Adopting combination of passive design strategies to optimize building energy needs

Kolla Navaya1*, Ashwin Raut2, Sravan Chilukuri3 and N Sugandha Rathan4

1Department of Civil engineering, Koneru Lakshmaiah Educational Foundation, Vaddeswaram, Guntur (Dt.), Andhra Pradesh, India. kollanavya1997@gmail.com
2Department of Civil engineering, Koneru Lakshmaiah Educational Foundation, Vaddeswaram, Guntur (Dt.), Andhra Pradesh, India. ashwin7588@gmail.com
3Department of Civil engineering, Koneru Lakshmaiah Educational Foundation, Vaddeswaram, Guntur (Dt.), Andhra Pradesh, India. sravan999chilukuri@gmail.com
4Department of Civil engineering, Koneru Lakshmaiah Educational Foundation, Vaddeswaram, Guntur (Dt.), Andhra Pradesh, India. sugandharathan@gmail.com

ABSTRACT The paper’s main goal is to analyze the efficiency of roof and wall systems based on varying insulating material layers in the tropical climatic region of Vijayawada, Andhra Pradesh, India. This research is carried out on “e-QUEST” software for energy analysis which is determined on monthly basis and the results gave evidence about energy consumption of building envelope and its operational life cycle costing. The wall and roof system have been studied for computation of the operating energy requirements and its subsequent carbon footprints which comes under concept of sustainability of building. The materials identified for insulating roof are vacuum insulated panels, wool glass, phenolic foam, expanded polystyrene, polystyrene, and for wall are cellulose, fiber glass, mineral wool, polystyrene, aero gel. Due to both have insulation of wall and roof systems the passage a source of heat minimized because of which the cooling demand is reduced on building and ultimately leads to lowering of energy consumption. Hence this study is crucial to understand the resident indoor air comfort, environmental and long-term economic benefits.

Keywords: Carbon-Emissions, Insulation Materials, eQUEST, Energy-Efficiency, Long-Term Cost Benefits.

1. INTRODUCTION

Building construction sector emits approximately 35% of total greenhouse gases (GHG) and also responsible to consumption of global natural resources. According to the data, the construction activities leads to the consumption of 16%, 40%, 25% of the worlds water, stone, and timber [1]. It has been approximated fast expansion of cities and societies will eventually lead to the rapid growth in the construction projects all across the world consuming lots of energy and resources. Energy requirements in a construction of a building are mainly divided into operational energy, embodied energy, transportation of material, demolition, and disposal [2]. The major allowance of energy is from electricity and embodied energy. The operational energy can be reduced by proper selection of insulating materials by combining with structure. It also elevate the scope of developing urban heat islands When comparing India to other rural areas.

Increased emissions of GHG into the atmosphere leading to extreme climatic conditions put onus in terms of indoor air systems in the residential places and raise the living conditions. Socio economic factors driven a way for better comfortable indoor air conditions in the building sector to give an indoor environment solaces. Also inhabitant are depended in terms of air conditioning. Hence, The
construction industry is getting more energy efficient, dependent and more capacity consumptive. It is to required to select the best way in air conditioning using passive energy techniques

With the analysis conducted different types of passive energy strategies in order to lift up the indoor air comfort and decrease the power consumption mainly energy simulation software, natural and mechanical ventilation, solar shading performance such as sun cast, double glazing [3] dynamic simulations with TRNSYS software, use of different wall constructions [4].

Building Envelope obstructs the passing of heat indoors, majority of the surface area is being shading by the roof and wall segments. So, providing a combined insulation film is a best technique one can be adopted. Roof and walls restrict the direct transfer the humidity to the interior of the building by solar blazes which origins the discomfort to the residents by increasing heat in the building envelope. Roofs and walls segments play the part of a barrier to restrict the other environmental factors. The modifications to these structures are one of the popular acquaintance cooling technologies used in green buildings worldwide. The results of these combined insulating technologies with walls and roofs are studied in Vijayawada region. Vijayawada is a city in India, comes under a tropical climate and temperature more than 40 ° in the months of March to July results in excess usage of indoor comfort technologies which directly increases the electricity consumption. The focus of the paper is to examine the various combinations of roof and wall non conducting materials and its outcomes on operational energy. As in modern world we have different types of insulating options in the retail but selecting the material which can be give best results by lowering energy consumption of the indoor spaces as well as financial constraints can precisely serve as a green building material.

1.0.1 Insulation Materials
Through ground work it spots out different kinds of materials which act as heat insulation that eventually reduce the movement of heat by the serval components of the building envelope. Insulation material products like wool, fiberglass, rock wool, polystyrene, polyurethane, etc., are commonly used for insulation. All these insulating materials possesses comparatively lower values of thermal conductivity as stated in Table 1. By using all such materials, roofs and walls are modeled for study to attain the results of insulating layers on building energy system. The modeled slab and wall system data for different types of materials is presented in the Table 1.

1.0.2 Thermal parameters
Methodology was to use analytical method for computation of the R-value (m²k/w), thermal conductivity (w/mk), specific heat capacity, durability, and costing. The insulating value of an object is called as R value. Higher the R-value, The heat transfer through the building is reduced.Envelope components and thus lowers the energy consumption. Thus, for better insulation purpose the R value should be high.

To design ecological and thermally efficient buildings we make use of thermal properties of materials. High conductivity indicates fast heat flow into the building and low pressure represents slow heat flow. And conductivity is mainly dependent on the layer of the slab as well as insulating material. The thermal conductivity ‘k’ and thickness is ‘l’ has a conductance of C=k/l this indicates how heat can be transmitted through the walls and roofs. The slab having expanded polystyrene and mineral wool padding reduces the cooling load on the roof shelter. The walls having polystyrene and cellulose reduce the orientation need for a wall system.

1.0.3 Factors affecting energy-consumption
The following categories can be used to differentiate overall building energy consumption:
   a) The weather (e.g., outdoor air temperature, solar-radiation, wind velocity, etc.).
   b) Features of construction (e.g., type, area, orientation, construction materials, etc.).
   c) Building services systems and operations (for example, space cooling/heating, hot water supply, and so on).
   d) The behavior and activities of the building’s occupants (i.e., time they come and leave the
building, whether they turn light off when they leave, etc.).

   e) Materials for insulation (type, properties, thickness, etc.).

1.1 Thermal issues in India

The energy consumed due to the obligaton on heating and cooling of building enveloped account to 50%-70% of total energy requirements of an average household [5]. The knowledge and understanding of structure ability have improved the quality of research on user practices and association with building systems for energy use [6]. The decision support system assists the users or designers to make appropriate decision regarding choice of insulation [7]. The study found that occupant behaviour does affect the energy consumption of a building [8]. The actions and behaviours of occupants of the building are the most difficult to predict with reasonable precision [9]. To get a more precise and practical overview various patterns of energy usage in buildings will need to be implemented [9]. The occupants behavioural pattern has significant impact on the buildings liveliness [10]. Occupants can use a range of appliances, which will influence the buildings energy usage. It also depends on the number of people who live in the house. Highly accurate information is available near real-time using people counters, allowing for the creation of more practical occupancy schedules and a better assessment of established building performance. [9]

   The energy consumption of a building sleeve is also carried off by its openings. In the winter, reducing the natural ventilation rate will help to save 45% on heating and cooling. [11] The air-conditioning load can be minimised in a few ways, one of which is insulation [12]. Heating our buildings consumes 30% of overall energy consumption [13]. The construction industry is now considered as one of the crucial sectors for development activities responsible for environmental impacts, thus a sustainable way forward has to be adopted [14]. The use of high-yield insulation materials and energy-efficient components has potential to significantly improve the energy efficiency of building [15]. The heat transmit along walls and roofs owing conduction mechanism accounts for a large portion of a building’s overall thermal load [12].

1.2 Insulation

Insulation is characterised as materials or mixtures of materials that reduce the flow of heat energy by inhabit on the strategies. Classification, Insulation can be done according to its composition, type, heat transfer resistance, environmental impacts, and more. A radiant barrier is a exierior which is thermally reflective is often applied to a material to minimise heat dissipation by radiation and conduction.

   - Insulation Material reduces the carbon emission in the atmosphere.
   - Control the temperature of the building
   - Increase the building's efficiency by heating, ventilation, cooling etc.
   - Maintain proper comfort and safe working temperature to control the surface
   - Save to benefit for electricity by reduce heat loss or gain

1.2.1 Properties of insulation materials

The nature and properties of the materials has atmost consequences on energy consumption. The materials with the explicit characteristics is used to reduce the building’s energy consumption and also in selected layers for insulation. Based on the literature, the thickness of the sheet, depend upon U-value, and R- value excute a major part in energy consumption. According to the literature, products with a flat U-Value and a elevated R-Value would perform better in terms of reducing source consumption.U value and R value are only two materials belonging which are used in subject research. A research on how to develop the energy efficiency of a building is done. [10] By using eQUEST design to develop a model for constructing an organization using various insulation materials. And the study used energy
consumption and renewable energy for findings, choosing suitable materials with U and R values to minimize the structure life usage and meet the green building standards.

A research focused on nature-based Materials for thermal insulation made from renewable resource. [14] The Paper goes over everything on the various forms of natural-based insulation materials, their properties, and their advantages. Based on researcher’s, findings concluded that using natural shielding materials such as wool, fabrics, and additional natureborn materials would minimize energy consumption and emissions.

2. BUILDING ENERGY MODELLING

A building’s resource requirements are construction materials, lighting, water heating, cooling, HVAC, refrigeration, components efficiencies and strategies are included in BEM software. This software gathers the information inputs through local weather file and calculate the thermal loads, system results the energy use like occupant comfort and energy costs. BEM which calculated the hourly, monthly, annual of energy usage. Depend upon the literature service and edge software, the overall energy consumption used in commercial building is category to space heating (32%), lighting (23%), water heating (15%), cooling (7%), office equipment (6%), ventilation (3%), refrigeration (3%), cooking (4%) and others (7%).

![Figure 1. Energy use in commercial buildings.](image)

2.1 Passive design

The term refers to a type of architecture that takes advantage of the regional conditions to keep a comfortable temperature range in the home. Passive architecture decreases or removes the need for mechanical means heating via cooling system needs, which accounts for around 40% of energy usage in the typical home (or even more in some climates).

The passive design strategies adopt natural sources heating and cooling without consuming artificial means of energy source. To utilize the natural sunlight as a potential source of energy orientation of building should be appropriate apart from that other parameters for designing building envelope such as window to wall ratio, shading devices and insulation aspects (roof, walls, windows,
and the floors of a building) needs to be considered. Passive design adopted for the construction enclosure shows finest amount of heat gain/loss. However, unasseretive design viewpoint can enable the occupants with better thermal comfort, low energy bills, and low greenhouse gas emissions, good passive design is important.

3. RESULT ANALYSIS

Based on the eQuest tools specific date, simulation of the structural performance is carried on by choosing the appropriate type of the run to obtain the simulated results using Energy efficiency wizard. Consider roof insulation as example, select EEM Wizard at the left panel of the screen popping a window, select EEM run name and measure type.

Ensuring the type of the run, for simulating the structure, select simulate building performance Wizard at left of the screen and get the results. In the above figure, the left small window as shown will display the quantity and names of runs those will takes place for simulation. The flexibility is that we can delete or can create runs needed using Energy Efficiency Wizard.

After selecting the simulate option, simulation process will take place, in that several runs will transper to obtain complete energy analysis. The result we get will be in two types i.e, result and detailed result. Summary result will give the high-level result containing several graphs, values, etc., while detailed summary report will give total result in detailed output pdf format.

| Insulation | Material               | Thermal Conductivity (W/Mk) | Density (Kg/M³) | Topmost Service Temperature (°C) | Durability (Years) | R-Value (M².K/W) | Material Cost (Rs./Sq. Ft.) | Specific Heat Capacity (J.Kg/°C) |
|------------|------------------------|-----------------------------|-----------------|----------------------------------|-------------------|-----------------|-------------------------------|----------------------------------|
| Roof       | Vacuum insulated panels| 0.07                        | 195             | 950                              | 50                | 3.3             | 120                           | 800                              |
|            | Glass wool             | 0.03                        | 55              | 300                              | 25                | 1.5             | 150                           | 670                              |
|            | Phenolic foam          | 0.02                        | 50              | 150                              | 50                | 1.0             | 225                           | 1400                             |
|            | Expanded polystyrene   | 0.03                        | 34              | 75                               | 40                | 1.65            | 10                            | 1200                             |
|            | Polystyrene            | 0.03                        | 37.5            | 78                               | 50                | 1.75            | 10                            | 1400                             |
| Wall       | Cellulose              | 0.04                        | 50              | 250                              | 50                | 1.25            | 278                           | 1680                             |
|            | Glass wool             | 0.04                        | 275             | 230                              | 25                | 3.3             | 150                           | 670                              |
|            | Mineral wool           | 0.025                       | 70              | 650                              | 25                | 2               | 165                           | 3516.9                           |
|            | Polystyrene            | 0.033                       | 38              | 78                               | 50                | 1               | 10                            | 1400                             |
|            | Aero gel               | 0.03                        | 110             | 650                              | 20                | 1.5             | 95                            | 2100                             |

*Density*: The heat insulation of a material is influenced by its density. The insulating property is in inverse relationship with the density of the material. The insulation performance improves as the density
minimizes. Expanded Polystyrene with a soliddness of the component of 18-50 kg/m3 for roof insulation and Polystyrene with a density of 38 kg/m3 for wall insulation.

**Thermal conductivity:** The best insulating matter should be used as heat conductivity. The insulation prevents heat from escaping and keeps the room at a comfortable temperature. Phenolic Foam has a thermal conductivity of 0.018-0.023 W/mK for roof insulation, while Polystyrene possesses thermal conductivity of 0.033 W/mK for wall insulation.

**Durability:** The longevity of any component should be sufficient, and it should be provided on a timely basis, as well as the number of years. By comparison, Phenolic Foam and poly styrene has a 50-year of durability over both wall and roof insulation.

**R-value.** The elevated R-value (Resistance) is ample the insulation. It refers to a material’s designed to sustain heat transfer through one side to some other. By modified inquiry that, Phenolic foam having the R-value is 6.7-7.5 M2.K/W in roof insulation, Cellulose posses that R-value is 3.5 m2.K/W.

### 3.1 Building energy analysis

An energy survey was done on individually for roof and wall system to understand the insulation effectiveness and its wellbeing on its overall homelike and energy conservation comfort. The energy analysis is done on Simulated house as indicated in figure. The source that were used for simulation purpose is “eQUEST” software. The modelling was done on auto desk Revit software for G+3 building located in Vijayawada, AP, India. The comparative analysis is based on the parameters in the model is not changed except the roof and walls system having values shown in the table-1.

![Building model for energy analysis in eQUEST software](image)

The simulation results study obtained as an energy requirement significane of roof and wall system built on insulating films is portrayed in figure 3 and 4. Assumption can be made that conventional non defending roof and wall systems have highest vitality consumption when compared with insulated systems. The roof system with expanded polystyrene and rock wool insulation proves to be the most economical among other insulating layers. The wall system having polystyrene and cellulose proves to be the best in conjunction with insulated wall systems. These roof and wall systems when binded with
insulating layers shows lower usage of energy consumption which directly leads to lesser electricity costing. The monetary benefits will be near to 10% when compared with non-insulated buildings with roof and wall manner.

Figure 3. Annual costing values for building envelope with various roof insulation

Fig. 3 points out the annual energy needs of roof system having various insulation materials. The heat redirects through non-insulated roof was observed to be greater than insulated roofs. Moreover, relating on R-values of various insulated material, the heat dissipation rate is changed, Followed by changing the energy requirements. The purpose of providing insulating is to retard the passage of high temperatures through the structure envelope and provide the thermal comfort to users. This will automatically lead to less energy consumption leading to lesser annual electricity consumption. The twelve - month electricity consumption, the energy use and values are shown in the figure 7. So, the more capacity to maintain the indoor air comfort reduces the burden on electricity which reduces the electricity consumption due to this the usage of insulation will results as a passive technique in providing the thermal comfort.

Figure 4. Annual costing values for building envelope with various wall insulation
Figure 4 based on monthly peak demand, shows the monthly energy usage. This shows the average utilization of the energy based on the climatic conditions of the area. The area we took into consideration is Vijayawada region where the climate is harsher in the summer months (March-June) where the demand for cooling is higher. Therefore, the demand for cooling is high when the insulation is less. The above results show polystyrene and cellulose reduces the cooling requirement required for a system. This automatically reduces the monthly electricity expenses.

![Space Cooling - Roof Insulation](image)

**Figure 5.** Space cooling and roof insulation

In figure 5 and 6, Illustrates the monthly energy usage of space cooling monthly of both roof and wall. Cooling demand is having high load is obviously larger in the Vijayawada region due to the hot weather conditions. Summer, i.e., May, June, and July record the highest cooling load demands. In case of low of insulation, the following scenario of conventional roof systems, the demand for cooling is higher. The results indicate that expanded polystyrene and glass wool insulation reduces the cooling load on the HVAC system, lowering monthly energy use. The monthly energy-consumption of the various roofs are explained by graphical comparison as in the below graph. The roof having low R-Value, show less energy-consumption when compared to other roofs. The graph represents how different roofs consume varying amounts of energy, as indicated by the graph label.

![Space Cooling - Wall Insulation](image)

**Figure 6.** Space cooling and wall insulation
Annual electricity bills variations with respect to different roof systems are explained in the graph. The roof has highest R-Value, show less electricity bills when compared with other roofs. The graph shows the annual electricity bills of different roof systems as shown in graph label.

4. CONCLUSION

The research analyzes the capacity of insulating layers for building envelope to reduce energy consumption and energy costing. The research successfully recommends the usage of combined function of producing film with roof and wall by providing sedentary comfort by restricting the heat transfer through walls and roofs and proved being energy efficient. The research identify that the slab having expanded polystyrene and rock wool insulation reduces the cooling load on the roof systems. The walls having polystyrene and cellulose reduce the cooling burden required for a wall system. This demonstrate to be efficient energy and provides best indoor air comfort. Thus, the research cornerstone on adopting substance having less energy consumption i.e., operational energy should be utilized considered while constructing a building. The chances in insulation elements have been explored to provide overall sustainability during the building life cycle. After comparing all the results, the roof system having highest R-Value will consume considerably less energy when compared to other roof system. Relating to the study, the insulation materials with highest R-values consume less energy when compared to other materials. Hence it is proved experimentally using energy-models.

REFERENCES
1. Romanova IN, Morkovkin DE, Nezamaikin VN, Gibadullin AA, Ivanova MA. IOP Conference Series. Materials Science and Engineering, 2020; 734:012166.
2. Paone A, Bacher JP. The impact of building occupant behavior on energy efficiency and methods to influence it: A review of the state of the art. Energies. 2018 Apr; 11(4):953.
3. Choi BE, Shin JH, Lee JH, Kim HJ, Kim SS, Cho YH. Energy Performance Evaluation and Economic Analysis of Insulation Materials of Office Building in Korea. Advances in Civil Engineering. 2018 Jan 1; 2018.
4. Jia M, Srinivasan R, Ries R, Bharathy G, Silverman B, Weyer N. An agent-based model approach for simulating interactions between occupants and building systems. In Proceedings of the 15th IBPSA Conference 2017 (pp. 2407-2413).
5. Syed Tabish Zaidi ET. al., “Energy Modeling of University Buildings: A Case Study”, 52nd ASC Annual International Conference Proceedings, 2018.
6. Altan H, Douglas J, Kim Y. Energy performance analysis of university buildings: Case studies at Sheffield University, UK. J Architectural Engineering Technology. 2014; 3(129):2.
7. Fernando Del Ama Gonzalez- “Building Energy Modeling by means of BIM Software: A Case Study with Water flow Glazing”, 7th European Conference on Renewable Energy Systems, Madrid/Spain 10-12 June 2019.
8. Al-Homoud MS. The effectiveness of thermal insulation in different types of buildings in hot climates. Journal of Thermal Envelope and Building Science. 2004 Jan; 27(3):235-47.
9. Bozsaky D. Nature-Based Thermal Insulation Materials from Renewable Resources–A State-Of-The-Art Review. Slovak Journal of Civil Engineering. 2019 Mar 1; 27(1):52-9.
10. Jindal AS, Mittal EP. DESIGNING AN ENERGY EFFICIENT INSTITUTIONAL BUILDING USING EQUEST.
11. Ibrahim M, Wurtz E, Biwole PH, Achard P. Performance evaluation of buildings with advanced thermal insulation system: a numerical study. Journal of Facade Design and Engineering. 2016 Jan 1; 4(1-2):19-34.
12. Raut A, Khatoon S, Goud P. A comparative study on effects of various insulating layers of roof system on energy usage of building envelope. In IOP Conference Series: Earth and Environmental Science 2019 Oct 1 (Vol. 354, No. 1, p. 012055). IOP Publishing.
13. Deshmukh G, Birwal P, Datir R, Patel S. Thermal insulation materials: A tool for energy
conservation. *Journal of Food Processing & Technology*. 2017; 8(04):1-5.

14. Ajeet Kumar et.al. - “Analysis Of Energy Conservation for A Building Model Of Research Institute, (Using Design Builder Simulation Software)”, *International Journal of Applied Engineering Research* ISSN 0973-4562 Volume 12, Number 18 (2017).

15. Jadhav PP. ASSESSMENT OF BUILDING ENERGY BY PERFORMING SIMULATION WITH BIM. *Annals of the Faculty of Engineering Hunedoara*. 2019 Nov 1; 17(4):49-53.

16. Deshmukh G, Birwal P, Datir R, Patel S. Thermal insulation materials: A tool for energy conservation. *Journal of Food Processing & Technology*. 2017; 8(04):1-5.

17. Ajeet Kumar et.al. - “Analysis of Energy Conservation for A Building Model Of Research Institute, (Using Design Builder Simulation Software)”, *International Journal of Applied Engineering Research* ISSN 0973-4562 Volume 12, Number 18 (2017).

18. Jadhav PP. ASSESSMENT OF BUILDING ENERGY BY PERFORMING SIMULATION WITH BIM. *Annals of the Faculty of Engineering Hunedoara*. 2019 Nov 1; 17(4):49-53