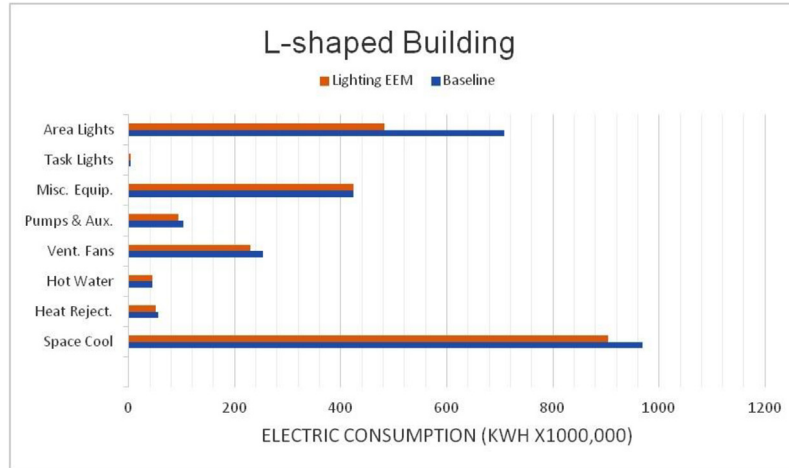
a. Annual electricity consumption comparison between baseline and lighting EEM rectangular building

Fig. 8a. Annual electricity consumption comparison between baseline and lighting EEM rectangular building.



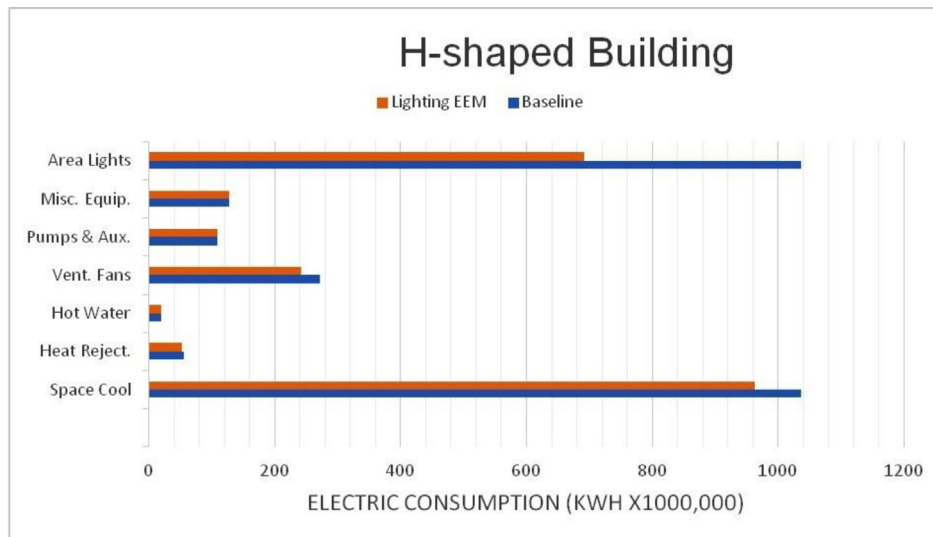
b. Annual electricity consumption comparison between baseline and lighting EEM T-shaped building

Fig. 8b. Annual electricity consumption comparison between baseline and lighting EEM T-shaped building.



c. Annual electricity consumption comparison between baseline and lighting EEM L-shaped building

Fig. 8c. Annual electricity consumption comparison between baseline and lighting EEM L-shaped building.



d. Annual electricity consumption comparison between baseline and lighting EEM H-shaped building

Fig. 8d. Annual electricity consumption comparison between baseline and lighting EEM H-shaped building.

From the simulation, the average daylight factor during a year obtained is 28.98% shown in Fig. 9. It varies between 0 and 60 %. The figure analyzed that there is no need for external lighting in the front and middle part of the building, but there is a need for external lighting in the back part of the proposed building as daylight factor at that point is low. The recommended daylight factor for the retail buildings is below 10%. The higher daylight factor indicates that a building majorly depends upon artificial lighting during darkness and nighttime. The walls with higher reflectance increased the daylight factor. Simulation results showed 30.84 % daylight factor. The daylight factor increases in the direction perpendicular to the atrium and external windows. The recommended design for sky illuminance for the composite climate is 8000 lx. The experimental average indoor illuminance through the luxmeter

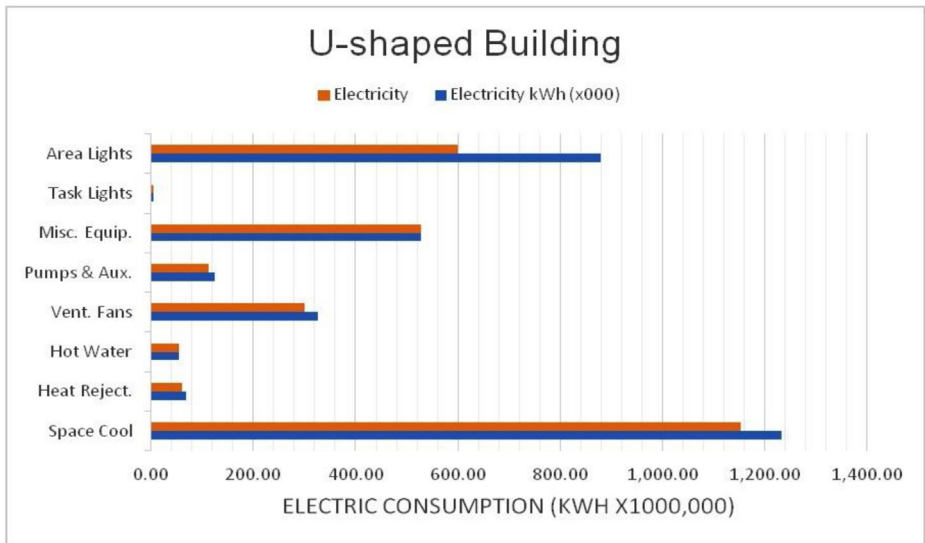
was 2400 lx. Table 2b shows the variation of daylight factor values on different floors during the year. It is observed that the daylight factor decreases with height.

The experimental daylight factor measured is compared with a simulated value which is shown in Fig. 10. It is seen that there is a close agreement between experimental and simulated values, root means square error found between these two values is 5.167 during summer days and 2.97% at noon on cold winter days.

#### 4.4. Building orientation

The rectangular baseline building was simulated at different orientations, and their results are represented by Tables 3a–3f. The live model or Ranchi Commercial retail building has an orien-





e. Annual electricity consumption comparison between baseline and lighting EEM U-shaped building

Fig. 8e. Annual electricity consumption comparison between baseline and lighting EEM U- shaped building.

Daylight Analysis  
Daylight Factor  
Value Range: 0.0 - 60.0 %  
© ECOTECT v8

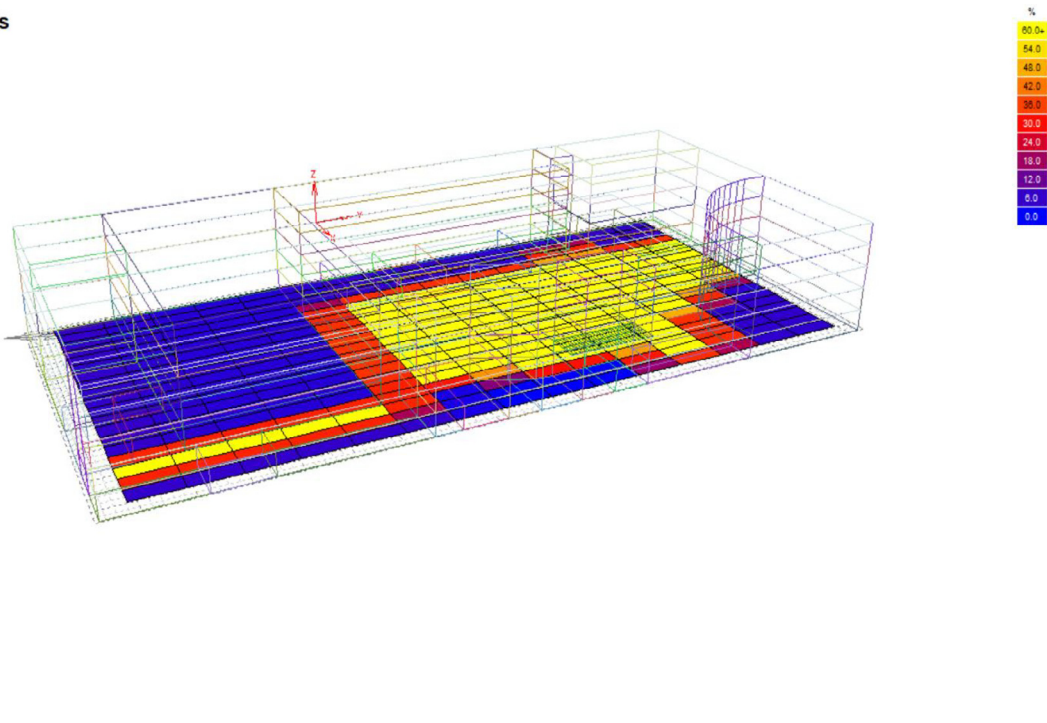


Fig. 9. Thermal model of Commercial retail building with daylight factor value.

tation of South-South-West. The simulated models have East, West, North, South East, North West, and North East orientations. Fig. 11 shows the comparison of electric consumption in all the orientations in kWh (kilowatt-hour). Surprisingly, the South-South-West configuration of the building, which is the original orientation of the live model, consumes

the second most amount of electricity. Only the building with its orientation set to North had higher electricity consumption despite a very small difference. The building with an orientation of East consumes relatively the least amount of electricity shown in Fig. 11. Rectangular-shaped buildings consume less energy because they fit as a fiddle and give a more comparative moulded house.

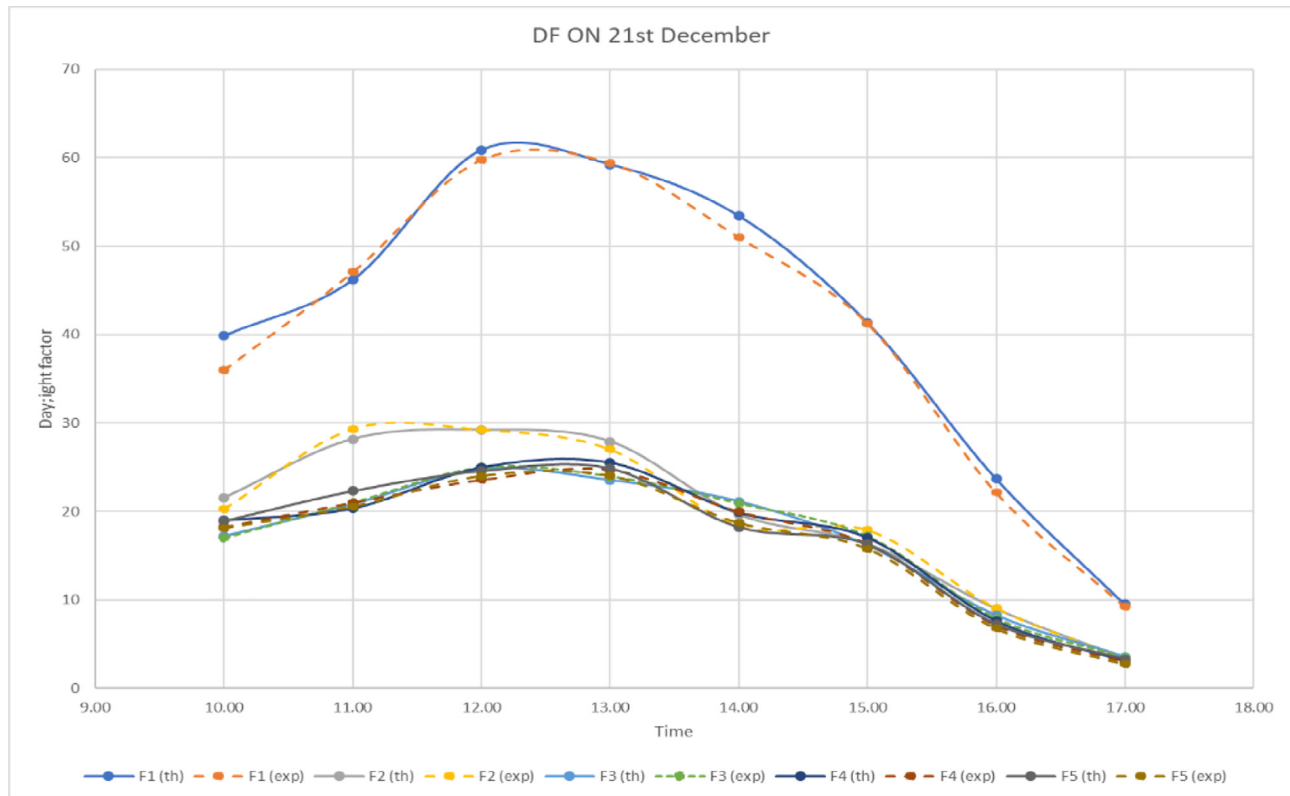


Fig. 10. Daylight factor value measured experimentally and through simulation during a day.

Table 3a

Experimental daylight factor value of Commercial retail building on hot summer days.

Time	Sunshine from top ceiling	Sunshine from the front window	Overall sunshine	Daylight factor
At 1 pm	11,000	25,000	36,000	50%
At 4 pm	9600	4500	14,100	19.60%
Overall Daylight factor				34.80%

Table 3b

Daylight factor value at different floors of the retail building (Commercial retail building).

Months	Daylight factor (%)				
	Floor- 1	Floor- 2	Floor- 3	Floor- 4	Floor- 5
March	61.19	29.03	24.56	24.65	24.87
August	61.19	29.24	24.94	25.03	25.03
December	61.19	29.21	24.79	25.50	24.87

Table 4a

Annual electricity consumption of rectangular building with an orientation of East.

Electricity Use	Electricity kWh (x1000)
Space Cool	914.4
Heat Reject.	122.3
Hot Water	24
Vent. Fans	147.4
Pumps & Aux.	269.7
Misc. Equip.	163.1
Task Lights	1,332.70
Area Lights	2,973.50
Total	914.4

Table 4b

Annual electricity consumption of rectangular building with an orientation of West.

Electricity Use	Electricity kWh (x1000)
Space Cool	923.40
Heat Reject.	123.70
Hot Water	24.00
Vent. Fans	147.50
Pumps & Aux.	273.90
Misc. Equip.	163.10
Task Lights	1,332.70
Area Lights	2,988.30
Total	923.40

**Table 4c**

Annual electricity consumption of rectangular building with an orientation of North.

Electricity Use	Electricity kWh (x1000)
Space Cool	959.90
Heat Reject.	128.80
Hot Water	24.00
Vent. Fans	147.90
Pumps & Aux.	292.00
Misc. Equip.	163.10
Task Lights	1,332.70
Area Lights	3,048.30
Total	959.90

**Table 4d**

Annual electricity consumption of rectangular building with an orientation of South East.

Electricity Use	Electricity kWh (x1000)
Space Cool	930.70
Heat Reject.	124.50
Hot Water	24.00
Vent. Fans	149.50
Pumps & Aux.	276.70
Misc. Equip.	163.10
Task Lights	1,332.70
Area Lights	3,001.00
Total	930.70

**Table 4e**

Annual electricity consumption of rectangular building with an orientation of North West.

Electricity Use	Electricity kWh (x1000)
Space Cool	935.60
Heat Reject.	125.30
Hot Water	24.00
Vent. Fans	149.70
Pumps & Aux.	278.80
Misc. Equip.	163.10
Task Lights	1,332.70
Area Lights	3,009.10
Total	935.60

**Table 4f**

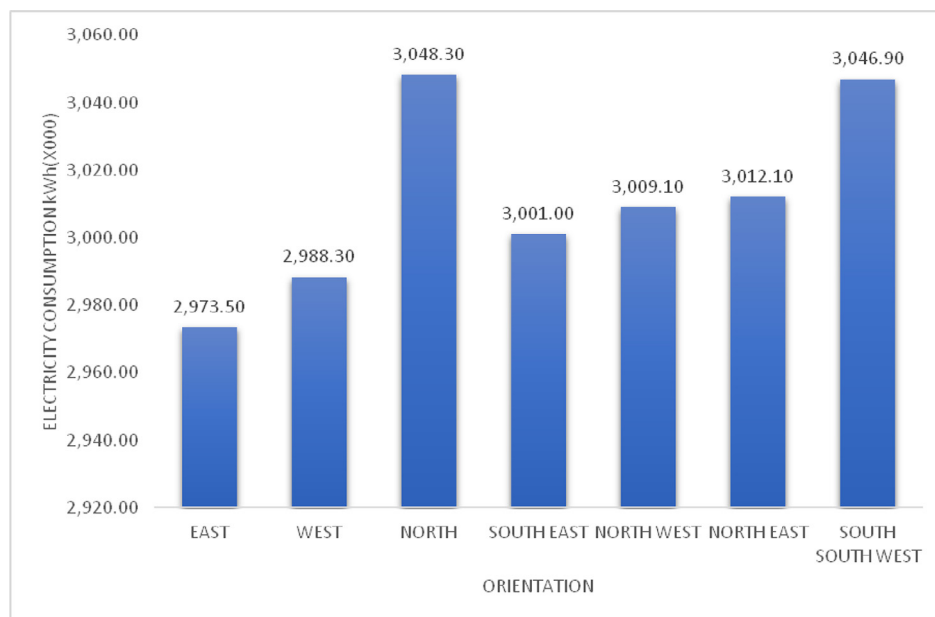
Annual electricity consumption of rectangular building with an orientation of North East.

Electricity Use	Electricity kWh (x1000)
Space Cool	937.70
Heat Reject.	125.70
Hot Water	24.00
Vent. Fans	149.10
Pumps & Aux.	280.00
Misc. Equip.	163.10
Task Lights	1,332.70
Area Lights	3,012.10
Total	937.70

## 5. Conclusion

In this study, annual energy consumption analysis of the retail building in the humid subtropical climatic zone has been taken place for five different baseline shapes (Rectangular, T, L, H and U). Twelve different source of energy consumption is being considered for this study namely Space Cool, Heat Reject., Hot Water, Ventilation Fans, Pumps & Aux, Misc. Equip., Task Lights, Area Lights, Task lighting, Exterior usage, Refrigeration and space heating. Study reveals that for humid subtropical region where annual energy consumption is high for space cooling, space heating and hot water. In such condition, rectangular shaped building is found to be more efficient in comparison with other building.

In order to enhance the thermal comfort in buildings, energy efficient building material is being used in simulation. The results were validated through simulation when the conventional wall material is replaced by innovative (vacuum inside) with a similar thickness of 290 mm. The simulation results show a decrease of thermal lag from 16.48 to 11.12 and an increase in thermal decrements from 0.02 to 0.18. It was found that energy-efficient measure wizard (EEM) plays a particularly prominent role in energy savings, and T8 fixtures should replace all the T12 fluorescent fixtures since T8 consume 35 W while T12 consume 150 W. For monthly electricity consumption, May was the most electricity consuming month of the year, regardless of the types of building. In May, the highest amount of space cooling was required to

**Fig. 11.** Annual electricity consumption of rectangular building with every orientation considered.

increase the occupancy comfort level. On an annual basis, the most electricity consuming building was the U-shaped building which consumed 3219.30 kWh overall annually. The list followed by the rectangular i.e. 3046.90 kWh, T-shaped i.e. 2863 kWh, H-shaped i.e. 2654.30 kWh and L-shaped buildings i.e. 2559.80 kWh. The application of EEM wizard has positively impacted the electricity consumption of buildings by reducing the consumption in specific building areas, thus reducing the total energy consumption by 15 to 20 %. The maximum reduction in energy consumption was seen in the rectangular-shaped buildings (by 19%). The average daylight factor showed that there was no artificial lighting needed in the proposed model. Based on the error analysis between experimental and simulated daylight factors, the results were found realistic in close agreement. The root means square error is found between these two values is 5.167 from March to June and 2.97% at noon from October to January. The daylight factor was maximum at 4 pm in the Commercial retail building. The use of artificial lighting system can be avoided during this time. The east orientation of the rectangular building in the Ranchi composite climate area consumed the least amount of electricity. This methodology can connect high and low-level parameter to acquire a comprehensive framework of the energy performance of the building, assisting with understanding what ought to be done to improve it and where further investigations to be led.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Appendix. [25]

- Root mean square deviation is given by:

$$E = \sqrt{\frac{\sum (e_i^2)}{N}}$$

$$\text{where, } e_i = \left[ \frac{X_i - Y_i}{X_i} \right] \times 100$$

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