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Optimization Techniques for Energy Efficiency in Residential Building

**Shubham U.Kamble, Suhas R.Paramannavar, Tayba A.Navalgund, Vinuth M.Gonnagar,
Bharatkumar Patil**

U.G. Students, Department of Civil Engineering, Tontadarya College of Engineering, Mundaragi Road,
Karnataka, India

Assistant Professor, Department of Civil Engineering, Tontadarya College of Engineering, Mundaragi Road,
Karnataka, India

ABSTRACT: Employing Building Information Modelling (BIM) software in the building design and construction helps to widen the scope of research in the field of sustainability. with BIM buildings are composed smartly, monitor energy use improving efficiency of utilization of resources. A building designed using BIM by considering energy saving parameters helps in reducing initial investment and economic costs throughout the life cycle of building as energy consumption is lowered. Through this paper energy analysis and its optimization by considering simple parameters like planning, materials and their utilization has been put forward. Basic idea about how factors such as building orientation, window to wall ratio, materials used for the wall construction will affect the energy consumption is discussed in the paper. Insight-360 is the key software which makes optimization of above-mentioned parameters very easy for users also co-relating those parameters to energy expenses.

KEYWORDS: Building information modelling, 3D Modelling, Revit, Energy settings, Energy efficiency, Insight 360.

I. INTRODUCTION

Building Information Modelling (BIM) software or technology was introduced in India in early 2000's to provide energy efficient buildings. BIM consists of many key features like less time consuming, better accuracy, more thorough design and it can also predict lifecycle performance in Engineering and Construction. Architecture, Engineering, Construction and Operations (AECO) is working under pressure to bring down the quantity of polluting emissions and is forced to increase the energy efficiency through materials, processes, equipment, buildings. One of the major contributors to global environmental impact has been found out and i.e. building and construction sector because of their high energy consumption. In the Architecture, Engineering, Construction, and Operations industry, much pressure to cut down on polluting emissions and improve energy efficiency has been seen and felt. This industry has become more slanted towards materials, processes, equipment, and building designs that will help it solve problems. For instance, the building and construction industry is a massive contributor to the world's plight on environmental spurs as it consumes a lot of energy. To curb the consuming levels and promote sustainability, the players in the industry have been forced to do it with much urgency than before. BIM is becoming more relevant in the construction and architecture scenes than ever before[1].

II. RESEARCH PROBLEM

The aim of this study is to improve energy efficiency in buildings using Building Information Modelling. The primary objective is to explore the parameters which will affect the innovation of energy-efficient structures. So, researchers might as well come up with strategies that are fitting to raise energy efficiency in new building developments. Today, the specific aim of this research is practice of energy performance analysis on a typical case (residential building) to achieve energy optimization.

Encouraging energy efficiency in buildings reflects the very heavy demand for energy. Additional to being energy efficient, buildings constructed this way offer savings of money and a reduction of greenhouse gas emissions.76% of the total urban household electricity comes from buildings. Energy utilization in the construction sector is developing

faster than any other sector. This paper approach towards energy efficiency, in terms of simpler ideas in planning and construction.

III. METHODOLOGY

1. Energy Analysis Using BIM

Building energy simulation, which is currently in vogue, takes time and effort. It also still has that considerable gap between theoretical and actual energy data. The early stages of the building design process are the most fundamental to its performance in terms of mineral use, energy consumption, and Price over lifetime of minerals for energy analysis is a Building design planning of huge support. Now especially vibrant demand and global warming demand that building system of course need optimization. Using Building Information Modeling (BIM) –going on foot or using a lot of renewable energy tools such as Autodesk Insight is the way we determine building energy consumed[2]. BIM is an intelligent 3D model-based process for more efficiently planning construction and management of infrastructure, which gives engineers a myriad of new tools with which they can use this perspective to great advantage. BIM can help designers analyze different choices in the forestage of building so that we may have energy victories with constraints that are dictated by what have since been built up as this is really one nation savior type strategy[3]. Refer Figure.1

Architectural plan of considered building:

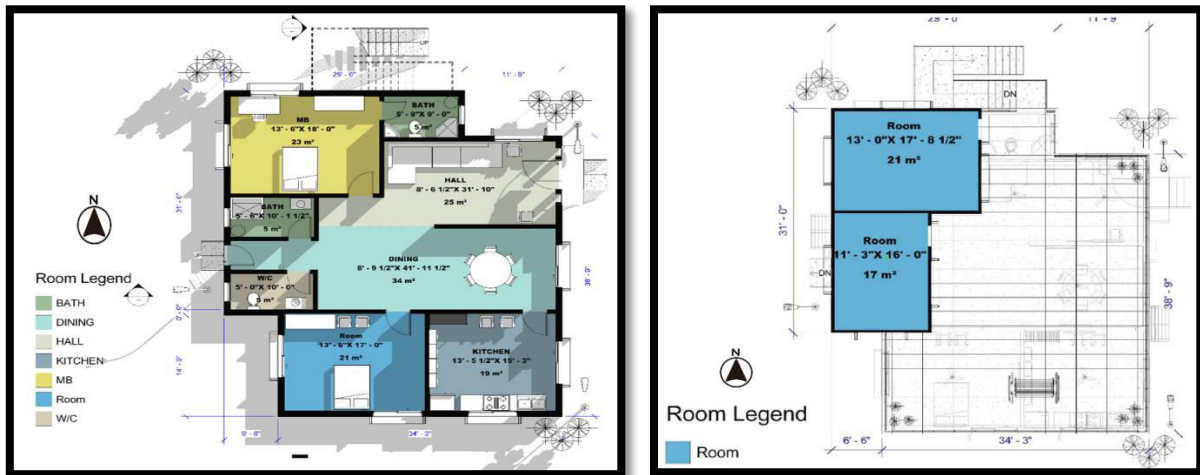


Fig.1: Plan

1. Building Energy Model:

A. Material assignment:

In building elements like exterior and interior walls, the roof, floors, windows and doors, this trial analyzed different materials. The best among these was chosen to save the most energy transmission of energy in various forms which are defined in Table.1

Component	Material types used & Layer thickness
ExteriorWalls	AAC Blocks-9”
Interior walls	AAC Blocks -4”
Floors	Carpet-Concrete-Granite Flooring- 4”
Roofs	Concrete Slab-Acoustic Ceiling Tile- 6”
Windows	Double Glazed Domestic
Doors	Panelled- Wooden Doors

Table.1: Material assigned for the building model

R-value and U-value are the fundamental benchmarks when analysing the thermal functionality of construction materials, indispensable for energy-efficient building. The R-value quantifies thermal obstruction, signifying how well an element withstands heat transmission. Greater R-values denote more proficient insulation. This measure is conventionally communicated in °F·ft²·h/Btu in the United States and is employed for insulating stuffs, windows, walls, and roofs. Conversely, the U-value gauges the aggregate heat exchange coefficient, representing how well a building part conducts warmth. Lower U-values symbolize better insulation. Expressed in W/(m²·K), the U-value considers conduction, convection, and radiation within an assembly. It is pivotal for examining the thermal operation of complex assemblies such as partitions, windows, and entryways. The selection of materials can significantly impact the efficacy of a structure in retaining or releasing thermal energy. Variations in R-values and U-values amongst elements must be considered during design to optimize energy efficiency and comfort.

R-values denote thermal resistance while U-values signify heat transfer, with an inverse relationship binding these metrics. Standards dictating minimum R and maximum U values help architects craft highly insulated building envelopes, decreasing energy demands for temperature regulation and reducing operating expenses over the lifespan of the structure. Within Building Information Modelling programs like Revit, specifying thermal properties accurately enables thermal simulation that faithfully represents real-world performance. Calculating U values from composite R-values or direct input streamlines compliance verification against codes. Precise energy modelling supports optimization of the building shell for minimal utility costs and maximum comfort for inhabitants. Designers can thus craft facilities promoting sustainable habitation with lower environmental impacts through decreased consumption of non-renewable fuels. Following is the R- values utilized for the analysis of the building. Following R-values adopted are mentioned in Table.2

Components	R-value (m ² .k/w)
Exterior Walls	0.9525
Interior walls	0.6251
Floors	0.0318
Roofs	0.6350
Windows	0.3196
Doors	0.4557

Table.2: R-Values

B. Location of building:

Building Location and Energy Analysis

After modeling, building location need to be set, the location of the building is at Gadag, Karnataka, India the location is set by using the internet mapping and by using meteorological reports from the nearby village of Chitradurga. Gadag's sweltering, semi-arid locale considerably impacts the structure's thermal performance, with solar profusion, temperature deviations, and humidity regulation all influenced.

The flat landscape surrounding Gadag also shapes wind currents and natural air flow, allowing optimal sun exposure while maximizing the utilization of solar energy's benefits. Orienting the architecture properly relative to prevailing breezes can advance passive cooling tactics, reducing reliance on mechanical ventilation and thereby heightening energy efficiency.

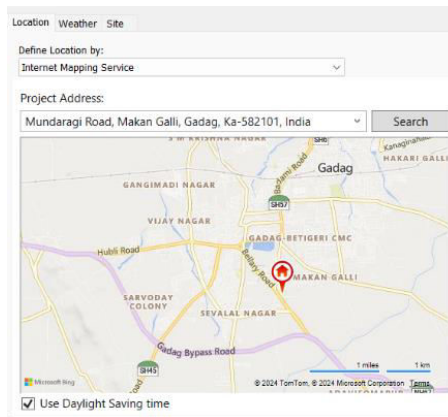


Fig.2: Location

C. Energy Settings:

The Revit "Analyse" menu contains tabs for the Advanced Energy Setting, besides an option selection called Energy Setting. Rather than library elements, which are information that can be utilized in an energy simulation to reduce (or eliminate) the effort involved in creating new databases, the energy model is a type of computer graphic that represents an architectural building's position and features. Energy settings can only be changed at start-up. Generated output data will reflect Server Operating System setting specifications of the Revit model, additional information that is optionally specified such as material attributes and thermal properties of spaces (a mass can be given density). Different components of the building, such as walls, roof and ceiling, slabs, floor and glass, have their thermal input values which affect the heating load or cooling in recreational rooms. Refer Figure 3

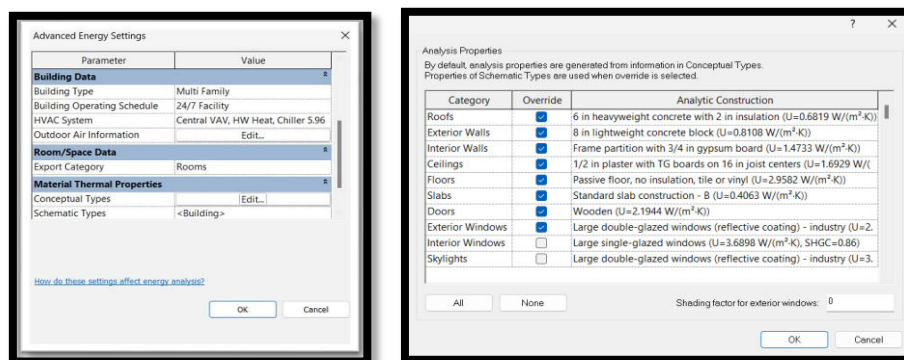


Fig.3: Energy settings

D. Energy Model:

The "Create Energy Model" command within Autodesk Revit's "Analyse" tab plays a vital role in detailed building energy examination. Upon execution, it transforms the architectural design into an analytical energy model that mimics thermal conductivity and energy performance through computational fluid dynamics simulations[4]. An accurately documented building form with walls, ceilings, floors, windows, doors, as well as internal partitions demarcating zones,

are indispensable for fruitful use. Spaces properly characterized by thermal qualities and boundary conditions are additionally important.

Users can refine the prototype generated by adjusting simplification of surfaces and zoning techniques to balance exactness and computational efficiency. The command converts the construction into an analytical depiction incorporating surfaces symbolizing the building envelope, thermal areas, and openings for examining airflow and thermal behavior. Precise geometry and system configuration, such as insulating assemblies, roofs, floors, glazing units, portals, and mechanical systems, are critical for effective employment. Refer Figure.4

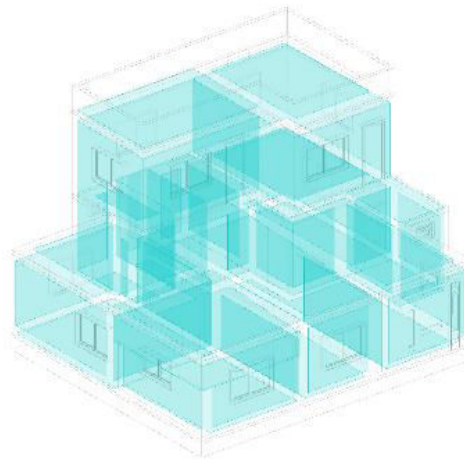


Fig.4: Energy model

2. Optimization (Insight 360)

Autodesk Insight 360 provides a structured process for detailed building energy analysis with value informed from Revit to Insight 360, once the building model is uploaded from Revit to Insight 360, the dashboard will provide critical information like Energy Use Intensity (EUI) and even cost estimates, providing the end user near instant feedback into the energy efficiency of their design. with Insight 360, users can change variables like Building orientation, window-to-wall ratio, window glass, daylight occupancy, insulation levels and immediately see feedback on energy use and costs. This iterative methodology allows a range of design options to be considered to improve energy efficiencies. It is up to the user to enter your utility and gas rate data, because the financial analysis, and the ability to compare it to energy performance, is only as good as the information entered into Insight 360. This data can then be used for accurate costing, economic analysis (including payback periods) and evaluating similar energy use patterns. Performance metrics detailed and color-coded visualizations (green, yellow, red, and blue for qualifying for optimal, ok, poor, and exceptional performance levels) that feature immediate guidance on exceptional energy efficiency successes, and opportunities for improvement. This visual feedback helps stakeholders to make educated decisions to improve building design and sustainability. Insight 360 ultimately enables users to realize energy performance, operational cost, and sustainability objectives of energy-efficient building with the ease of decision-making based on data captured from them[4].

Refer Figure 5



Fig.5: Analyticalmodel

IV. ANALYSIS & RESULTS

However, depending on the complexity of the project, the analysis process may take some time; Insight will tell you when it is completed by intimating through e-mail. First, energy analysis on the building was done using the plugin Insight in the Revit. Segregating energy by the settings of the project, the energy consumption level of the building will be estimated in dollars (USD /m² / year). In the analysis report various design options will appear, such as operating schedules, window to wall ratios, building orientation and lighting efficiency, to change and control the energy use of a building. whose explanation is further given below:

1. Building orientation:

A building's orientation refers to its elevations with relation to original geographical north including south. While in the design phase of a building, it is important to check how much, or as mentioned in this paper "Actual angle," solar radiation comes into a building at any point in time. This has a direct effect on the buildings thermal load and controls of thermal behavior and comfort level as well[5]. More importantly, however, it also determines how much of the airflow through building passes out from inside thereby determines how much energy is required for living and comfort heat or other purposes."To achieve higher overall performance in energy usage, the optimal orientation is 180 degrees with the north. As this study shows, changing the orientation of our instructional building to 270 degrees relative to the north reduces our costs from 21USD/m²/year [Rs 1,753.94] to 20.3 USD/m²/year [Rs 1,695.48]

Results after analysis:



Optimized results:

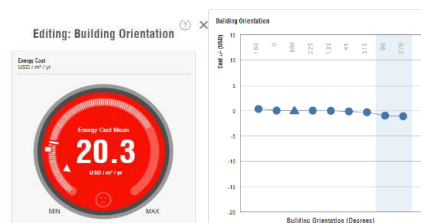


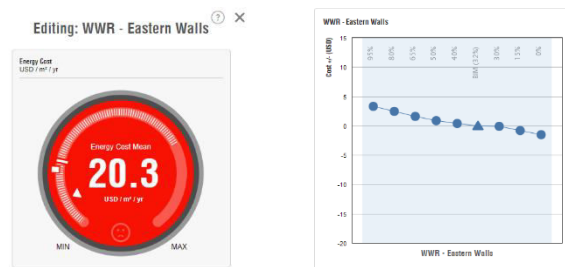
Fig.6: Cost Reduction Comparison of Building Orientation

2. Window to Wall Ratio (WWR):

The window-to-wall ratio (WWR) is one of the most important building design parameters that impact energy efficiency, thermal comfort and daylighting. It is the ratio of total window area to exterior wall area.

Although high WWRs can result in more heat gain in summer and heat loss in winter, more of those windows let in daylight, which could mean less electricity use to keep the home well-lit. Windows themselves are orientated to determine solar exposure. North facing windows receive diffused light, providing even day-long natural light without the extreme heating or cooling effects. When trees are planted on the south side of a building, they can offer winter solar gain, but they can also be part of the shading that blocks the high summer sun. morning sunlight comes through east-facing windows and these windows are a source of potential heat gain, which makes it important to have the right size of shading device. Windows on the west wall of the house are blasted with hot afternoon sun, requiring small window area and effective shading strategies[5]. Strategies for WWR to save energy include minimizing ratios for east and west facade, maximizing on north facade and controlling on south facade appropriately through shading to minimize glare. The results indicate that counterclockwise optimal window is the best way to maximize building energy efficiency, minimize operational costs, and enhance occupant comfort. You can see that the cost can be reduced from 20.3USD/m²/year [Rs 1,695.48] to 19.3 USD/m²/year [Rs 1,611.96] when adjusting WWR from 30% to the current design. Refer Figure7

Results after analysis:



Optimized results:

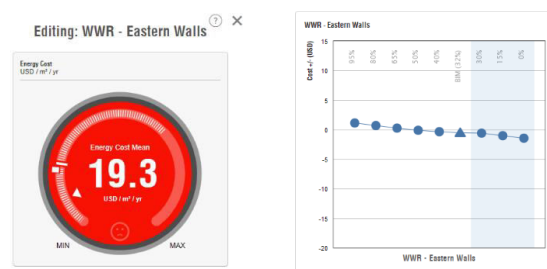


Fig.7: Cost Reduction Comparison of WWR

3. Exterior walls:

The research is focused on the energy efficiency of AAC (Autoclaved Aerated Concrete) block walls in construction. AAC blocks are constructed from lightweight material, and they have good insulation performance, accordingly, will reduce the amount of energy used to heat houses. This paper assesses the potential of AAC blocks to save energy by reviewing literature and drawing on case studies. It talks about aspects which concern the air tightness, insulation performance and heat transfer coefficient of AAC blocks, showing that they can make construction more energy efficient. AAC blocks are made of abundant natural resources and thus are highly resource - efficient and environmentally friendly. They amount to an average 20% cut in construction costs when taking into consideration renovation expenses as well as a 30-40% decrease in upkeep charges per year. Furthermore, the insulation properties of AAC help cut energy consumption; compared with ordinary concrete production techniques that also leave behind a

large amount of industrial waste--it can reduce in this regard by about 35%. By using AAC blocks for exterior walls the energy cost reduces from 17.5 USD/m²/year [Rs 1,461.62]to 16.6 USD/m²/year [Rs 1,386.45]. Refer Figure 8

Results after analysis:



Optimized results:

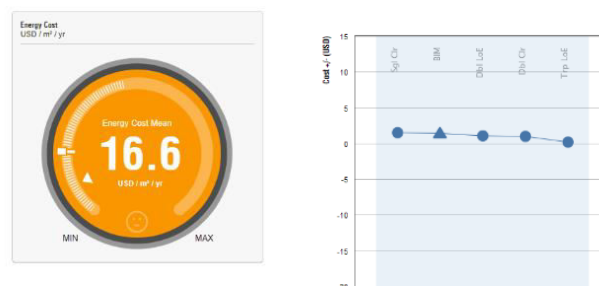


Fig.8: Cost Reduction Comparison of Wall construction

4. Window Glass:

Heat loss or gain, ventilation, and lighting all affect the daily utilization of power. glass is the most prominent element of openings which acts as a medium for light rays to penetrate building. Once the solar ray reaches the glass, part of it enters space and is absorbed, part is absorbed by glass substance itself, yet another portion is reflected outside. The rays penetrated due to convection and conduction qualities of substances; the part reflected depends on angle of incidence with any solar ensemble Domestic double-glazed glass - average cost is 16.6 USD/m²/year [Rs 1,386.45] When replaced with double clear or triple glazed, the energy cost of glass drops to 15.7 USD/m²/year [Rs1,311.28] and these numbers were affected by heat loss or gain, lighting, ventilation, and daily power consumption. Being a significant component of openings, glass permits natural light rays to come in the buildings. When the rays of the sun strike the glass, some of those rays will pass into the space and be absorbed, some will be absorbed by the glass material itself, and some rays will be reflected outdoors. Reflectance varies with the angle of incidence with the solar assembly. Refer Figure 9

Results after analysis:



Optimized results:

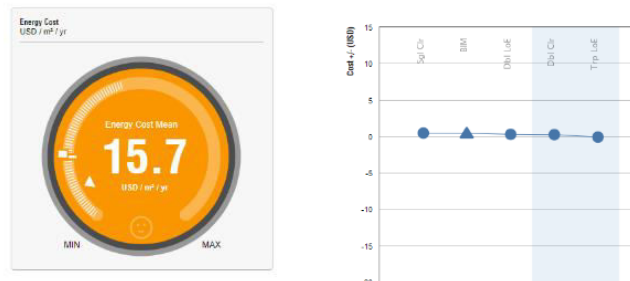
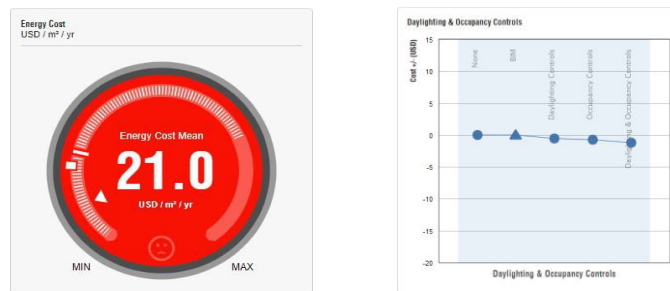


Fig.9: Cost Reduction Comparison of Wall construction

5. Daylighting and occupancy control:

How Daylighting and occupancy control can improve building energy efficiency. Daylighting takes advantage of natural light to decrease the use of electrical lighting, using windows, skylights and light wells and allowing sunlight to reach wider areas while minimizing glare and heat gain. They use daylight to complement or replace electric lighting and regulate indoor temperatures, reducing the demand for mechanical cooling. The occupancy controls automatically turn lighting and climate systems on and off through use of sensors and programmable controls to optimize energy use by adjusting settings as spaces are vacated. The impact of these strategies leads to a decrease in energy consumption and costs. With this, they achieve a better comfort level of the people, and the building is more sustainable! With Insight 360 software, users can optimize these controls, model different daylighting scenarios, and adjust occupancy settings to inform the energy model. Users can customize window sizes, skylight placement and sensor settings to achieve optimal energy savings while the system operates as you want it to and only when needed. Insight 360 also offers energy cost savings estimates and validates compliance with energy codes, informing users of energy-efficient design decisions[6]. Ultimately, the model offers significant potential for energy cost reduction and for design and operation of buildings that contribute to sustainability. by modifying the daylight & occupancy controls the energy cost is reduced from 21 USD/m²/year [Rs 1,753.94] to 13.9 USD/m²/year [Rs 1,159.16].

Results after analysis:



Optimized results:

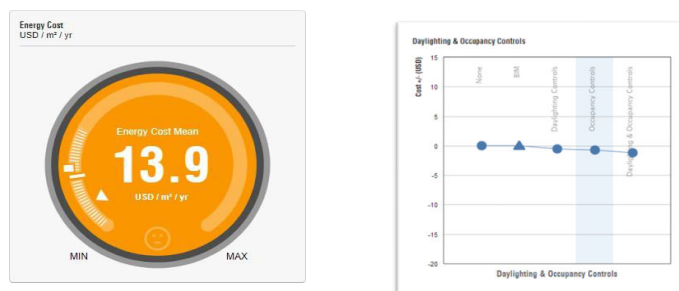


Fig.10: Cost Reduction Comparison of Daylight & occupancy control

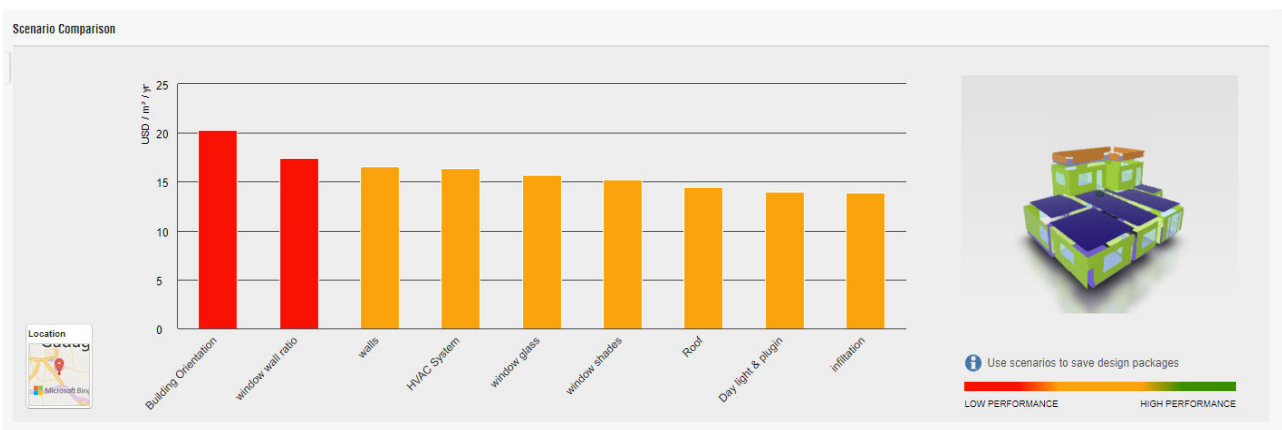
V. FINAL RESULTS

Insight 360 is one such powerful tool, providing precise analytics to let users assess performances and compare scenarios. The parameters can be modified in the software by the user; the outputs change accordingly and automatically update insights and bar graphs. Comparison of scenarios so detailed supports data-driven choices and therefore promotes energy-efficient, eco-friendly building practices.

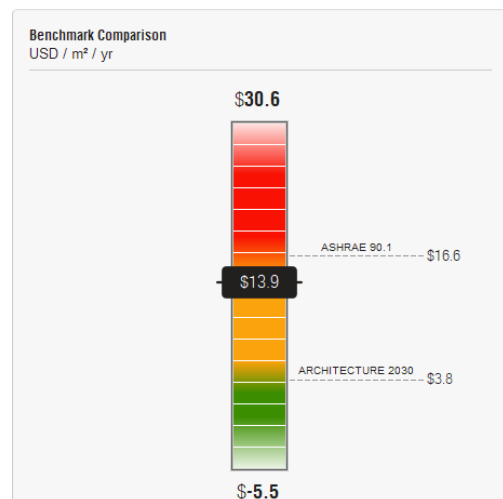
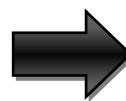
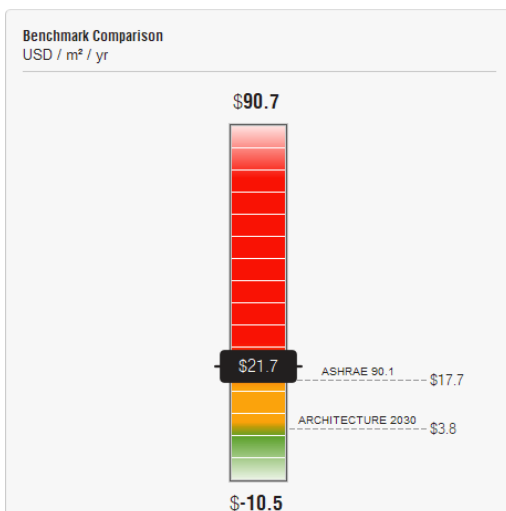
The analysis reviews building design packages, underlining the effect of parameter variation on energy efficiency. As shown in the graph, proper decision-making is essential to optimize these building parameters with a view to energy performance. It should be on every architect, engineers, and building professional's agenda in their striving toward sustainable yet cost-effective designs[7].

In the below graph x-axis includes parameters such as building orientation, window-to-wall ratio, window glass, window shades, exterior walls, roofs, lighting control, and occupancy control. In that regard, the y-axis will have energy consumption or inefficiencies that result from all these variations.

Cost comparison:



The above graph shows the variation of energy consumption against various parameters which were analysed in insight 360 software such as building orientation, window to wall ratio, walls. HVAC system, window glass, window shades, roof, daylight & plugin, etc.



Cost calculation:

BuildingArea:175m²

EnergySavingsperYear=(7.8kWh/m²/year) X(175m²)=1365kWh/ Year.

CostSavingsperYear=(1365kWh/year)X(0.075perkWh)=102.375 USD(\$)/Year. Cost Savings per Month =102.375/12 = 8.53USD (\$)/ Month.

CostSavingsperDay= 8.53/30USD(\$)/Day=0.28USD(\$)/Day.

Conversion:

Currency Conversion

Dollars	Rupees
102.375USD(\$)/Year	8549.77 Rs/year
8.53USD(\$)/Month	712.38 Rs/ Month
0.28USD(\$)/Day	23.38Rs/Day

VI. CONCLUSION

Use of BIM and Insight 360 for motoring residential energy usage and cost-effectiveness. Building information modelling software, also known as BIM, is used to create an accurate digital model of a building that structures its physical components, energetic systems, and consumption of resources involved in it. Insight 360 is another analysis tool that evaluates the different design and operational decisions on energy use and expenses incurred by them.

For example, this would be changes to building materials and architectural features of buildings with new technologies available for energy efficiency. We can simulate and analyse using Insight 360 for performance attainment on the lines of energy efficiency and cost reduction from such modifications.

By changing the orientation of the building, we can reduce the energy cost. Similarly, we reduced it from 21.0 to 20.3 USD /m²/year. The window-to-wall ratio for the current design is changed to 30% of the wall ratio to reduce the cost even more than sufficient; when it was done, the value decreased from 20.3 to 19.3 USD /m²/year. By using AAC blocks for exterior walls, the energy cost is reduced from 17.5 to 16.6 USD/m²/year. The average price for double-glazed domestic glass is 16.6 USD/m²/year, and when the glass is changed to double-clear, or triple-glazed its energy cost decreases to 15.7 USD/m²/year. And when the Daylight & occupancy control is changed to occupancy control the cost is decreases to 13.9 USD/m²/year.

Here are the percentage reductions in cost for each change mentioned in the paragraph:

- Changing building orientation : 3.33%
- Adjusting the window-to-wall ratio to 30% : 4.93%
- Using AAC blocks for exterior walls : 5.14%
- Changing to double-clear or triple-glazed glass : 5.42%
- Implementing daylight and occupancy controls : 16.27%

By comparing all the above parameters percentage of cost reduction is more by implementing daylighting and occupancy controls (about **16.27%**) compared to all other parameters.

These changes collectively contribute to significant reductions in energy costs. the implications of this project, therefore, expand to the construction industry and policymakers. This work will show that insights of our research might enable a future building design practice to lead toward more sustainable residential structures through more stringent energy efficiency standards. Innovation in the sphere of low-energy housing provides the drive toward an environmentally sensitive and economically feasible built environment.

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