

ENERGY ANALYSIS AND DESIGN OF HVAC SYSTEM USING BIM

Mohammed Hussain, Anand Kumar S. Malipatil, Rajesh Holkar

Department of Mechanical Engineering, Visvesvaraya Technological University,
Kalaburagi, Karnataka, India

ABSTRACT

Over the past decade, there is substantial growth in the building's energy consumption. This has drawn attention to the contradiction between high energy use and low energy efficiency in the construction industry. The HVAC system accounts for the major energy consumption in the buildings. Therefore, it's important to examine and assess energy-conserving solutions for HVAC systems. The total cooling and heating load of the building is determined by various factors such as its location, orientation, heat gain through walls, window glass, roofs, people, lighting, electrical appliances, and ventilation infiltration rate. It is necessary to consider energy analysis and optimization in the conceptual design phase of a project. Starting energy analysis during this phase is the most effective as it is the most flexible stage of the design, allowing for numerous adjustments while saving the most energy. Earlier energy analysis used to take a long time, but with Building Information Modeling (BIM), it can now be done rapidly. The BIM model can be directly used for analysis of energy with Energy analysis tools (Autodesk Insight), eliminating the complex computations. BIM provides a complete solution for system analysis and design. The central theme of this research is a commercial school building project in Karnataka, India. This research proposes a BIM-based energy analysis using Insight, heating and cooling load analysis, and its variation with different thermal properties (U-value) as well as creating the 3D HVAC design Model in Autodesk Revit.

Keywords: BIM, Energy Analysis, HVAC System, U-Value, Heating and Cooling Loads.

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1. INTRODUCTION

Buildings are the significant consumers of energy and contribute to a substantial portion of the global energy consumption. The energy usage in buildings typically includes electricity for heating, ventilation, air-conditioning (HVAC) systems, lightings, appliances, and other electrical equipment. Electricity is the main source of energy for buildings in India. The trend of entire energy usage in India from 2012-13 to 2021-22 as illustrated in Fig. 1. From the data, an average increase in energy consumption is 2% to 5% in India. Since the energy usage of the buildings makes up the largest part of total energy utilized by societies, energy usage of HVAC systems is the highest consumer of building energy, which contributes more than 60% of it. Therefore, it is most important to optimize the energy saving of the HVAC systems.

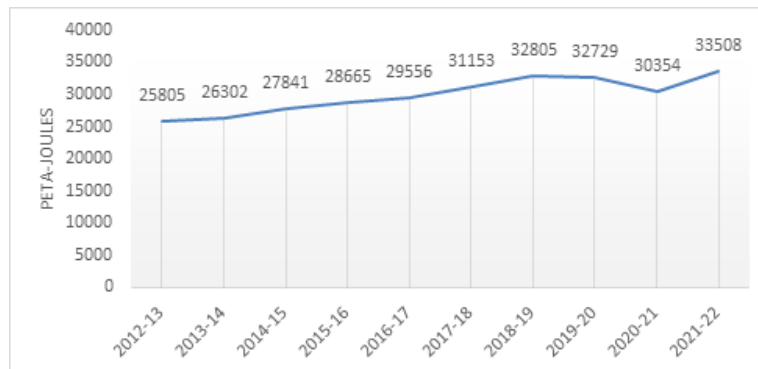


Fig. 1— Trend of total consumption of Energy in India

In this project, the process & significance of the energy analysis of a building is given. Based on building material and its thermal coefficient properties the energy analysis is carried out. This project demonstrate a detailed idea of model creation using the BIM process and how the BIM model analysis is made using the software itself. Here we used the Revit software with Autodesk insight to make a 3D model of the buildings, to create an Energy analysis model and its energy optimization. In the HVAC system design, the heating & cooling load analysis, how it varies with the U-values of wall, window, and roof, and creating the 3D BIM model of the HVAC system is discussed.

The literature survey provides a comprehensive overview of studies focused on energy analysis and HVAC system design, employing the framework BIM. The works collectively emphasize the transformative potential of BIM technology in optimizing energy efficiency and sustainable building practices. Abhilash Jangalve [1] addresses residential building energy analysis, highlighting the role of BIM in Autodesk Revit and Autodesk Insight for effective energy assessment. Fatemeh BOLOORCHI's [2] work emphasizes optimizing eco-building windows, recognizing their substantial impact on energy demand. Utilizing Autodesk Insight 360, the study seeks to minimize energy consumption through optimal window-to-wall ratios, materials, shading, and positioning. Tianyi Zhao [3] delve into BIM-based energy efficiency analysis in alignment with GB50189-2015. Through Autodesk Revit, they model a single-story laboratory building in Dalian, China, adhering to thermal analysis and HVAC design standards. Mohd Sohail [4] focuses on HVAC systems in commercial spaces, particularly shopping malls, offering insight into various air-conditioning systems with distinct features and applications. Hongxin Wang [5] and collaborators present an automated HVAC system design for office buildings via BIM, encompassing the entire process from BIM modeling to load calculations, equipment selection, and system diagram creation. Christoph van Treeck [6] explore energy analysis using BIM tools, detailing energy load calculations and total energy demand assessments through gbXML format conversion.

Finally, Salman Azhar and Justin Brown [7] underline BIM's role in complex building performance analysis, utilizing software like Ecotect, Green Building Studio, and Virtual Environment for sustainable analyses. Collectively, these studies illuminate BIM's transformative potential in enhancing energy efficiency and sustainable design across various building contexts.

The main objective and scope of this project are as follows:

- To create the BIM model of the school building using Revit.
- To create the Energy Analysis Model (EAM)
- To Analyze and study how the building orientation, wall-to-window ratio (WWR), Wall construction, Roof construction, window glass, shades, and other various parameters will reduce the Energy Used Intensity (EUI) using the Insight.
- To Perform the heating & Cooling load analysis and to study Cooling and heating load with different construction material properties of roofs, walls, and windows.
- To create the 3D BIM Model of the HVAC system in Revit.

2 MATERIALS AND METHODS

2.1. Building Description:

Building name	: School Building
Location	: Kalaburagi, Karnataka, India
Building type	: Commercial school/university
Orientation	: North
No. of Floors	: Two Floor (GF+FF)
Latitude	: 17.32 E
Longitude	: 76.85 N

Category	Description	U-value BTU/h.ft ² .F (W/m ² .K)
Exterior wall	8 in masonry 0.5 in gypsum	0.32(1.82)
Interior wall	4 in brick both side plaster	0.21(1.19)
Roof	4 in lightweight Concrete	0.22(1.25)
Floor	4 in concrete deck floor	0.33(1.87)
Window	Ordinary glass (Medium color)	0.56(3.18)
Doors	wooden	0.41(2.33)

Table 1—The building elements construction with U-values.

2.2. Creating the Architecture BIM Model using Revit

Before starting a new Revit model, it is essential to set up the project with the appropriate units, project location, and other relevant settings. This ensures that the model accurately reflects real-world conditions and aligns with project requirements. The first step in creating a Revit model is to develop the architectural design. This involves generating the building's floor plans, elevations, sections, and other architectural elements. Revit provides a wide range of tools and features to aid in creating walls, doors, windows, roofs, and other architectural components. The 3D Architectural Revit Model of the school building as illustrated in Fig. 2. As the Revit model is developed, it is crucial to generate accurate and comprehensive documentation. Revit automates the process of generating construction documents such as floor plans, sections, schedules, and material take-offs. These documents can be customized to meet project requirements and updated dynamically as the model changes.

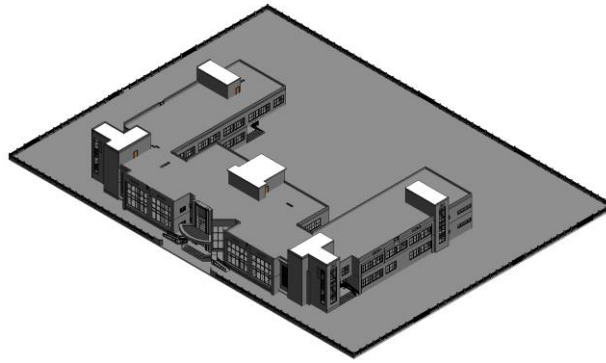


Fig. 2—3D Architectural Model of the School Building.

2.3. Energy Analysis of the Model

Energy analysis of a building is the process of evaluating and assessing the energy performance and consumption of a building. It involves analyzing various aspects of a building's design, construction, and operation to understand how it uses energy & identify opportunities to improve its energy efficiency. An energy analysis model in the context of building energy analysis refers to a computational representation of a building that is used to simulate its energy performance and consumption. It can be used to evaluate the impact of design changes, such as different insulation levels, window types, or HVAC systems, on the building's energy performance. This iterative process helps designers optimize the building's energy efficiency and identify the most effective energy-saving measures. There are five main steps in the energy analysis of the 3D Revit model, which are as follows:

1. Location
2. Energy setting
3. Create the Energy Analysis Model (EAM).
4. Generate
5. Optimization with different scenarios

2.3.1. Location

The first step in energy analysis is to define the location and select the nearest weather station. The Location and Weather station data provide valuable climatic information that helps in running energy simulations. Accurate data about external conditions such as temperature and solar radiation is essential for the predicting energy usage of building and HVAC loads. The Fig. 3 shows the location and weather of the 3D Revit Model of the school building.

2.3.2. Energy setting

There is one key setting connected to conducting the simulation and a few more that must be addressed to generate a valid EAM in the Energy Settings dialogue, which has been streamlined in Revit. All other inputs can be modified in the cloud afterward to evaluate their real-time influence on overall performance. The Energy Settings dialogue is divided into two sections.

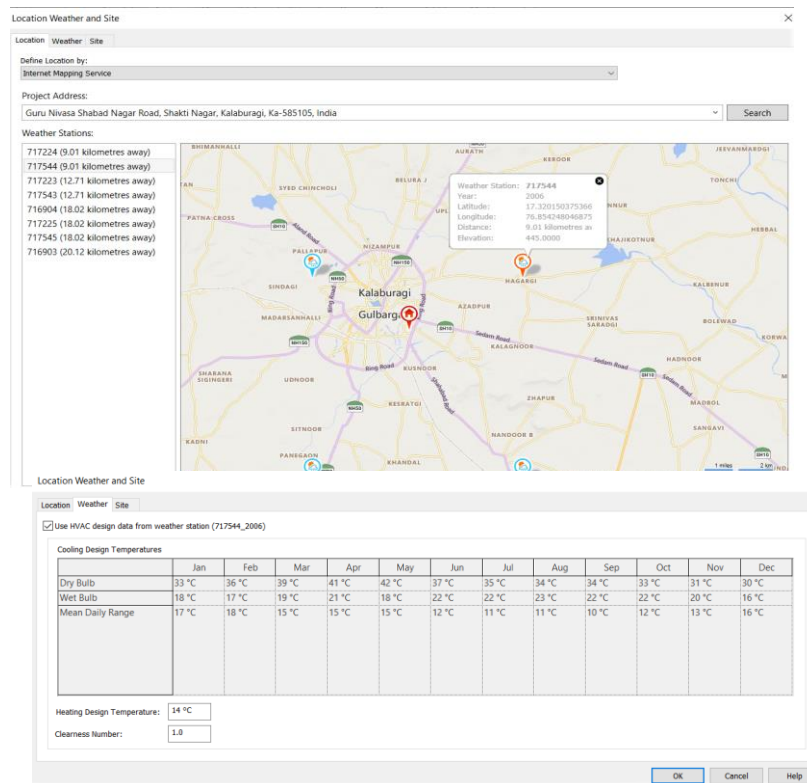


Fig. 3— Location and Weather Details

One important selection as describe in Fig. 4 is the schematic types where the Analytical construction, simply the U-value, is selected depending on the building elements materials shown in Table 1 and checked to override this value.

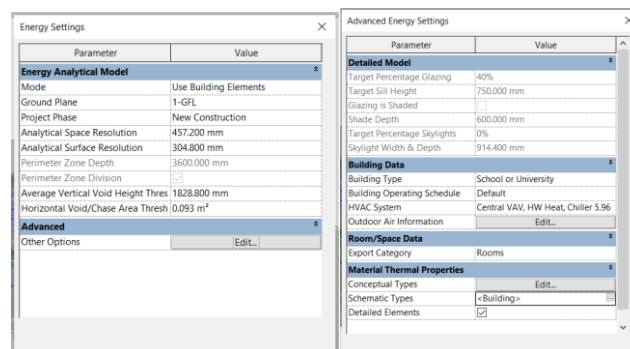


Fig. 4—Energy settings

2.3.3. Create Energy Analysis Model

The design data collected by Revit, such as Location, weather data, building data, and thermal properties (U-value), is used to generate the various codes that allow Insight to carry out energy simulations. The energy analysis model resulted in the creation of the analytical spaces model as shown in Fig. 5 and the Analytical Surfaces Model as shown in Fig. 6. Analytical Spaces, also known as thermal zones, are virtual representations of the internal spaces within the building that helps for energy analysis purposes. Analytical Surfaces are the elements that enclose Analytical Spaces and define their thermal boundaries. They play a critical role in determining how heat is transferred between spaces during energy simulations.

2.3.4. Generate

With Generate tool, the EAM is sent to the Insight to generate the energy simulations and set the ranges for the different scenarios. Through Insight, the building energy model, monthly temperature variation and windrose speed variation graph is generated as shown in Figs. 7, 8, and 9.

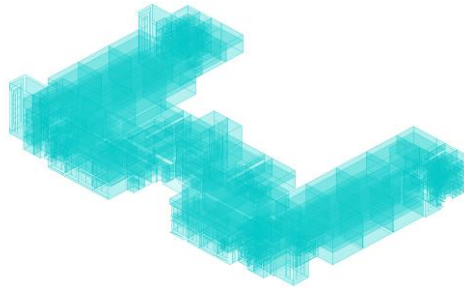


Fig. 5—Analytical Space Model

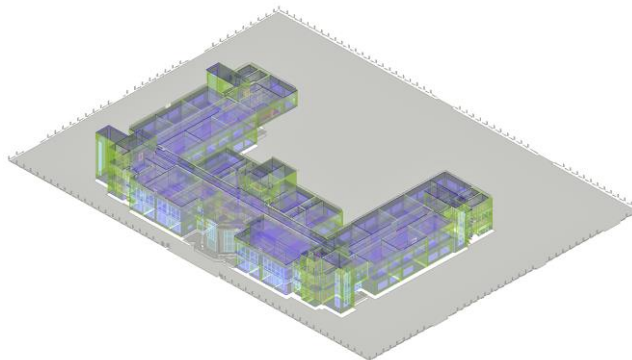


Fig. 6—Analytical Surface Model

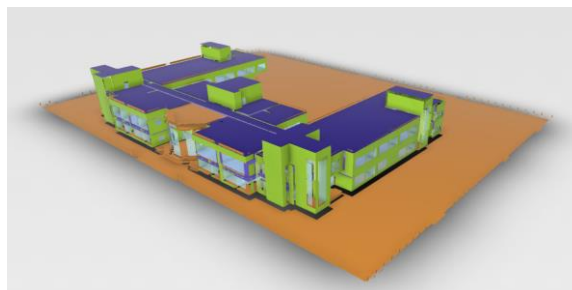


Fig. 7—Building Energy Model generated by Insight.

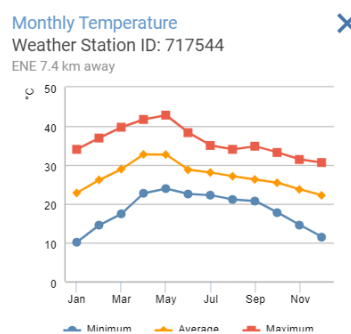


Fig. 8—Monthly Temperature variation generated by Insight

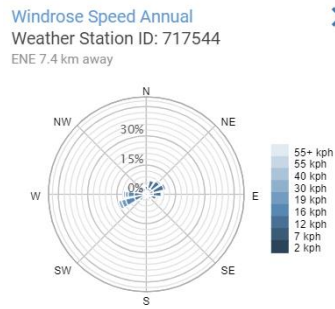


Fig. 9—Annual Windrose Speed variation generated by Insight

Summer	
Dry Bulb Temperature (°F DBT)	75 ± 2
Relative Humidity (%)	50 ± 10
Winter	
Dry Bulb Temperature (°F DBT)	72 ± 2
Relative Humidity (%)	50 ± 10

Table 2—Indoor Design Conditions:

2.3.5. Optimization and Energy Analysis

After creating and editing the energy model, the next step is performing energy analysis and generating design options using Insight. The optimize tool allows access to Insight statistics on energy and environmental performance. Insight offers visualizations and reports that present the analysis results in a user-friendly and informative manner. Insight allows for parametric analysis, where users can adjust design parameters within specified ranges to explore multiple design scenarios quickly. This enables optimization and sensitivity analysis for the identification of the most energy-efficient design solutions. The energy analysis and optimization are based on the energy usage intensity (EUI) in kWh/m²/yr. Energy Use Intensity is calculated as the ratio of total energy consumed by the building per year to the building's total built floor area. The different scenarios are made by using various parameters like Building orientation, Operating schedule, Electrical parameters, windows-to-wall ratio (WWR), Wall construction, Window glass, Roof construction, HVAC system, and Infiltration rate for minimizing the building energy EUI.

2.4. Heating and Cooling Loads Analysis

As we see in the energy analysis and its optimization of the school building using Insight, the window glass, roof construction, and wall construction will play a role in energy optimization and minimizes the total consumption of energy. After the Building energy analysis and optimization, Heating & Cooling load calculations are performed. Heating & cooling load refers to the quantity of energy required for achieving comfortable temperature within a building or space. The thermal comfort conditions or indoor design conditions used for heat load calculations are shown in Table 2.

2.4.1. Creating Project File

To start the heating and cooling load, the first step is to create a new project file using the mechanical template in Revit, and the Architecture model is linked to this. Using the collaborate tool, the levels, floor plan, and ceiling plan are copy/monitor to the new file, which will create the HVAC floor plan, ceiling plan, and elevations.

2.4.2. Creating Space and Space Schedule

The second step is to create the spaces. The spaces are created using the Analyze-space-select rooms. A space schedule provides a comprehensive list of the spaces in a building, along with their characteristics, occupancy, lighting and power load density, and minimum ventilation rates. Each space is analyzed individually to determine its unique heating and cooling requirements. A typical space schedule is described in Table 3. An example of the space type classroom as illustrated in Fig. 10. If space type is not available in Revit, then we can create a new space type, and the various space parameters are taken from the ASHRAE standards 62.1 and 90.1 using the ASHRAE handbook.

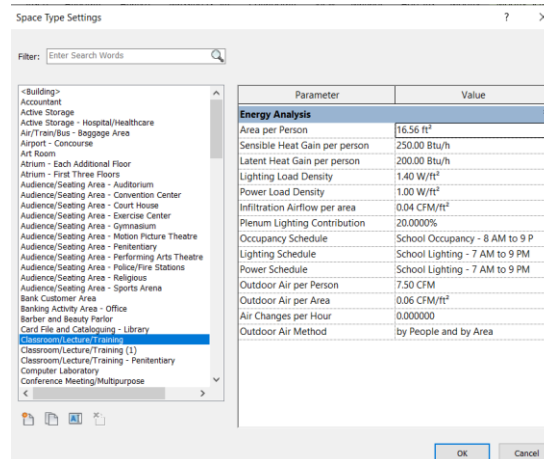


Fig. 10—Space type settings

Space Name	Space Type	Outdoor Air per Person	Outdoor Air per Area	Area per Person or number of people	Specified Lighting Load per area	Specified Power Load per area
CLASSROOM	Classroom/Lecture/Training	7.5 CFM	0.06 CFM/ft²	17 ft²	1.40 W/ft²	1.00 W/ft²
ACCOUNTANT	Accountant	5.0 CFM	0.06 CFM/ft²	5 No	1.10 W/ft²	1.50 W/ft²
ART ROOM	Art Room	10.0 CFM	0.18 CFM/ft²	20 ft²	1.50 W/ft²	1.00 W/ft²
CAFETERIA	Dining Area - Hotel	7.5 CFM	0.18 CFM/ft²	15 ft²	1.30 W/ft²	0.54 W/ft²
CLINIC	Exam/Treatment - Hospital/Healthcare	0.0 CFM	0.00 CFM/ft²	54 ft²	1.50 W/ft²	1.50 W/ft²
COMPUTER LAB.	Computer Laboratory	10.0 CFM	0.12 CFM/ft²	25 ft²	1.40 W/ft²	1.50 W/ft²
ELECT	Electrical	0.0 CFM	0.06 CFM/ft²	2 No	1.50 W/ft²	0.30 W/ft²
ESL.COORD	Office - Enclosed	5.0 CFM	0.06 CFM/ft²	2 No	1.10 W/ft²	1.50 W/ft²
LIBRARY	Reading Area - Library	5.0 CFM	0.12 CFM/ft²	108 ft²	1.20 W/ft²	1.50 W/ft²
MEETING	Conference Meeting/Multipurpose	5.0 CFM	0.06 CFM/ft²	22 ft²	1.30 W/ft²	1.00 W/ft²
MUSIC ROOM	Music Room	10.0 CFM	0.06 CFM/ft²	17 ft²	1.50 W/ft²	1.00 W/ft²
PRINIPAL	Office - Enclosed	5.0 CFM	0.06 CFM/ft²	2 No	1.10 W/ft²	1.50 W/ft²
RECEP.	Reception/Waiting - Transportation	7.5 CFM	0.06 CFM/ft²	11 ft²	1.10 W/ft²	0.54 W/ft²
S.E.N.CO	Office - Enclosed	5.0 CFM	0.06 CFM/ft²	2 No	1.10 W/ft²	1.50 W/ft²
SCIENTIFIC LAB.	Scientific Laboratory	10.0 CFM	0.18 CFM/ft²	25 ft²	1.20 W/ft²	1.00 W/ft²
SEN. ROOM	Classroom/Lecture/Training	7.5 CFM	0.06 CFM/ft²	25 ft²	1.40 W/ft²	1.00 W/ft²
TEACHER. R	Conference Meeting/Multipurpose	5.0 CFM	0.06 CFM/ft²	22 ft²	1.30 W/ft²	1.00 W/ft²
TRAINING NICHEN	Classroom/Lecture/Training	7.5 CFM	0.06 CFM/ft²	17 ft²	1.40 W/ft²	1.00 W/ft²
VP	Office - Enclosed	5.0 CFM	0.06 CFM/ft²	65 ft²	1.10 W/ft²	1.50 W/ft²

Table 3—Space Schedule

2.4.3. Creating Zone

The third step is to create the Zones. A zone comprises a single space or combines multiple spaces into one zone based on their similar thermal characteristics and occupancy patterns. The zone is created using the Analyze tool-zone and select the single or multiple spaces to create. In this project, each space as described in Table 3 is selected as individual Zone.

2.4.4. General Settings

Using the Analyze tool, select “Heating and Cooling loads” will open the dialogue box with the 3D simulation model as illustrated in Fig. 11. The general parameters include the Building type (office, single family, hotel, library, hospital, and school or university, etc.), Location, Building service (central cooling system, central heating system, VAV (Variable air volume) system, Fan coil system, variable refrigerant flow (VRF), etc.), and Schematic type.

As describe in the Energy analysis section, schematic type or construction type is the type of materials that are employed for constructing building elements. In Revit, the various Walls, Roofs and Windows assemblies with U-value are available in its material library. These assemblies consist of various layers of materials for walls, windows, and roofs with and without insulation. Some assemblies with different U-values is selected for the heating & cooling load analysis as described in Table 4. The selection of assembly is according to decreasing U-value with increasing the insulation thickness. The different combination of wall, roof, and window glass material is selected making the different scenario with name S1, S2, S3.... S15. After the General setting, clicking on “Calculate” will start calculating Heating & Cooling Loads and generate the Load report.

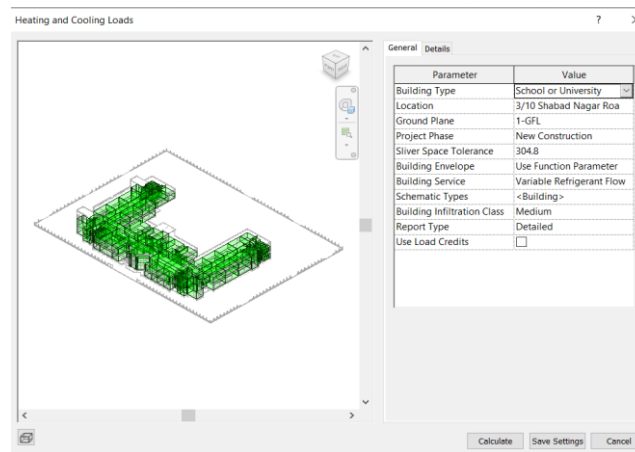


Fig. 11—Heating and Cooling Loads

Type	Analytical Construction Assembly	U-value BTU/h.ft ² .F(W/m ² .K)
Wall 1	4 in face brick, 8 in common brick	0.2131 (1.2100)
Wall 2	4 in face brick, 8 in common brick - 1 in insulation	0.1425 (0.8091)
Wall 3	4 in face brick, 8 in common brick - 2 in insulation	0.0964 (0.5475)
Roof 1	6 in heavyweight concrete with 1 in insulation	0.2011 (1.1418)
Roof 2	6 in heavyweight concrete with 2 in insulation	0.1201 (0.6819)
Roof 3	6 in heavyweight concrete with 4 in insulation	0.0561 (0.3184)
Window 1	Single-glazed window - domestic	0.5809 (3.2983)
Window 2	double-glazed Low-E	0.3500 (1.9873)
Window 3	Triple-glazed Low-E	0.2700 (1.5330)

Table 4—Analytical Construction Properties: U-value for Walls, roof, and window glass for Load Comparison:

2.5. Design and Modeling of HVAC System

As per the climate condition of the school building location and referring to the monthly temperature variation as illustrated in Fig. 8, a heating system is not essential for the school building. The heating loads in the above sections are calculated only to see the variation of heating loads with U-Value. From Fig. 8, the average temperature is above 20 °C (68 °F) which is closest to the indoor comfort condition. During the winter season, the temperature can drop in the early morning and late evening.

Why VRF

The HVAC system selected for the school building project is a variable refrigeration flow (VRF) system. VRF systems are well-suited for school buildings due to their zoning capabilities and energy efficiency. These systems allow individual control of indoor units, providing personalized comfort for teachers and students. They use variable-speed compressors that can adjust the refrigerant flow to match the exact cooling or heating demands of each indoor unit. By modulating the refrigerant flow, VRF systems can avoid the energy losses associated with frequent start-stop cycles, leading to significant energy savings and operational costs. VRF systems are ductless or require minimal ductwork, saving valuable space and simplifying installation. While the Chiller systems serve the entire building as a single unit, they lack the individual control and zoning capabilities of VRF systems. VRF systems' energy efficiency, heat recovery, and design flexibility make them a compelling choice for modern schools. Though VRF systems may have a higher initial cost, their multiple advantages made it increasingly popular in educational environments where personalized comfort, energy efficiency, and quiet operation are crucial factors.

Modeling the HVAC system using Autodesk Revit involves creating a comprehensive 3D representation of the HVAC components within a building model. Starting with the architectural model, spaces are defined and categorized as zones to establish areas with similar thermal requirements. HVAC systems, such as VRF, central air, or others, are then added using Revit's built-in families, including air handling units, ductwork, grilles, and mechanical equipment. The ductwork is laid out throughout the building, connecting air handling units to diffusers or grilles in each space. Parameters, properties, and system connections are defined to make sure a logical flow of water & air within the HVAC system. Load analysis is performed to size the HVAC equipment correctly, and detailed documentation, plans, and schedules are generated for construction purposes. Collaboration with other disciplines helps coordinate the HVAC system design with the overall building model, ensuring an efficient and coordinated HVAC system.

3 RESULTS AND DISCUSSION

3.1. Energy Analysis and Optimization

The Energy analysis and optimization are done in according to the energy usage intensity (EUI) of the building in kWh/m²/yr. The analysis report generated by the insight has various design scenarios like building orientation, wall construction, window-to-wall ratio, roof construction, lighting efficiency, and plug load efficiency for controlling the energy usage of the building. In Insight, the topmost window shows the “Building form” in 3D and an overall benchmark of the project, by default energy usage intensity, as illustrated in Fig. 12.

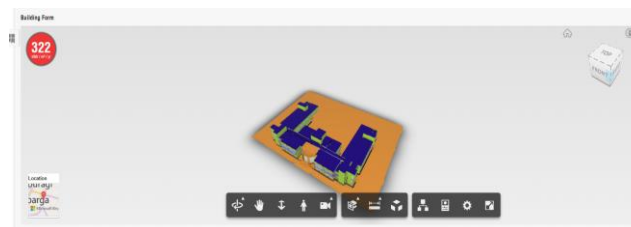


Fig. 12—Building Form

The next is the Benchmark Comparison widget. Fig. 13 shows the results of the energy analysis measured against the ASHRAE 90.1 and Architecture 2030 efficiency standards. This gives a rough idea of how close the building is to meeting efficiency goals and whether the current design will meet current and future performance standards.

Initially, the Benchmark comparison of our BIM Model is 322 kWh/m²/yr, and after changing the design condition, the EUI reduces to 167 kWh/m²/yr.

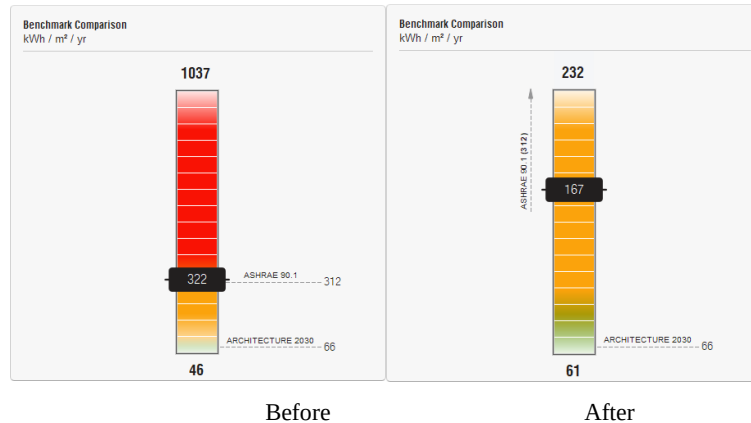


Fig. 13—Benchmark Comparison

3.1.1. Building Orientation:

The school building is oriented to the North face. At this orientation, the average energy usage intensity is 322 kWh/m²/yr. The BIM in the graph shows the current orientation of the building. When the range is changed, the EUI is reduced to 318 kWh/m²/yr.

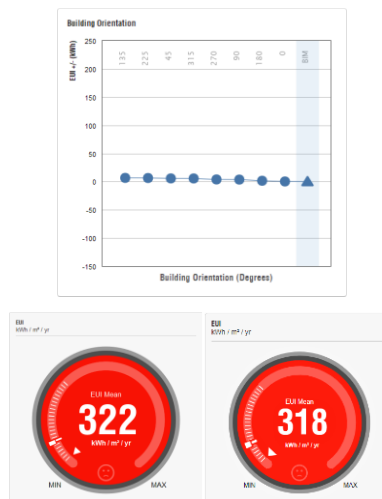


Fig. 14—Building Orientation

3.1.2. Operating Schedule

The operating schedule of a building describes the hours and days during which building is open to the occupants and the specific activities or services available during those times. From the graph shown in Fig. 15, The BIM shows the current schedule, with an increase in operating schedule like 24/7 will increase the EUI. For school buildings, a 12/6 schedule is selected and EUI reduces to 278 kWh/m²/yr.

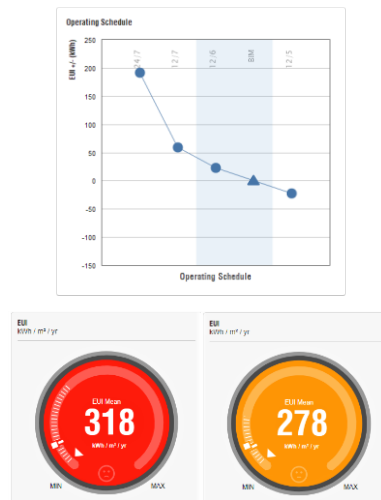


Fig. 15—Operating Schedule

3.1.3. Electrical Parameters

The Lighting efficiency represents the amount of energy consumption by power required for lighting purposes and heat gain through lighting per unit area.

Plug load efficiency represents the total amount of energy consumption by electrical equipment such as computers.

Daylight and occupancy control: The efficiency in day lighting and occupancy control can be obtained by the usage of advancements in technology for daylight dimming and occupancy sensor systems.

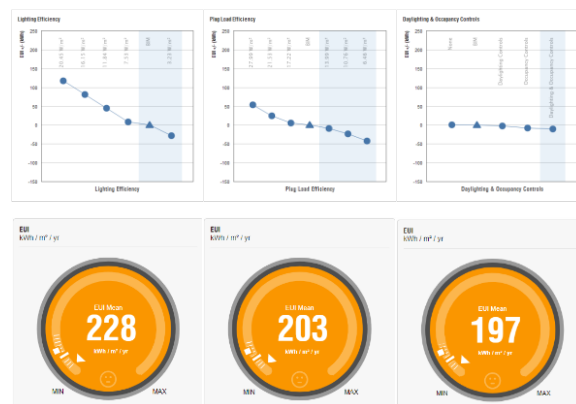


Fig. 16—Electrical Parameters

3.1.4. Window-to-Wall Ratio (WWR)

A higher window-to-wall ratio (WWR) allows more natural light to enter the building, reduces the use of artificial lighting while daytime and creating a more pleasant indoor environment. But a high WWR can increase cooling and heating loads, affecting the building's energy consumption. The current BIM model has a WWR is 26% and reducing the WWR percentage will reduce the EUI. From all the exterior walls, the EUI decreases maximum from 197 kWh/m²/yr. to 193 kWh/m²/yr. as illustrated in Fig. 17, when the WWR of the western wall is changing. This is because the maximum heat gain is from the west side wall.

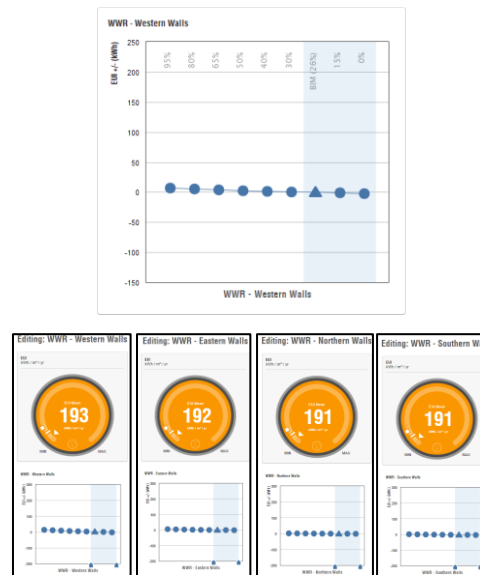


Fig. 17—Window to Wall ratio (WWR)

3.1.5. Window Glass

From the above section, it is clear that higher heat gain is from the west window and that can be reduced by reducing the WWR and using the window with glazing. The Window glass built with ordinary glass without any glazing will have an energy consumption intensity of 191 kWh/m²/yr. With glazing (double/triple glazing) the energy consumption intensity reduces from 191 kWh/m²/yr. to 190 kWh/m²/yr. as illustrated in Fig. 18.

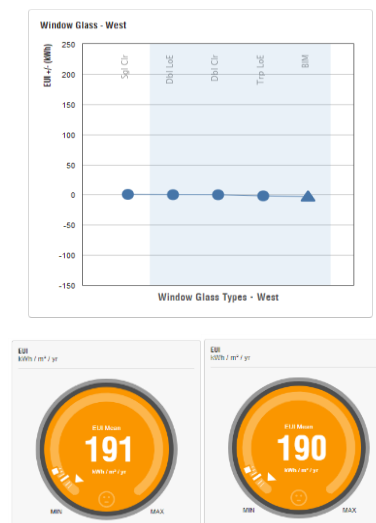


Fig. 18—Window Glass

3.1.6. Wall Construction

Wall construction helps in reducing heating and cooling loads by providing the proper insulation layer in wall construction. The various insulation material is recommended by Insight as shown in Fig. 19. In this Project, the wall is built with two 4 in bricks and ½ in gypsum. With this wall construction, the energy usage intensity is 190 kWh/m²/yr. When Insulation is added it may lower the energy usage from 190 kWh/m²/yr. to 186 kWh/m²/yr. as shown in Fig. 19.

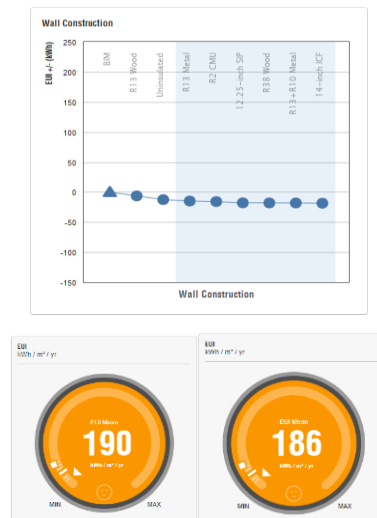


Fig. 19—Wall Construction

3.1.7. Roof Construction

Roof construction helps in reducing heating and cooling loads by providing the proper insulation layer in roof construction. The various insulation material are recommended by Insight as shown in Fig. 20. In this Project, the roof is built with 4 in lightweight Concrete without any insulation. With this roof construction, the energy consumption intensity is 186 kWh/m²/yr. When Insulation is added it may lower the energy consumption from 186 kWh/m²/yr. to 183 kWh/m²/yr.

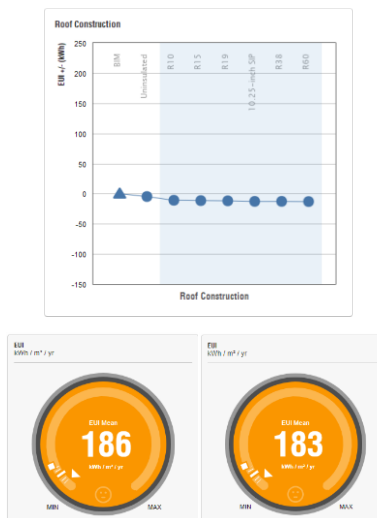


Fig. 20—Roof Construction

3.1.8. HVAC

Since the majority of the energy consumption is by the HVAC system as compared to other services, it is important to select the energy efficient HVAC system. The energy efficient system recommended by Insight are High-efficiency package terminal units, high efficiency heat pumps, ASHRAE package terminal heat pumps, and high efficiency VAV as illustrated in Fig. 21. One common type of high-efficiency heat pump HVAC system is called a "Variable Refrigerant Flow" (VRF) or "Variable Refrigerant Volume" (VRV) system.

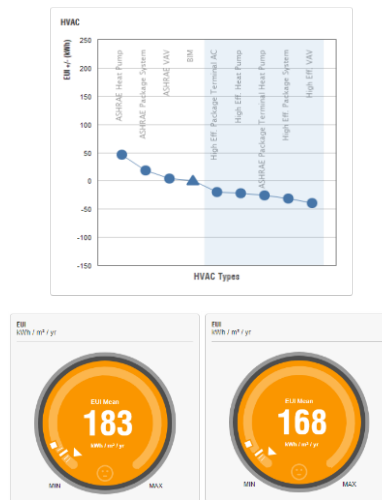


Fig. 21—HVAC System

3.1.9. Infiltration

It is the unintentional or uncontrolled entry of outside air in indoor environment. It is the result of air leakage through gaps, cracks, and openings in the building envelope, such as doors, windows, walls, ceilings, and floors. It is reduced by the tight construction of the building using sealing or making the positive pressure inside the building.

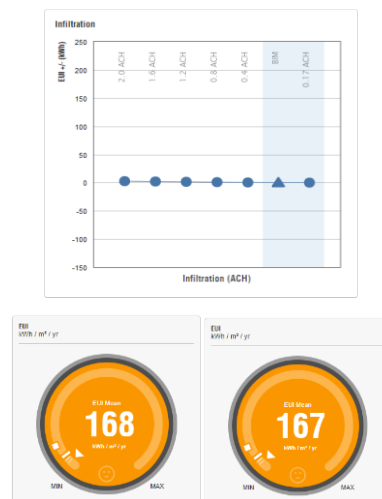


Fig. 22—Infiltration

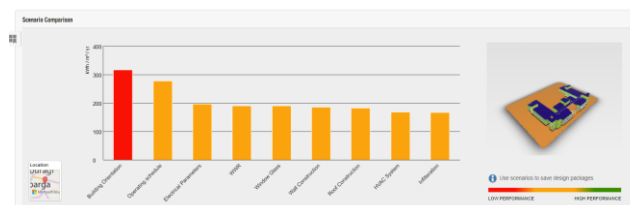


Fig. 23—Scenario Comparison

Scenario Comparison

From Fig. 23, it is clear that building orientation, operating schedule, window-to-wall ratio, construction of wall, roof, and window glass, and type of HVAC system will play a significant role in building energy consumption. Adding Insulation to the wall and roof, providing glazing to window glass, and selecting an energy efficient or heat pump system with high COP minimizes the building energy consumption and workload of the HVAC system and hence helps in energy saving.

3.2. Heating and Cooling Load Report

The intensity of Heating & cooling load with different Window glass types, wall and roof construction with insulation, and no insulation is shown in Table 5. In First Scenario S1, the Window 1 ($U = 0.5809$ BTU/h.ft².F), Roof 1 ($U = 0.2011$ BTU/h.ft².F), and Wall 1 ($U = 0.2131$ BTU/h.ft².F) are selected in schematic type in the general setting as mention in the section 3.4.4 and click on “Calculate” which start calculating the loads. The cooling load and heating load for scenario S1 is 184.32 Ton(648.24kW) and 106.22(kW) respectively. Similarly, using a different combination of window, roof, and wall, the cooling load and heating load are calculated as describe in Table 5.

Scenario	Window	Roof	Wall	Cooling Load (Ton)	Cooling Load (kW)	Heating Load (kW)
S1	1	1	1	184.32	648.24	106.22
S2	1	1	2	183.54	645.49	103.68
S3	1	1	3	183.44	645.14	102.02
S4	1	2	1	177.01	622.53	96.43
S5	1	2	2	176.13	619.43	93.89
S6	1	2	3	176.10	619.33	92.23
S7	1	3	1	171.66	603.71	88.69
S8	1	3	2	170.87	600.93	86.15
S9	1	3	3	170.54	599.77	84.49
S10	2	2	2	151.65	533.34	86.63
S11	2	3	1	147.85	519.97	81.77
S12	2	3	2	147.40	518.39	79.26
S13	2	3	3	147.07	517.23	77.97
S14	3	3	2	141.35	497.11	76.84
S15	3	3	3	134.03	471.37	75.37

Table 5—Heating and Cooling Loads with different scenario.

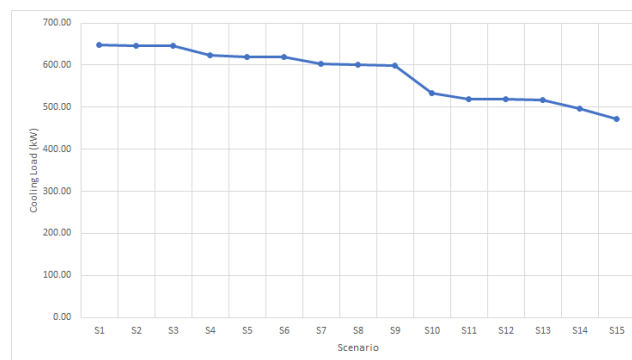


Fig. 24—Cooling Load graph

The graph in Fig 24 demonstrates how different scenarios with varying insulation levels (indicated by U-values) affect the cooling load of the building. Increasing insulation by using materials with lower U-values reduces the cooling load, leading to potential energy savings and improved efficiency in cooling the building. Single glazing refers to windows with one layer of glass, while double glazing has two layers separated by a space that provides additional insulation. By making this change, the cooling load is reduced by 12%. The total cooling load with Scenario 1 (wall 1, roof 1, and window 1) is 648.24 kW, and reduces with Scenario 15 (wall 3, roof 3, and window 3) is 471.37 kW. Comparing these two scenarios, it's noted that the cooling load in Scenario 15 (Wall 3, Roof 3, and Window 3) is about 27% lower than in Scenario 1 (with Wall 1, Roof 1, and Window 1).

This significant reduction in cooling load can be credited to the improved insulation provided by the components in Scenario 15, which have lower U-values.

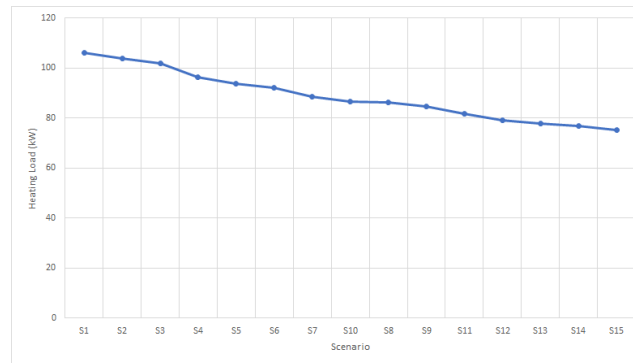


Fig. 25—Heating Load graph

The graph in Fig 25 demonstrates how various scenarios with different degrees of insulation affect the heating load of the building. Increasing insulation by using materials with lower U-values reduces the heating load, as better-insulated components help retain the heat generated indoors. By adding insulation and glazing to the components in Scenario S15, the heating load is reduced from 106.22 kW (Scenario S1) to 75.37 kW (Scenario S15). This represents a reduction of about 29% in the heating load. The enhanced insulation helps to better trap and retain the heat generated indoors, preventing it from escaping to the outside. As a result, the heating system needs to work less to maintain the desired indoor temperature, leading to energy savings and improved heating efficiency.

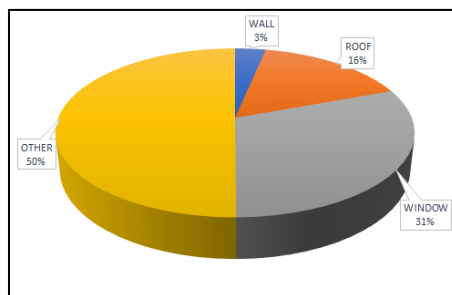


Fig. 26—Building elements with the cooling percentage

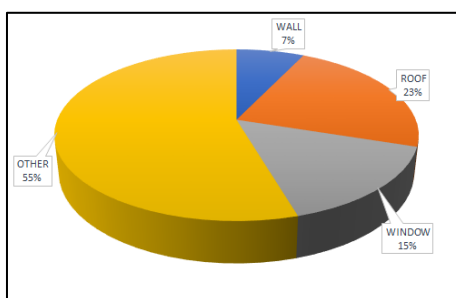


Fig. 27—Building elements with the heating percentage

Figs. 26 and 27 shows variation in the cooling load and heating load percentage with wall, roof, and window. The maximum cooling load and heating load are due to the window glass because windows are typically areas of higher heat transfer in buildings. Therefore, the load changes as illustrated in Fig 26 and 27 are highly influenced by the type of window glass. In hot climates, poorly insulated windows can allow heat to enter the building, increasing the cooling load. Similarly, in cold climates, poorly insulated windows can allow heat to escape, increasing the heating load.

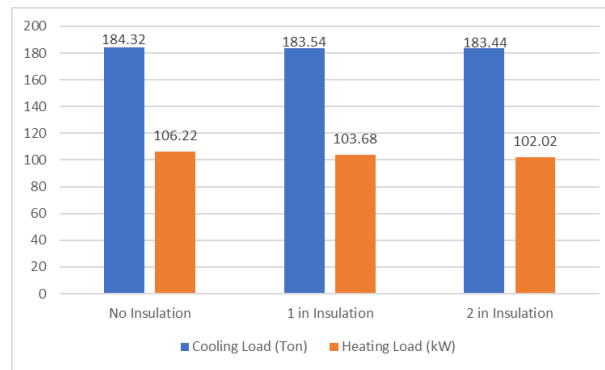


Fig. 28—Variation of Loads with Wall Insulation

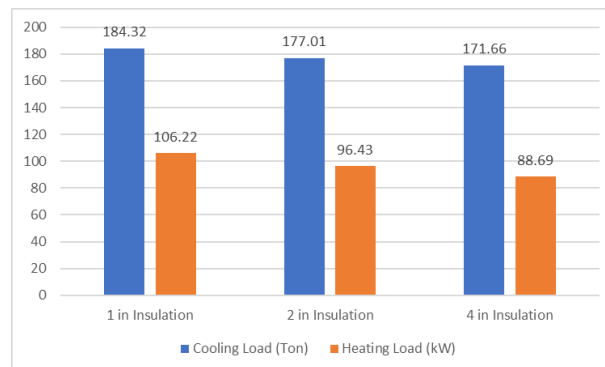


Fig. 29—Variation of Loads with Roof Insulation

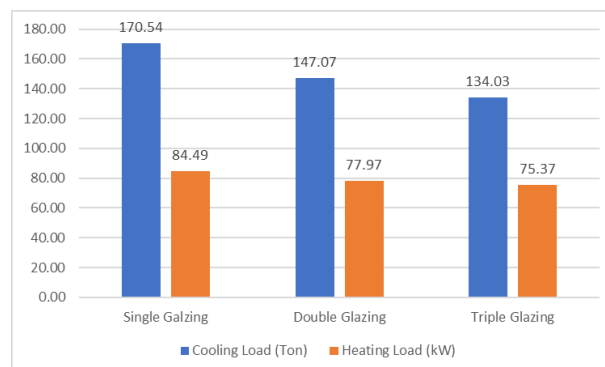


Fig. 30—Variation of Loads with Window Glazing

The Figs. 28, 29, and 30 illustrate the relationship between cooling load (measured in tons) and heating load (measured in kilowatts, kW) with varying U values obtained by adding insulation to walls, roofs, and glazing to windows, respectively. Well-constructed walls and roofs with proper insulation, along with windows featuring glazing, play a key role in establishing a thermal barrier that prevents the exchange of heat between indoor and outdoor environments. This results in optimized cooling and heating loads, contributing to energy efficiency and improved indoor comfort.

3.3. Schedules and Layouts

SL Number	Tag Number	Equipment Name	Quantity	Specifications
1	IDU-C1	4 way cassette	26	Power supply: 1-phase, 200-240V, 50Hz. Cooling capacity: 11.2kW
2	IDU-C2	4 way cassette	2	Power supply: 1-phase, 200-240V, 50Hz. Cooling capacity: 3.6kW
3	IDU-C3	4 way cassette	1	Power supply: 1-phase, 200-240V, 50Hz. Cooling capacity: 5.6kW
4	IDU-C4	4 way cassette	5	Power supply: 1-phase, 200-240V, 50Hz. Cooling capacity: 14kW
5	IDU-C5	4 way cassette	3	Power supply: 1-phase, 200-240V, 50Hz. Cooling capacity: 4.5kW
6	IDU-C6	4 way cassette	1	Power supply: 1-phase, 200-240V, 50Hz. Cooling capacity: 7.1kW
7	IDU-C7	4 way cassette	1	Power supply: 1-phase, 200-240V, 50Hz. Cooling capacity: 9kW
8	IDU-W1	Wall mounted	6	Power supply: 1-phase, 200-240V/220V, 50Hz. Cooling capacity: 5.6kW
9	IDU-W2	Wall mounted	3	Power supply: 1-phase, 200-240V/220V, 50Hz. Cooling capacity: 2.2kW
10	IDU-W3	Wall mounted	2	Power supply: 1-phase, 200-240V/220V, 50Hz. Cooling capacity: 3.6kW
11	IDU-W4	Wall mounted	2	Power supply: 1-phase, 200-240V/220V, 50Hz. Cooling capacity: 9kW
12	IDU-W5	Wall mounted	4	Power supply: 1-phase, 200-240V/220V, 50Hz. Cooling capacity: 4.5kW
13	IDU-W6	Wall mounted	2	Power supply: 1-phase, 200-240V/220V, 50Hz. Cooling capacity: 2.8kW
14	IDU-D1	Ducted	1	Power supply: 1-phase, 200-240V/220V, 50Hz. Cooling capacity: 28kW
15	ODU-1	Outdoor Unit-1	1	Power supply: 3-phase, 380-415V, 50Hz. Cooling capacity: 117kW. Compressor: scroll type
16	ODU-2	Outdoor Unit-2	1	Power supply: 3-phase, 380-415V, 50Hz. Cooling capacity: 123kW. Compressor: scroll type
17	ODU-3	Outdoor Unit-3	1	Power supply: 3-phase, 380-415V, 50Hz. Cooling capacity: 140kW. Compressor: scroll type
18	ODU-4	Outdoor Unit-4	1	Power supply: 3-phase, 380-415V, 50Hz. Cooling capacity: 134kW. Compressor: scroll type
19	ODU-5	Outdoor Unit-5	2	Power supply: 1-phase, 230V, 50Hz. Cooling capacity: 2.8kW

Table 6—Equipment Schedule

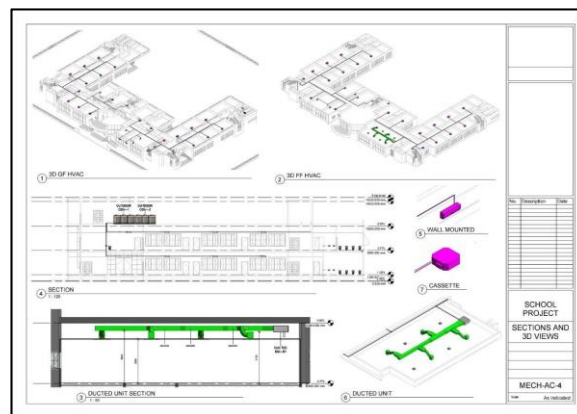


Fig.31—3D views HVAC

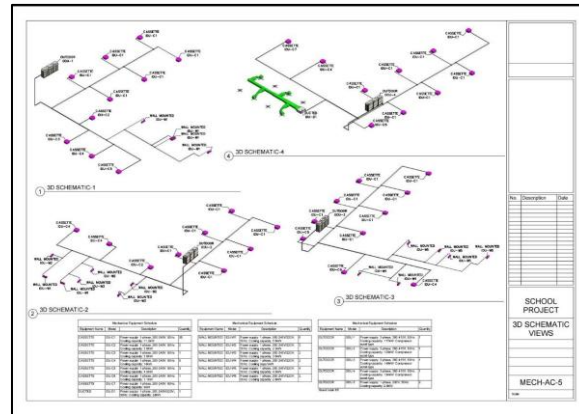


Fig. 32—Schematic of System zones

4. CONCLUSION

An Energy Analysis and Heating and Cooling Load Analysis was performed for a Commercial School Building located in Karnataka, India, as the part of this project. The findings demonstrate that optimizing various parameters, including building orientation, operating schedule, electrical parameters, window-to-wall ratio (WWR), wall and roof construction, window glass, HVAC system, and Infiltration, can significantly reduce the building's energy consumption. By implementing these energy-efficient design parameters, the Energy Usage Intensity (EUI) was successfully reduced from 322 kWh/m²/yr. to 167 kWh/m²/yr. Additionally, the Heating and Cooling Load Analysis revealed that lower U-values for walls, roofs, and window glass contribute to a substantial reduction of cooling and heating loads, with approximately 27 to 29 percent improvement. The HVAC system was successfully modeled in Revit, and various schedules and different views were plotted as part of this project.

The project highlights the integration of BIM (Building Information Modeling) in energy analysis and HVAC design to enhance building energy efficiency. The following conclusions were drawn from my investigation:

- By integrating energy analysis into the early stages of design, architects, and engineers can make informed decisions that prioritize energy efficiency.
- Factors like building orientation, operating schedule, window-to-wall ratio, window glass, wall construction, roof construction, HVAC system, and infiltration significantly influence energy consumption.
- Through BIM tools like Autodesk Insight and Revit, professionals can optimize energy usage by analyzing these factors and designing the building envelope accordingly.
- The study particularly emphasizes the impact of reducing U-values, which represent the overall thermal transmittance of building elements. By employing energy-efficient materials and construction that lower U-values, buildings can minimize transfer of heat through windows, walls, and roofs, leading to improved energy performance and reduced energy consumption.

The future scope of BIM-based energy analysis and HVAC design research involves integrating life-cycle cost analysis and cost-saving considerations. By assessing long-term economic impacts and exploring cost-effective energy-saving measures, this approach ensures sustainable solutions that balance upfront expenses and long-term savings.

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