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BUILDING ENERGY PERFORMANCE MODELING AND SIMULATION OF HOTEL BUILDING

Laxmi Gupta [1]
R L Sharma

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ABSTRACT

Building energy simulation using building information modeling (BIM) is proving to be an efficient technique in recent years for overcoming the challenging energy modeling process, reducing time, and advancing building energy modeling (BEM) and simulation into the digital design process. It facilitates the simulation of the energy performance of both new and existing buildings on a single platform. However, there is still a sizable discrepancy between the actual energy usage and the outcomes anticipated on longer time scales (monthly or annual basis) for a variety of reasons. We simulated the energy performance of a multi-storey hotel to investigate the applicability and efficacy of this approach. Using the same building data, ASHRAE's CLTD/SCL/CLF method and Autodesk's Revit 2021 were used to anticipate the cooling load of the building. The building's actual yearly energy usage was also modelled using Revit 2021 and compared to the observed data.

1. INTRODUCTION

According to the International Energy Agency (IEA, 2010), the operation lifecycle phase of buildings accounts for one-third of global energy use. It is anticipated to grow at an average annual rate of 1.0% until 2035 (IEA, 2018). If the energy consumed in the building's construction phase is also included, this number grows to more than 50%. Over the years, large-scale exploitation of mechanical systems for active cooling of buildings and other anthropogenic activities has significantly impacted our fragile ecosystem, leading to serious environmental problems. The extreme heat that engulfed significant portions of India and Pakistan in April/May 2022 had numerous, cascading effects on human health and ecosystems, agriculture, water and energy supplies, and many other key sectors of the economy. It will take months to assess the health and economic ramifications and cascading impacts of the present heat wave, including the number of extra deaths, hospitalizations, lost wages, and reduced working hours (Fawzy et al., 2020). Such catastrophic realities coupled with ever-increasing energy prices are leading to the creation of many regulatory mechanisms to reduce energy consumption and promote energy-efficient solutions for buildings.

These climatic occurrences show that the traditional mitigation measures - such as adopting low-carbon technologies, implementing regulatory policies, and limiting energy consumption - are not sufficient to meet the targets outlined in the Kyoto Protocol and Paris

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[1] Corresponding author: Laxmi Gupta
Email: lakshmigupta2007@gmail.com

Agreement. Despite many pledges and efforts by various governments, black carbon emissions have rather increased. The utilization of different alternative routes is inevitable to secure a low-carbon future below 1.5^0C. We need to secure emission reductions by managing our resources including buildings and smart cities more efficiently. Heating/cooling, ventilation, and air conditioning are the major energy consumption components in buildings contributing about 35% of total building energy use (IEA, 2010). Lighting contributes about 11%, appliances 18%, and the remaining 36% result from miscellaneous sources including electronics. Hence, there is enough potential to reduce energy consumption in the built environment by improving efficiency, selection of energy-efficient equipment and appliances, effective operation and control management, etc.

Several studies have been conducted by numerous authors to assess the energy performance of buildings using different methods (Zhang et al., 2020; Truong et al., 2021; Chou et al., 2016). The most common methods are (i) the degree-day method; (ii) the bin method; and (iii) Building simulation software. Energy predictive performance of multi-output energy models based on Bayesian adaptive spline surface and deep neural network was conducted by Li et al. (2022). The Building Energy Software Tools (BEST) directory (Sousa, 2012) provides good information on building software tools, ranging from simple databases and spreadsheets to whole-building energy simulation programs. A complete analysis of the existing BIM-based building energy modeling techniques and forecast of upcoming trends is given by Architecture (2019), Muslim (2021), Khaddaj & Srour, I. (2016). An in-depth and exhaustive comparison of modeling features of different simulation tools is also offered by Sousa, 2012; Architecture (2019), Muslim (2021), Khaddaj & Srour, I. (2016); Sola et al., 2018. A thorough analysis of the building energy prediction tools and the uncertainties associated with them is provided by Yu et al. (2022).

BIM is a comprehensive process for creating a digital prototype of a specific building or project using the entirety of the data about building geometry, materials used, weather parameters, internal and external loads, operation schedule, etc. The process culminates in 3D output referred to as a building information model which can help in achieving the ultimate goal of designing net-zero energy buildings (GSA, 2014). According to Bazjanac (2003), a time savings of 80% can be achieved in small buildings in the creation of building geometry alone through the appropriate application of BIM. It, therefore, appears to be very attractive particularly, during the conceptual design and development phase of the buildings which emphasizes the creation of alternate solutions for inexplicit buildings, including the planning of the layout, material selection, HVAC options, water and wastewater management, etc. (Gao et al., 2019). ArchiCAD and Revit are the two well-known tools of BIM technology. However, the current state of the collection of inputs for the building information modeling is a lengthy, tiring, and time-consuming process. As the building size and complexity grow, the input collection, analysis, and simulation become more and more difficult.

Contrarily, BEM is a process for developing energy models for buildings to conduct their energy simulation, asses energy performance, and quantify the effects of design choices on energy usage. Green building studio (GBS), eQuest, DesignBuilder, and EnergyPlus are some of the commonly used BEM tools (Kim & Anderson, 2013). EnergyPlus is a new-generation building energy performance simulation tool commonly used for buildings, especially multi-story offices, hotels, hospitals, or schools (Van Dessel et al., 2019). It has several comprehensive graphical interfaces, geometric modeling, and data exchange capabilities. More realistically than DOE-2, EnergyPlus features built-in equations and algorithms like TARP that take into account factors like occupant behavior, glazing material, internal and external gain, local climate, etc. (Crawley et al., 2008).

Autodesk’s Revit is a whole building energy simulation program that integrates both BIM authoring tools and simulation engine GBS/ eQuest/ EnergyPlus to facilitate designers to analyze the thermal performance of their designs (Kota et al., 2014; Yang et al., 2022). It makes use of the Radiant Time Series (RTS) approach (Yang et al., 2022) and can produce several energy analysis scenarios by taking into account different building aspects such as location, building height, the material used for the envelope, and the design of the building. The calculation can be done both on an hourly and annual basis.

It is expected that the integration of BIM in BEM is likely to make the process of realizing the energy-saving potentials of the building sector a reality. Despite large-scale efforts, gaps remain between the modeled and actual consumption data due to the complexity of energy consumption characteristics of the buildings, the type of analysis performed, the level of experience of the modeler, and personal preferences in terms of the workflow (Swan & Ugursal, 2009; Elnabawi, 2020). Inconsistencies are also associated with the selection of inputs, operation schedules, weather files, and the interoperability of data (Yang et al., 2022). The interoperability challenges between BIM and MEM have been outlined by several authors (Van Dronkelaar et al., 2016; (Alshibani & Alshamrani 2017). However, DesignBuilder and Virtual Environment have lately made significant advances in data transfer between the two (Kamel & Memari, 2019). Farzaneh et al. (2019) have suggested that current BIM-BES execution techniques need to focus on process and technology for effective data transfer and better results.

This paper investigates the BIM-BEM energy modeling process by conducting a case study of a G+6-storey hotel located in Nagpur, India. The forecasting of peak cooling energy demand and total building energy consumption are the key focus areas. Autodesk Revit 2021, which supports both BIM and BEM on the same platform, was used to perform the energy analysis and compute the energy consumption. To examine the effectiveness and interoperability of data between BIM and BEM, the findings were compared with the actual results and peak cooling load computed using cooling load temperature difference/ solar cooling load factor/internal cooling load factor/ (CLTD/SCL/CLF) method. It estimates heating or cooling loads using the Transfer Function Method (TFM) which is a simple approach for computer implementation (Utami et al., 2020). The computation of heat gain or loss through various components of the building envelope can easily be represented in MS Excel for clarity and visualization.

2. BIM-BEM SIMULATION PROCESS

BIM-BEM simulation is a three-step process (Figure 1) that involves: (i) the creation of a detailed 3D digital model of the building by transferring the entire building information into BIM software, such as ArchiCAD or Autodesk Revit; (ii) transformation of BIM data to an energy simulation engine DOE-2 or EnergyPlus using relevant data exchange systems such as IFC or gbXML; and (iii) prediction of energy consumption and efficiency of the building. The BIM model contains structured building data and always remains consistent and coordinated throughout the entire process.

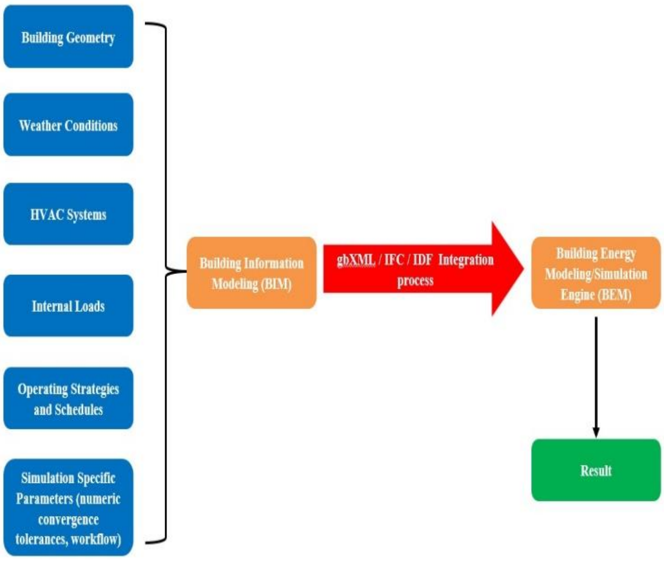


Figure 1. BIM-BEM simulation flow

At any stage, if any element is changed, BIM software updates the model immediately to reflect the change. The whole process of creating the digital BIM model and exporting the information to energy analysis tools relies on the enriched building information and data exchange ecosystems, categorized as Application Programming Interfaces (APIs), Green Building (gbXML) schema, and Industry Foundation Classes (IFC) (Li et al., 2020). Each approach has useful features (Jeong et al., 2016), but IFC is an open, ISO standard for information sharing between various software programs over the whole building life-cycle (Giannakis et al., 2015). Unfortunately, studies show that some data is constantly lost and the conversion of IFC-based models into other proprietary BIM systems is not entirely correct (Bazjanac, 2003). For better reliability, third-party products like EnergyPlus require BIM technologies like Revit or ArchiCAD. Autodesk Insight is the finest example of this approach that directly obtains BIM design information in the form of a gbXML file and carries out building energy simulation. The biggest disadvantage, however, is that BIM design data can only be communicated through a connected BIM authoring tool's API, which limits its flexibility and extensibility.

The Green Building XML schema (gbXML), is a spin-off from Green Building Studio that facilitates the interoperability of building data between BIM and BEM. Extensible Markup Language (XML), a text-friendly computer language that enables software programs to transmit information with little to no human interaction, serves as the foundation for this system. The schema is integrated into several CAD software and engineering tools and is supported by many leading vendors which have made it a standalone de facto industry standard. Since the gbXML format uses centreline representation for geometry, variances in estimated surface areas and space volumes have been noticed, which sometimes exceed the tolerance limits for larger complex building geometries (Li et al., 2020; Pinheiro et al., 2018). The absence of geometric representation of HVAC systems and equipment, which accounts for more than 15% of the total energy consumption in buildings, is yet another significant flaw in the gbXML format (Liu et al., 2013).

3. COMPONENTS OF HEATING/COOLING LOAD

Heat gain is the total quantity of heat energy produced by heat-producing objects, such as human bodies, lights, ovens, etc., as well as heat emitted by the sun that enters a building through conduction, convection, and radiation. The conditioned space absorbs the heat gained, changing the temperature therein. A building's heat gain or loss is influenced by a variety of factors (Van Dessel et al., 2019). Cooling load is the amount of cooling exerted by the air conditioner that is required to offset the heat gain, to maintain the desired temperature. A building's cooling load is divided into two main categories:

(a) External heat load: The external heat load is made up of

- Heat transmitted through building envelop (exterior walls, doors, windows, roof, etc.),
- Heat radiated through windows and glass,
- Heat convected through fenestration,
- Heat gained through ventilation and infiltration and
- Heat gained due to bypassing the airflow of the HVAC system.

(b) The internal heat load is the heat generated within the space by the

- Occupants,
- Lights and
- Equipment and Appliances.

The heat load due to infiltration and ventilation and heat generated by occupants and equipment can be further categorized as sensible and latent loads. Sensible heat is the heat absorbed by a substance while its temperature goes up. It impacts the dry bulb temperature and is immediately added to the area through conduction, convection, and radiation. However, because of the heat storage provided by the thermal mass present in the area, only the convective portion of the sensible heat gain enters the space. It instantly transforms into a cooling load. The latent heat load is the heat required to change the moisture contents of the air drawn into the conditioned space from internal or external sources. Although it doesn't affect the temperature of the conditioned environment, it does have an impact on how much moisture is present there. Figure 2 shows the different elements of the cooling load, while Figure 3 shows the several ways heat can move into or out of the building envelope.

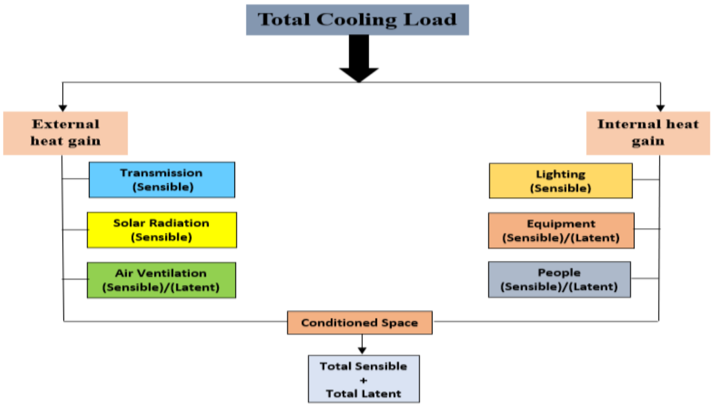


Figure 2. Components of Cooling load in Building

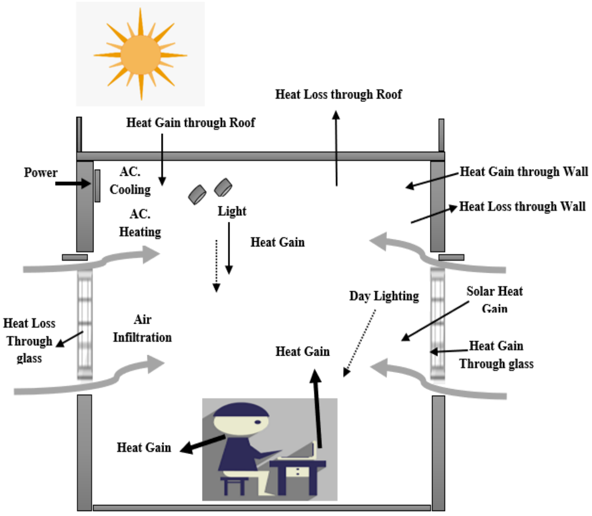


Figure 3. Modes of Heat Gain and Loss Through Building

4. CASE STUDY BUILDING

A hotel building with a G+6 storey located in the Nagpur district of Maharashtra, India was used as a case study. The gross area of the building is 12987.5 m^2 which includes bedrooms, banquet halls, conference rooms, cafeterias, and related services (kitchens, stairs, corridors, washing rooms, washrooms, etc.).

Figure 4. Front View of the Hotel Building

A typical front view of the building and its ground floor plan are illustrated in Figures 4 and 5 respectively.

The input data used for the energy performance analysis of the building is shown in Tables 1 and 2. Table 1 shows the building's input data which includes the type of building, building dimensions, orientation, glazing properties, materials used, materials U-values, etc., whereas Table 2 shows the weather data taken from Dr. Babasaheb Ambedkar International Airport, Nagpur applied for energy simulation. Maintaining a comfortable temperature inside the building requires an optimum cooling set temperature and relative humidity which are taken as 23^{0}C and 50% respectively.

The maximum dry-bulb temperature corresponding to 1% monthly percentile temperature, corresponding wet-bulb temperature, relative humidity, and humidity ratio which were used in the prediction of peak cooling load during every month of the year 2021 are summarised in Table 2.

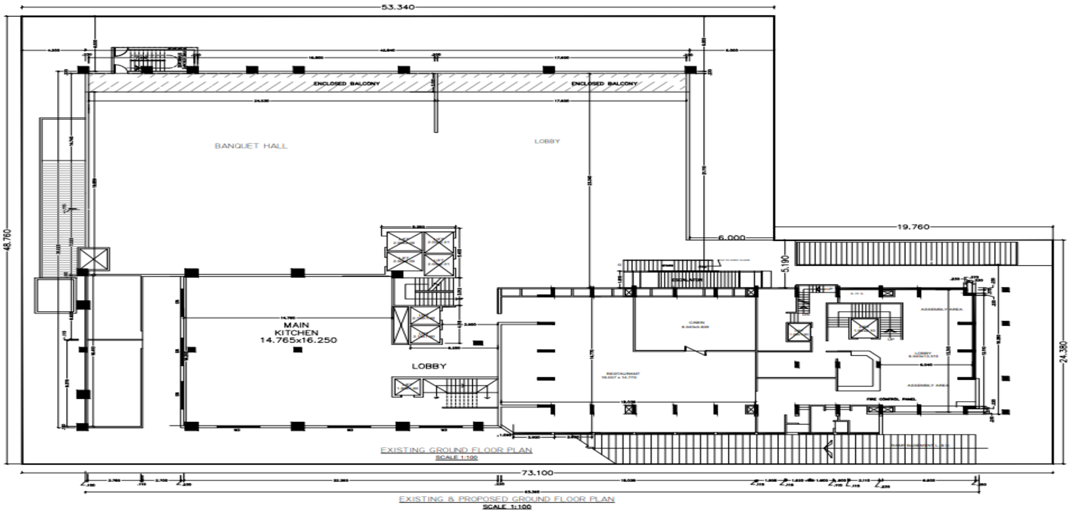


Figure 5. Building Ground Floor Plan

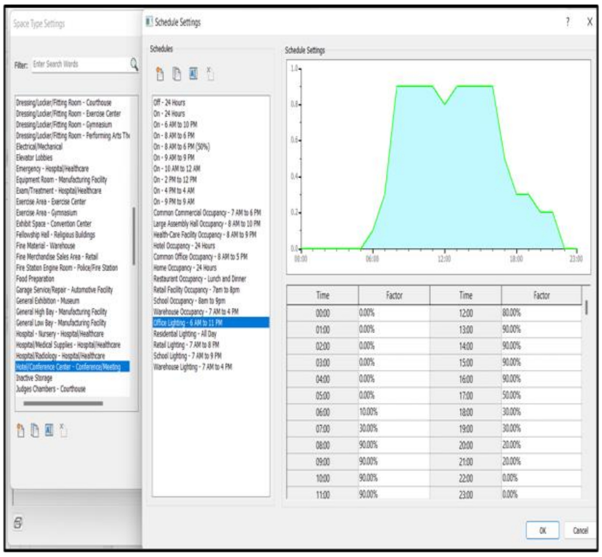
Table 1. Input BIM data for energy performance analysis

Parameter	Value	Description
Location (Latitude, Longitude)	21.13° N, 79.07° E	Nagpur (India)
Orientation	South	South
Net conditioned building area	12498.67 m^2	
No. of Floors	G + 6	RCC Building
Floor-to-floor height	3 m	
Window opening area	862.8 m^2	
Gross wall area	4037.54 m^2	
Footprints	Hospitality	
(b) Heat Transfer Coefficient		
U-value (Exterior walls)	0.48 W/(m^2·C)	Outer walls - Brick 230mm thick
U-value (Windows)	2.86 W/(m^2·C)	Window panes - Double glazed.
U-value (Roof)	0.256 W/(m^2·C)	RCC lightweight
Airtightness	0.12	Doors, Windows, etc.
Ventilation rate	1 ACH	Air change per hour for ventilation
Sensible heat gain per person	70 W	According to the seated condition of the people.
HVAC System	-	Central VAV
Building operation schedule	-	Default
Services	-	Heating and Cooling

Table 2. Maximum and Minimum dry-bulb and wet-bulb Temperature and Humidity

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum Dry-bulb temp. (^{0}C)	29.1	33.6	37.0	43.1	43.8	38.3	31.6	31.8	33.3	33.9	31.3	29.8
Minimum Dry-bulb temp. (^{0}C)	12.2	14.4	18.5	24.4	27.8	26.4	24.2	24.1	23.8	21.1	15.1	11.6
Wet-bulb temp. (^{0}C)	23.0	24.4	24.0	25.1	29.2	31.5	28.7	29.1	30.4	29.9	25.6	24.3
Relative humidity %	58.4	44.8	31.1	20.6	31.4	60.5	80.2	81.7	80.4	73.8	62.9	62.9
Humidity ratio	0.005	0.006	0.003	0.004	0.009	0.017	0.015	0.02	0.018	0.016	0.009	0.008

Building operation schedule: The service/occupancy operating schedules as illustrated in Figure 6 were used for evaluating the energy performance of the building. A typical lighting schedule (6 AM – 11 PM) is shown on the right side of Figure 6.



Time	Factor	Time	Factor
00:00	0.00%	12:00	80.00%
01:00	0.00%	13:00	90.00%
02:00	0.00%	14:00	90.00%
03:00	0.00%	15:00	90.00%
04:00	0.00%	16:00	90.00%
05:00	0.00%	17:00	50.00%
06:00	10.00%	18:00	30.00%
07:00	30.00%	19:00	30.00%
08:00	90.00%	20:00	20.00%
09:00	90.00%	21:00	20.00%
10:00	90.00%	22:00	0.00%
11:00	90.00%	23:00	0.00%

Figure 6. Customized Operation Schedule

5. ENERGY SIMULATION

5.1 Calculation of Energy Consumption and Cooling load by Autodesk Revit

The building input simulation parameters used in the case study are summarized in Table 1. The 3D base model of the building developed in Autodesk's Revit 2021, using the information given in Table 1, is shown in Figure 7. Weather parameters specific to the building location were selected automatically. Building spaces sharing identical thermal characteristics and operating identically were agglomerated into different zones and the model was simplified by adjusting the settings available on the menu of the Revit software to improve the accuracy.

The maximum outside dry-bulb temperature, minimum outside dry-bulb, and wet-bulb temperature at the time of the maximum dry-bulb temperature and humidity ratio are the essential input weather parameters for cooling load prediction. Indoor design conditions for cooling/heating depend upon the user's choice and season. However, ASHRAE has recommended the set point temperature and relative humidity as 25^0 Celsius and 50% respectively for the Indian subcontinent. In the instant case, the indoor temperature was set at 23^{0}C and relative humidity at 50%.

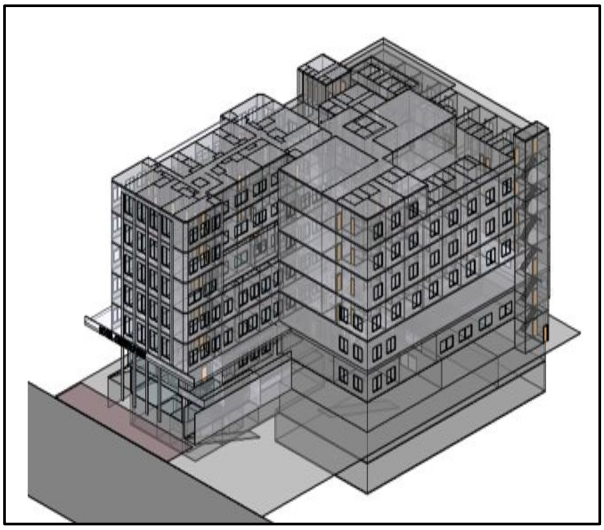


Figure 7. 3D Energy Model of the Building Generated in Revit

The BIM input file containing the building information including spaces and zones of the building and the weather data was imported to EnergyPlus to run an energy performance analysis. There are many formats available for data exchange between BIM and BEM applications. However, IFC and gbXML are the two well-known and commonly used schemas in the industry (Dong et al., 2007). The gbXML, which is a simple and straightforward format, is used to integrate data between the BIM and EnergyPlus. The simulated output includes peak heating, cooling load, the energy needed for lighting and operation of equipment and appliances, and, annual energy consumption for the same.

5.2 Calculation of Energy Consumption and Cooling load by CLTD/SCL/CLF Method

The CLTD/CLF/SCL is a data-driven static method developed by ASHRAE using a transfer function approach to make energy consumption simpler. The method first calculates the sensible cooling load based on the TFM. The result is divided by the sensible heat gain to generate the cooling load temperature difference (CLTD). Since, conductive and radiated heat gains are not instantaneous and hence, CLTD and cooling load factor (CLF) has been introduced to account for the thermal lag. The CLTD accounts for the combined effects of conduction and radiation storage, whereas, SCL accounts for the delay before solar heat radiated directly into the conditioned space becomes the cooling load. It is the product of the solar heat gain at that hour and the fraction of heat storage effect due to various types of room construction and floor coverings. Energy load calculation using the CLTD method can be either computer-aided or performed manually using an Excel sheet. The explicit equations used to compute the sensible and latent components of energy consumption are as follows:

(a) Sensible solar heat gain through conduction: The heat transmitted through opaque components such as walls, floors, ceilings, doors, and windows constitute the major portion of sensible cooling load and can be computed as

$$Q_s = U \text{ x } A \text{ x } CLTD \tag{1}$$

where Q_s is the sensible heat conducted (W), U is the overall heat conductivity coefficient (W/m^2-K), A is the surface area (m^2), and CLTD is the equivalent temperature difference across the surface (^OC).

(b) Solar heat gain through fenestration: The sensible heat gain through fenestration comprises heat convected through the glazing and radiated through the window frame. The convective load is calculated using equation (1), whereas, heat gained due to radiation is estimated as

$$Q_s = A \text{x } SC \text{ x } CLF \tag{2}$$

The shading coefficient (SC) can be found in the manufacturer's product data and is normally unique to the glass manufacturer. Alternatively, instead of SC, Solar Heat Gain Coefficient (SHGC) is can be used as specified in the 2005 ASHRAE Handbook of Fundamentals.

(c) Heat gained through ventilation and infiltration: Ventilation is the process of providing indoor air quality in a conditioned space, whereas infiltration is the air that leaks into a building through recesses and creaks in doors and windows, gaps, cracks, and holes in the building envelope. It contributes to both sensible and latent heat loads. The sensible heat load due to ventilation and air infiltration can be estimated as

$$Q_s = c_p \, \rho \, q \, [T_o - T_i] \tag{3}$$

where c_p is specific heat (1.006 kJ/kg ^oC), ρ is density (1.202 kg/m^3), and q is the air flow rate in m^3/s. T_o and T_i are the dry bulb temperature and the conditioned space set point temperature respectively. Substituting the values of c_p and ρ, equation (3) can be expressed as

$$Q_s = 1.21 \, q \, [T_o - T_i] \tag{4}$$

In equation (4), q = ACH x V/3600 is the air infiltration rate in m^3/s, V is the volume of conditioned space in m^3, and ACH is the number of air changes per hour. The ACH value depends upon the age and condition of the building and varied between 0 and 1. For airtight constructions, it is zero, and for neutral average constructions, it can be safely assumed as 0.5. The latent part of the heat load, Q_L is calculated as

$$Q_L = \rho \, h_{we} \, q \, \Delta w \tag{5}$$

where, Q_L = latent heat in kW, ρ is the density of air, q is air volume flow in m^3/s, h_{we} is the latent heat of vaporization of water, and Δw the humidity ratio in kg water/kg dry air.

(d) Heat load due to occupants, lights, and appliances: The heat load due to occupants and appliances depends upon the number of users, heat gain factor, type of equipment, and wattage. It can be calculated using the following equations:

Occupants: The persons inside the building contribute to both sensible (Q_s) and latent heat load (Q_l) computed as follows:

$$Q_s = \text{No. of persons x Sensible heat gain per person x } CLF \tag{6}$$

$$Q_L = \text{No. of persons x Sensible heat gain per person} \tag{7}$$

Lighting: Lighting contributes only sensible heat load and can be calculated as

$$Q_s = \text{Installed wattage x Ballast factor x } CLF \tag{8}$$

where CLF is the dimensionless cooling load factor which accounts for how well the area can absorb and store the heat produced by the lights. It can be taken as 1 if the lights are on for 24 hours. The Ballast factor is 1.2 for fluorescent lights and 1.0 for incandescent lights.

Appliances: The appliances may contribute only sensible heat (as is the case for a computer) or both sensible and latent heat (as is the case for a coffee maker). It can be calculated as

$$Q_s = \text{Installed wattage x usage factor x } CLF \tag{9}$$

(e) Heat Gain due to bypass airflow of HVAC: Some amount of air directly enters the conditioned space bypassing the cooling coil of the HVAC system. The sensible and latent heat components due to by-passed airflow can be calculated using equations (4) and (5) respectively by replacing q with q x BPF, where q is the ventilation rate and BPF is the by-pass factor of the cooling coil. Cooling load on the building also occurs due to air leakage in the supply ducts and electric motor which drive the fan. To take this into account, 5% of the room's sensible load was added to the total load.

6. RESULTS AND DISCUSSION

6.1 Prediction of Peak Cooling Load

The case study building is located in Nagpur (India) where energy is only needed for cooling, lighting, and operating various facilities and equipment for most of the year. The peak cooling load has been computed using BIM-based Revit 2021 and CLTD/CFL/SCL methods. The load is predicted by the Revit software automatically whereas, it is computed manually when the CLTD/CFL/SCL method is employed.

The output retrieved from the energy simulation include peak heating and cooling load, peak electricity consumption by lighting and appliances besides energy use intensity and cost. The peak cooling load is primarily used to calculate the volume air flow rate and tonnes of refrigeration needed for the air conditioning system. The other useful information provided by the analysis is the annual energy needed for the different end uses namely heating, cooling, lighting, and operation of appliances. It comprises sensible and latent heat released from the heat sources (people, electric lights, equipment, and appliances) inside the conditioned space.

Table 3 shows the peak cooling load predicted for each month for the year 2021 using Revit and CLTD/CLF/SCL methods. The Revit measured a peak cooling load of 1709.9 kW as compared to the CLTD/CLF/SCL method's 1626.8 kW. The comparison of the peak cooling load shows that, on average, the peak cooling load estimated using Revit is 10.3% higher than the load predicted using the CLTD/CFL/SCL approach. Figure 8 shows visually the peak cooling load curves predicted by the two approaches. Figure 8 also displays the monthly maximum dry bulb temperature for which the cooling load was computed.

Table 3. Peak cooling load

Month	BIM Revit 2021 (KW)	CLTD/CLF/SCL (KW)	Maximum Temperature in ^{O}C During the month	Set Point (^{o}C)	Relative Humidity in Percent
January	799.8	743.1	29.1	23	58.4
February	1020.3	951.5	32.8	23	44.8
March	1211.8	949.5	37.0	23	31.1
April	1571.0	1156.3	43.1	23	20.6
May	1531.3	1412.2	43.8	23	31.4
June	1658.8	1626.8	38.3	23	60.5
July	1371.6	1307.0	31.6	23	80.2
August	1356.7	1345.6	31.8	23	81.7
September	1709.9	1479.3	33.6	23	80.4
October	1630.3	1429.4	33.9	23	73.8
November	1282.3	1022.9	31.3	23	62.9
December	905.8	895.0	29.8	23	62.9

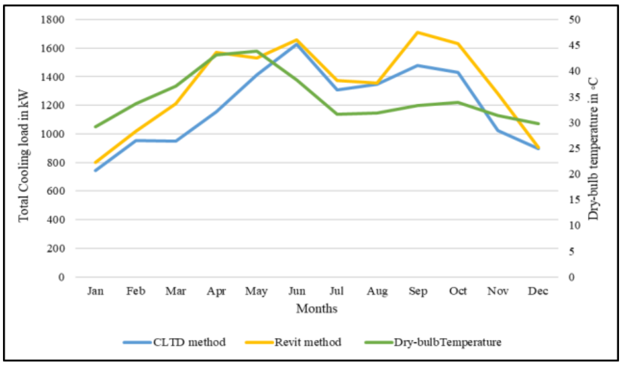


Figure 8. Peak cooling load (KW) prediction by month for 2021

The comparison also demonstrates that the peak cooling demands can be accurately predicted using both the Revit 2021 and CLTD/SCL/CFL modeling techniques. Figure 8 shows that the peak cooling load predicted by the two methods follows a comparable and similar trend. The cooling load is low during the winter months from January through December. To compute the peaking cooling or heating load, the building must be fully occupied and operating at peak capacity. This usually happens in the case of service buildings such as hotels located in tourist places and bigger cities. However, this is not the case for buildings situated in less significant locations or during off-peak times, when occupancy is based on client availability. From time to time and from season to season, it changes. In such cases, the prediction of true peaking heating or cooling loads requires complete adherence to the actual operation schedule which may not be possible. The actual operation schedules cannot be followed when multi-storey complex buildings are involved.

Residential structures, on the other hand, are straightforward and smaller in size, making it easier to identify and follow actual operation schedules and predict accurate energy usage on a daily or monthly basis. Therefore, it follows that by employing an automated BIM-based modeling and simulation method on a single platform, the peak cooling loads in all types of structures, from modest dwellings to complex multi-storey buildings and hotels, may be precisely anticipated which can be used for sizing the air conditioning systems or devising energy management strategies to reduce energy consumption.

6.2 Prediction of Annual Cooling load and Energy Consumption

The annual energy consumption of a building is the energy needed to keep the building operational and environmentally comfortable throughout the year. It includes the energy required for heating, cooling, ventilation, air conditioning (HVAC), and operating various equipment and appliances throughout the year. The component-wise annual energy consumption predicted by Revit 2021 is shown in Figure 9. The total yearly energy usage is 5423595 kWh, with cooling load accounting for approximately 4681464 kWh, while lighting and appliances use, respectively, 724275 and 242069 kWh. The yearly energy use intensity is 433.9 kWh/m^2, which is unusually high. The cooling load represents 81% of the total annual energy consumption. Electric load, which uses roughly 13% of the total annual energy, comes next.

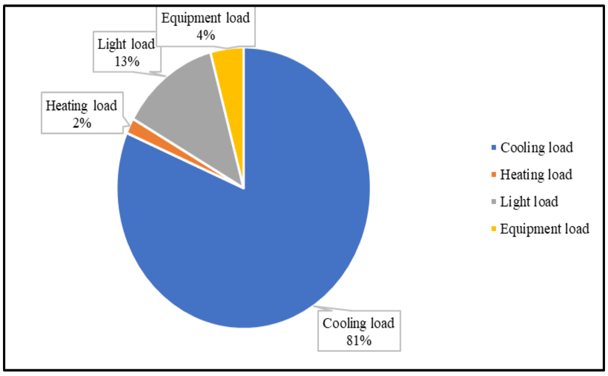


Figure 9. Components of Predicted Annual Energy Consumption Using Revit (kWh)

Lighting plays a significant role in energy consumption, particularly in commercial buildings. According to ASHRAE, every 100 watts of illumination requires 30 to 35 watts of cooling. However, well-designed lighting systems, upgrades, and utilization of solar energy can significantly reduce the lighting energy load in all kinds of buildings, especially commercial ones.

6.3 Comparison of Predicted and Measured Annual Energy Consumption

The predicted annual energy consumption using Revit 2021 is compared with the actual measured energy consumption. The actual electric load is the electricity consumption for both cooling as well as for lighting and operation of equipment and appliances during the whole year. It is measured on monthly basis as a performance appraisal system. The component-wise measured annual energy consumption is shown in Table 4 for the year 2021. The component-wise total annual energy consumption for the hotel building is shown in Figure 10.

Table 4. Comparison of Predicted and Measured Energy Consumption

Month	Actual load (kWh)		
	Cooling Load	Electric load	Total load (kWh)
January	28375	7479	35854
February	11997	8980	20977
March	3134	12555	15689
April	5736	15318	21054
May	9385	18052	27437
June	1460	17614	19074
July	16138	16172	32310
August	17038	13244	30282
September	19926	13145	33071
October	23446	13989	37435
November	25016	11292	36308
December	27957	11243	39200
Total Annual Consumption (kWh)	189607	159083	348690

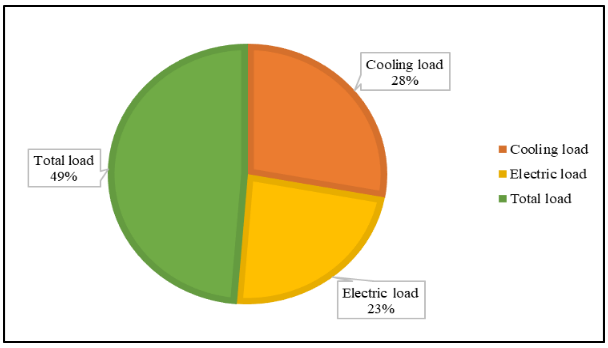


Figure 10. Component Wise Measured Energy Consumption (kWh)

It can be observed that the measured and predicted annual energy consumptions differ considerably. The difference is due to a large number of uncertainties and factors associated with the prediction process. For example, the factors related to energy consumption and usage of appliances depend upon people's choices, perceptions, habits, and physiological conditions. Development of actual schedules for all the occupants is necessary for accurate forecasting of energy consumption in buildings which is rather difficult.

Weather dataset profiles of insolation, outside dry bulb temperatures, humidity, etc. are required to predict energy consumption on a monthly or annual basis. These inputs have a direct bearing on energy consumption. The weather forecasts have greatly improved and are more accurate & reliable today as compared to thirty years ago. And it keeps getting better. Exceptionally accurate weather forecasts are now achievable thanks to a wealth of historical data, improved forecast models, a large array of atmospheric sensors (on and above the Earth), and technology advancements. However, despite all these developments, there are still limitations on how far ahead weather forecasts can be made accurately. Global warming and chaotic and unpredictable weather systems are all making long-term weather forecast a difficult task. According to meteorologists, weather forecasts for up to five days can insolation be made with a fair amount of accuracy. Due to these uncertainties and limitations, predicting the energy consumption of buildings, especially on a monthly or yearly basis, is a challenging process. Furthermore, BIM-based energy consumption predictions have their limitations and interoperability issues.

7. CONCLUSIONS

The application of BIM in BEM is likely to make the process of realizing the energy-saving potentials of the building sector a reality. It is likely to offer a wide range of benefits including the study of different design alternatives, designing sustainable built environments having reduced carbon footprints, facility management, and planning building operations post-construction. However, it is noted that the construction of a complete building energy model that includes everything right from building geometry, material and construction, building/space type, well-structured thermal zones, and operation schedules, to HVAC systems and components is still a complex and difficult task. Options for customization of the operational schedule are not enough which could be more beneficial for precise analysis. So far, the process of integrating BIM and BEM is non-standard and has its limitations and interoperability issues.

Autodesk’s Revit 2021 is a whole building energy simulation program that integrates both BIM authoring tools and BEM to facilitate users to analyze the thermal performance of their designs. Simulation in Revit 2021 provides useful information on peak heating or cooling demand, peak electricity demand for lighting, and the operation of appliances. The add-on works well and saves time by creating the energy model automatically and performing energy simulations on different time scales. Comparison of hourly output (peaking cooling load) from Revit 2021 and CLTD/CLF/SCL shows a close agreement, whereas, monthly and annual energy consumption output from Revit 2021 differs significantly as compared to the actual energy consumption.

The CLTD/CLF/SCL method provides a reasonably accurate result on different time scales because appropriate values of the coefficients about the region can be easily chosen from the SCL tables of the ASHRAE Handbook. The peak cooling loads for the hotel building predicted by the CLTD/CLF/SCL and Revit modeling are 1709.9 kW and 1763.3 KW, respectively which is close enough within an acceptable range of 10%. The comparison of the peak cooling load profiles shows an overall consistency in the predicted results. The study further shows that lighting represents the second largest source of energy consumption in commerce.

It is further noticed that Revit 2021 cannot anticipate energy consumption accurately on a monthly or annual basis due to non-adherence to actual operation schedules for various systems and devices which vary randomly and are hard to predict. Data on monthly power usage is crucial since it is used in various processes, including estimations of the local GDP and decision-making. Finding a strategy to anticipate monthly electricity use is crucial.

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Laxmi Gupta
Lovely Professional University, Punjab
Nagpur
India
lakshmigupta2007@gmail.com
ORCID 0000-0001-6645-7140

Ramlal Sharma
Lovely Professional University, Punjab
Phagwara
India
sharma.23743@lpu.co.in