Numerical and Experimental Analysis for Material and Energy Efficiency of a Building

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Abstract. Numerical and experimental studies on various wall materials and insulation materials are carried out. In numerical analysis we compared the energy and temperature of wall materials such as brick, concrete block, AAC block, CSEB block from all these wall materials. AAC block shows that less energy and less temperature. In numerical analysis we compared energy and temperature of various insulation materials such as mineral wool, eps, rice husk, foam glass, rubber. From all these insulation materials eps shows that less energy and temperature. AAC block and EPS are efficient materials for energy efficiency building. In experimental analysis the building was constructed with dimensions 23'*19'. In experimental analysis from the energy efficiency material the building construction was done. The eps is insulated on the west and south walls because they are more exposed to the sunlight. For energy efficiency, humidity sensors and temperature sensors have been installed. The computer set up was done to take out the daily temperature readings using dex2 software. The solar panel is also installed to the energy efficiency building. The recorded temperature is less for energy efficiency buildings.

Keywords: Energy efficiency, Wall materials, Insulation materials, AAC block, EPS (Expanded Polystyrene), Temperature analysis, Numerical analysis.

1 Introduction

Both buildings use energy at various stages throughout their life cycle. Mankind consumes about half of all unrenewable re- sources (including water, energy and raw materials) for building construction. Forty-three thousand years of civilization is now embodied in its buildings and their contents, the long-term prospect of which the planet cannot support. Construction is also very environmentally unfriendly in its use of energy. Energy use is increasingly a concern within structures, along with potential environmental effects. These are matters that the building trades around the world have to confront. The energy demand is growing fast driven by the population and urbanization. Residential energy demand differs across regions, while climate, housing typologies and or degree of development of a region influence demand and usage.

2 Literature Survey

Energy efficiency in buildings encompasses advanced techniques to reduce energy consumption for heating, cooling, and lighting. Recent developments include innovations in aerogel insulation, graphene-based materials, and smart HVAC systems that adjust based on real-time

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data. New simulation tools for energy-efficient building design, such as Design Builder and Energy Plus, now incorporate AI algorithms for optimal energy management. Water-efficient fixtures and AI-based energy optimization systems are also increasingly used in sustainable buildings [9] [12][4].

The building envelope refers to the components that physically separate a building's interior from the outdoor environment, including the walls, windows, foundation, basement slab, roof, ceiling, and insulation. Implementing energy-efficient practices in building design has important consequences for legislation, the economy, energy demand, and the environment. These aspects are reflected in the growing number of laws and regulations governing building performance [5][3].

Recent studies have evaluated new and innovative building materials to improve energy efficiency. Aerogel-based insulation and graphene-enhanced materials are leading advancements due to their superior thermal conductivity properties. AAC blocks still perform well in terms of energy efficiency, but newer materials like Phase-Change Materials (PCMs) and composite insulation are gaining attention for their thermal storage capabilities [4] [12]. Other studies have also focused on the evaluation of building materials, finding that natural materials like wood and gypsum mud brick generally have positive energy-efficient properties compared to others. Moreover, materials such as cellular concrete and waste ceramic insulation, despite their ecological benefits, often perform poorly in terms of energy efficiency [17] [11].

Further research has explored energy consumption in various building types, including educational campuses and residential buildings. Studies have shown that building design plays a critical role in energy consumption and sustainability, with green building concepts significantly improving energy efficiency [19] [16]. Multi-objective optimization models for retrofitting existing buildings also highlight strategies to reduce energy consumption in older structures [1]. Recent advancements in smart building technologies have led to the integration of AI-powered sensors and IoT devices that dynamically adjust energy consumption in real time. Passive design strategies, such as maximizing solar heat gain and wind ventilation, are now complemented by machine learning algorithms that predict energy consumption patterns and optimize building performance automatically [12] [13]. Simulation-based tools, such as Energy Plus and Design Builder, are now enhanced with AI-powered predictive models for more accurate energy demand forecasting. These tools also integrate new capabilities like real-time performance monitoring and optimization, enabling architects to refine designs for energy efficiency during the earliest stages of building planning [3][9] [14]. Evaluations of thermal insulation materials further emphasize the importance of choosing the right materials to conserve energy, with lifecycle assessments of buildings and building materials showing the importance of considering energy impacts throughout the material's entire lifecycle [6][7] [15].

Another significant aspect of energy-efficient building design is understanding the impact of building orientation, particularly in hot climates. The direction a building faces can greatly affect energy consumption, as certain orientations can minimize the need for cooling and heating [10][2] [18].

Lastly, occupant behavior plays a key role in the overall energy performance of buildings. By understanding how occupants use energy, energy models can be refined, leading to better strategies for improving building energy efficiency [13][8][8].

3 Methodology

To assess a building's energy efficiency materials created with design builder software the investigation is divided into three stages. Phase one is for study on thermal properties and the calculation of U values, i.e heat transfer by various materials such as fly ash, AAC, brick, CSBE, and so on. From these, we should select the top five most efficient materials for the second phase, and then compare both phases one and two using design builder software to obtain results. Then, in phase three, we will take the best three results from above and create three different proto types with those materials, after which sensors will be placed inside them and variables such as temperature, air speed, velocity, relative humidity will be known for best conclusion.

4 Calculations of U Values

Table 1 show the Thermal Properties of Building Materials: Comparison of Thermal Conductivity and U-Values.

Table. 1. Thermal Properties of Building Materials: Comparison of Thermal Conductivity and U-Values.

S. No	Material	Thermal Conductivity w/make	U – Values w/ (m2. K)
1	Brick	0.9	10.0
2	FlyAsh	0.9	9.128
3	AAC	0.7	1.84
4	CSEB	0.84	8.4
5	RCC	1.58	10.63
6	Concrete Block	1.63	8.7
7	Fiber reinforced concrete block	2.7	13.49
8	Gypsum plaster	0.512	25.6
9	Lime concrete	0.73	7.304
10	Cement plaster	0.721	36.0

5 Numerical Analysis

5.1 SCM Feature and Uses of Design Builder

Innovative productivity features some typical usage purpose is summarized below: •Evaluation of the optimum use of daylight. Modeling of lighting control systems and deter- mining the savings rate in the corresponding electricity.

- To calculate the buildings in/around temperature, velocity and pressure distribution by using the CFD (Computational Fluid Dynamics) module.
- Visualization of the site plan and shading. Thermal simulation in buildings which are ventilated with natural ventilation.
- Determining the capacity of heating and cooling equipment to include the issues to help.

5.2 HVAC Design

To provide material to design meetings for supporting inter disciplinary communication. •To be used in universities in energy modeling and simulation courses.

5.3 Input of Building Data

The project's major goal is to determine the standards for a building's energy efficiency. As a result, the primary elements impacting the building's energy features should be identified. For this project, the key influencing variables for energy efficiency features of the structure were building materials (such as wall materials, plastering materials, and insulation materials) and WWR (window to wall ratio). Design Builder provides tools to help you speed up and simplify data management activities.

5.4 Data Input

1.Create a new project using the model. 2.Go to the building level and the Constructions tabs. Click on External wall to load e Data management panel on the right of the screen. 3.Create a new external wall construction by clicking on the + Add new item toolbar icon. The new wall is to use a single layer of a new material which we will also define now.

The specifications for all types of building and construction materials and components will be preloaded in Design Builder, including conductivity, density, and specific gravity. As a result, we may readily access such material sand provide specification data to them. In the event that the specification data has to be changed or customized, we can simply make a duplicate of the material and adjust the attributes of that material. If any modifications in qualities are necessary, we may apply the same approach for all types of construction materials (for example, wall materials, plastering materials, and insulation materials). We must first input the number of layers necessary for the project wall. So that the programmed develops the various types of materials in the proper order and allow us to apply or alter them. You can build structures with up to six levels. Starting with the outermost layer and ending with the innermost, specify the layers in the same order they exist in the real build.

6 Experimental Analysis

From the numerical analysis we found that the best wall material as AAC and the best insulation material as EPS. For those materials we construct the building and we installed the humidity sensors and temperature sensors along with solar panels. The eps insulation is installed at south face and west face of the building because it is directly exposed to sunlight.

Cost of Conventional Building

QUANTITY: M20 Grade Concrete
Proportion – 1:1.5:3
Volume of ingredients in meter cube: Cement:0.181
Sand:0.271
Course aggregate:0.543
Total concrete Required (all are in meter cube)
Flooring :12.5

Column and Pedestal :5.5
Plinth Beam :3.3
Roof Beam :5.2
Lintel and Sunshade :2
Total: 34.6 1. COST
Slab :6.10
CEMENT Total Volume of Cement Required = 0.181*34.6
=6.2626m^3

Density of cement =1440kg/m^3
Amount of cement per meter cube=1440kgs
Total Cement Required = 6.2626*1440
= 9018.144 kgs
No of Bags Required = 9018.44/50
=181
Cost of Bag = Rs.350/-
Total Cost for Cement = 350*181
=Rs. 63,350 /-

SAND
Volume of sand required = 0.271*34.6
=9.3766
Cost of sand per m3=Rs.1250/-
Total cost of the sand=9.3766*1250
=Rs.11,720/-

Coarse Aggregate

Volume of Coarse Aggregate required = 0.543*34.6
=18.78
Cost of coarse aggregate per m3 = 700 Rs Total cost of the coarse aggregate = 700*18.78
=Rs.13,146/-

Brick Work: (Conventional Brick)

Total volume of Brick Masonry=38
Number of Bricks required per m3=500
Total number of bricks required= 500*38
=19000
Cost per each clay brick = Rs.9/-
Total cost of Bricks = 19000*9
=1,71,000

Plastering

Total Area of Plastering = 214 sqm
Total Area of Plastering in (sft) = 2304
Cost per each sft of Cement Plaster=Rs.20/-
Total cost of Plastering= 20*2304=Rs.46080/-

Single Glazed Windows

Total Area of Glazing = 130sft
Cost of Triple glazed Window per each sft = Rs.450 /-
Total cost of Single Glazed Window = 450*130
= Rs.58500 /-
Total cost of conventional Building
(63,350+11,720+13,146+1,71,000+46,080+58,500) = Rs.4,03,796/-

A. Cost of Building with Energy Efficient Materials

M20 Grade Concrete Proportion – 1:1.5:3
Volume of ingredients in meter cube:
Cement:0.181
Sand:0.271
Course aggregate:0.543
Total concrete Required (all are in meter cube) Flooring :12.5
Column and Pedestal :5.5
Plinth Beam :3.3 Slab 6.10
Roof Beam :5.2
Lintel and Sun shade :2
Total: 34.6

Cement

Total Volume of Cement Required = 0.181*34.6
= 6.2626 Amount of cement per meter cube = 1440 kgs
Density of cement = 1440kg/m3 Total Cement Required = 6.2626*1440
= 9018.144 kgs No of Bags Required = 9018.44/50
= 181 bags Cost of Bag = Rs.350/- Total Cost for Cement = 350*181
= Rs.63350/-

Sand

Volume of sand required = 0.271*34.6
=9.3766 Cost of sand per m^3 = Rs.1250/- Total cost of the sand = 9.3766*1250
=Rs.11720/-

Coarse Aggregate

Volume of Coarse Aggregate required = 0.543*34.6
=18.78 Cost of coarse aggregate per m3 = 700 Rs Total cost of the coarse aggregate = 700*18.78
=Rs.13,146/-

Brick Work (Auto Claved Areated Concrete Block

Size of AAC bricks = 0.6*0.2*0.23
= 0.0276

No of AAC brick required = (38/0.0276)

= 1376 No's Cost per each AAC brick = Rs.40 /- Total cost of AAC brick required = 1376*40

= Rs.55,040 /-

Plastering (Gypsum)

Total cost of Plastering = 46,080/- **Insulation (Eps)**

Total Cost of Insulation =Rs.30,000/- SINGLE GLAZED

WINDOW Total Area of Glazing = 130sft Cost of Triple glazed Window per each Sq. ft = Rs.450 /- Total cost of Single Glazed Window = 450*130

= Rs.58500/-

Solar Panels

Total cost of Solar Panels = Rs.3,00,000/-

TOTAL COST OF BUILDING =5,02,836/ -

7 Results

Fig. 1 show the Comparison of energy efficiency building and conventional building (west wall).

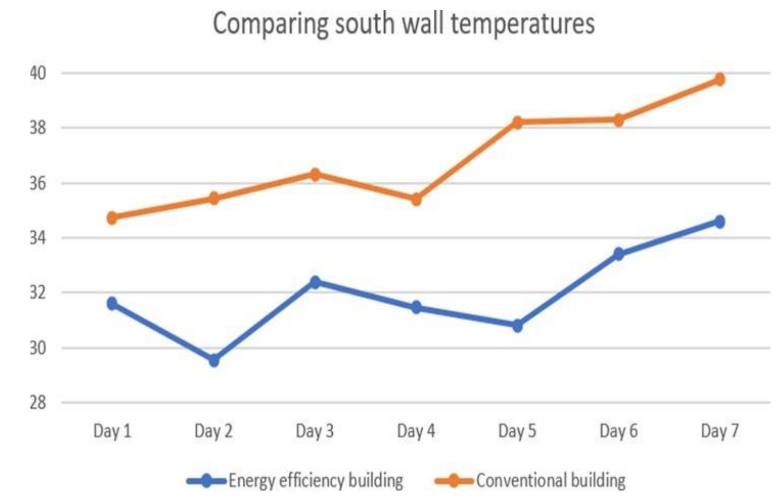

Fig. 1. Comparison of energy efficiency building and conventional building (west wall).

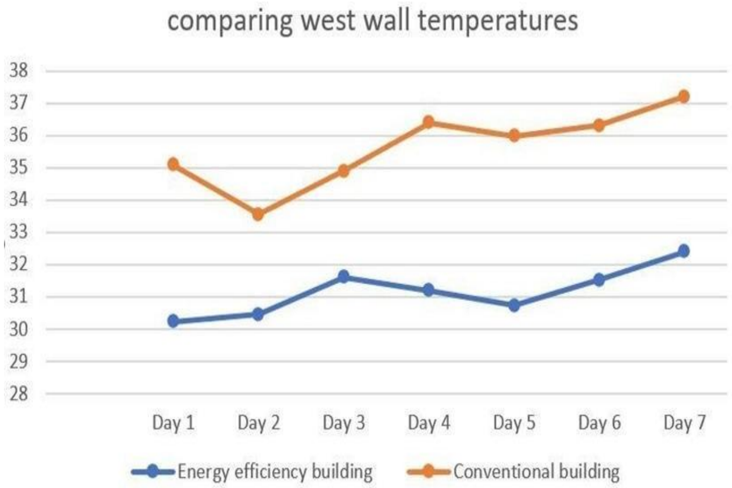

Fig. 2. Comparison of energy efficiency building and conventional building (south wall).

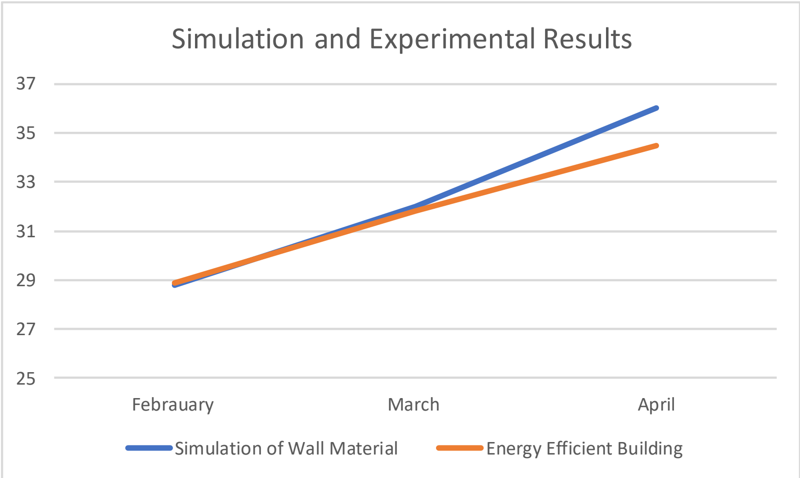

Fig. 3. Comparing simulation results and experimental results.

Fig. 2 and 3 shows the Comparison of energy efficiency building and conventional building (south wall) and Comparing simulation results and experimental results respectively.

8 Conclusions

The study conducted through both numerical simulations and experimental analysis clearly demonstrates the benefits of using energy-efficient materials in building construction. Among the various wall materials assessed including fly ash bricks, concrete blocks, lime concrete, and clay bricks the Autoclaved Aerated Concrete (AAC) block emerged as the most energy-efficient option. It exhibited the lowest U-value, indicating superior thermal insulation properties and reduced heat transfer. This results in lower annual energy consumption compared to conventional wall materials.

In the category of insulation materials, Expanded Polystyrene (EPS) continues to be an efficient material, demonstrating minimal thermal conductivity that significantly reduces indoor heat gain, particularly on the west and south-facing walls exposed to maximum sunlight. Recent studies have also explored more sustainable EPS alternatives, such as bio-based EPS and recycled EPS, which further enhance the environmental benefits and performance of insulation materials in energy-efficient construction (Li et al., 2025; Zhang, 2024). These newer alternatives not only offer the same thermal performance but also reduce the ecological impact, making EPS an even more attractive choice for sustainable building practices.

A comparative cost analysis between conventional and energy-efficient buildings revealed the following:

- Total Cost of Conventional Building: ₹4,03,796
- Total Cost of Energy-Efficient Building (with AAC & EPS): ₹5,02,836
- Percentage Increase in Construction Cost: ~25% (not 40%, based on the actual values)
- Although the initial construction cost of the energy-efficient building was higher by approximately ₹99,040, this additional investment leads to significant long-term savings. The energy consumption in the AAC-EPS building is reduced by nearly 20%, leading to lower operational costs in the form of reduced electricity bills for cooling.

Moreover, the additional cost incurred is recoverable within 4 - 5 years through energy savings alone, making the approach both economically and environmentally sustainable. The integration of solar panels further supports the transition towards renewable energy use and minimizes dependence on conventional power sources.

In conclusion, the use of AAC blocks and EPS insulation in building construction not only enhances energy efficiency but also contributes to sustainable development goals. The findings advocate for the wider adoption of energy-efficient construction practices, especially in hot climatic regions like Telangana, where temperature control is vital for occupant comfort and energy conservation.

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