Comparison of Energy Analysis in a Residential Building Using Building Information Modeling

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1 Introduction

In this research, the analysis of energy efficiency and its advantages in residential buildings using different materials as a substitute of cement which are more economical and eco-friendlier are mentioned. The energy analysis for a G+2 residential building taking different wall infill materials that satisfy the required standards [1] proposed an energy analysis for a G+2 building using the BIM tool. They did the energy analysis for different zones in India. They found different operational parameters like set point, heating, cooling by providing different design parameters like glazing type, wall type, roof type, and building orientation. They optimized the building for energy efficiency [2] and examined the impacts of the shape of the building and its orientations for the thermal efficiency of the two-story buildings. They have analyzed three different shaped buildings with 24 orientations for each building to check the thermal comfort of the building [3]. It also needs a large amount of spreading awareness of the advantages of BIM [4] that mainly focuses on using the ancient method to utilize the natural resources and lower the increasing energy usage requirement of a building. The paper fails to talk about optimizing the structure based on the economic factors and availability of the material in the particular area that is selected [5]. It talks on how to enhance the structure's energy by using the authors' in-house software. Various equations simulate the different layers of the walls and the change in the properties depends on the inner wall or external wall. The results are attained where the energy is preserved based on the various changes that include and are not limited to the changes in the window sizes, the ventilation openings, and the material composition of the walls [6]. The paper described the trends of increasing demand for electrical energy and the potential of increasing

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the energy efficiency of buildings by using different wall materials. The author also described how BIM had provided a platform for architects and engineers to visualize and analyze the energy efficiency of buildings. The research work was conducted for three different mortar mixes, which included the first mix in which the basalt fiber was not present, the second mix contains basalt fiber of length 5 mm, and the third mix contains basalt fiber of length 12 mm. The flexural strength and compressive strength were tested on the 3rd, 7th, and 28th day using suitable cubes and cylinders containing fiber and without fibers. From this research, the author concluded that the flexural strength of the mortar mixes increased by adding fiber of greater length, but at the same time, the compressive strength got decreased. Basalt fiber with lengths 5 mm and 12 mm decreased the compressive strength by about 5% or 10–15%. The research work in this paper is restricted to up to two tests only, such as flexural and compressive strength tests. Some other tests can also be conducted to find out properties such as porosity, permeability, electrical conductivity, and emissivity to get a broader idea about adding basalt fiber in a mortar [7]. After a 28-day curing period, the effect of the water/binder ratio on the hardened state characteristics of cement mortar was examined. The study is limited to cement mortar testing and mixtures. A comparable research may be conducted to determine the appropriate water/binder ratio for concrete using a similar procedure [8]. The paper discusses how the use of high-quality construction materials with strong thermal characteristics may enhance the energy efficiency of the buildings. The research is being conducted on a sample of energy-efficient buildings in the Czech and Slovak Republics. The sample comprises a variety of new energy-efficient buildings, including single and multi-story structures with or without basements and a variety of building materials. Buildings are powered by a variety of energy sources, including heating, hot water heating, controlled ventilation, cooling, and lighting. The author came to the conclusion that new and contemporary construction materials might help to decrease buildings' energy and environmental consequences. Building materials designed for use in a building outside cladding must have a strong resistance to heat transmission in thin layers. To improve energy performance and minimize greenhouse gas emissions, the amount of natural, recycled, and renewable construction materials must be increased. Building supplies should be acquired and made close to the building site. The reason for this is a reduction in transportation energy [9]. A study was conducted to identify building materials that may optimize a building's energy requirements over its entire life cycle by analyzing both embodied and operational actual material composition and energy usage in a climatically sensitive construction in southern Israel's Negev desert region. It was revealed that the incarnated energy of the building accounted for around 60% of total life cycle energy consumption, which may be considerably decreased by using "alternative" wall infill materials. This material replacement saves approximately 20% of total energy during a 50-year-life lifetime. While the investigated wall systems (mass, insulation, and finish materials) account for a substantial percentage of the building's initial EE, the concrete structure (columns, beams, floor, and ceiling slabs) accounts for approximately half of the building's preuse phase energy. The real building used as the foundation case for this research was constructed using reinforced concrete, cast in situ for external walls and floor and ceiling slabs. Extruded polystyrene (XPS) is used to cover the concrete walls (and roof), which is a hard foam with closed cells manufactured in a continuous extrusion process and sold locally as Rondopan. The findings of the research also show the significance of a number of additional methodological problems. Because LCA software techniques are currently restricted in their use owing to the size of accessible databases, site-dependence, and so on, identifying significant correlations required a comprehensive local study of material energy characteristics for each building phase investigated [10]. The author discusses how energy retrofitting of existing buildings decreases energy usage during the operating phase, while the usage of extra materials impacts energy usage throughout later life cycle phases of retrofitted structures. The purpose of this study was to examine the life cycle primary energy implications of several material options while upgrading an existing structure to reach high-energy performance requirements. For passive home requirements available in Sweden, the author created retrofitting alternatives assuming the greatest and lowest values of ultimate energy usage, respectively. Thermal enhancement of the building exterior is one of the retrofitting possibilities. The author computed the primary energy used in the operation phase as well as the manufacturing, maintenance, and end-of-life phases (operation primary energy and non-operation primary energy). The findings indicate that the non-operational main energy usage varies substantially based on the materials used for thermal insulation, cladding systems, and windows. Although the operation energy use decreases by 50–62%, they find that the non-operation energy for building retrofitting accounts for up to 21% of the operation energy-saving, depending on the passive house performance and material alternatives. A judicious selection of construction materials may decrease non-operational primary energy by up to 40%, especially when wood is used [11]. The paper described the major energy implications of a multi-story residential structure with various building technologies during its life cycle. The buildings' principal structural elements are precast concrete, cross-laminated timber (CLT), and prefabricated. The study includes energy and material fluxes from several life cycle phases of the building variants, which are meant to fulfill the energy performance requirements of the Swedish building code (BBR) and passive home criteria. CLT and modular structures were shown to use less primary energy and produce more biomass leftovers than concrete buildings. The heating value of the recoverable biomass leftovers from the CLT building's production phase is substantially more than the primary energy required for its creation. Primary energy usage for production and construction accounts for 20–30% and 36–47% of total primary energy usage for production, respectively, BBR and passive building construction, space heating, ventilation, and deconstruction. Space heating using combined heat and power (CHP) and ventilation electricity for the BBR and passive building variants account for 70–79% and 52–63% of total primary energy usage for production, respectively, while construction, space heating, ventilation, and deconstruction for an 80-year lifespan When space heating is provided by CHP, CLT and modular structures use 20–37% and 9–17% less total life cycle primary energy, respectively, than the concrete equivalent [12]. The study demonstrates how material selection may impact both embodied energy and recycling potential in one of Sweden's most energy-efficient apartment-type housing developments (estimated energy for operation is 45

2 Methodology

2.1 Building Design

Proper designing of the building is the most crucial part which can affect energy consumption because the factors which influence the energy consumption of a building mostly depend on the design. A standard residential building of G + 2 floors was designed using Autodesk REVIT software to obtain a 3D model of the building as mentioned in [1]. The orientation and ventilation of the building were provided in such a way that it can maximize the usage of thermal energy obtained from solar radiation and minimize the need for artificial energy. The orientation-related research of the building where there is maximum thermal comfort is mentioned in [2]. The selection of material is another major design criteria that affect the thermal energy requirement of a building. For this all the suitable materials were allotted to the building in REVIT Structure. A further material study to improve the building's energy efficiency is done in [13].

2.2 Building Description

The model created is rectangular-shaped with a front width of 7.62 mMm and a height of 10.27 mMm, which consists of a total of three levels each of height 3.42 mMm. Basic wall of 200 mm thickness was provided for the building. Internal dimensions of all the partitions are given in Figs. 1 and 2. Single flush doors were provided in the model and windows were provided with sash as frame material and glass as pane material. The isometric view of the building is shown in Fig. 3, and the elevation of the building is shown in Fig. 4.

2.3 Climatic Data

All the climatic data which are required to perform analysis such as average temperature, external temperature, and wind intensities are automatically taken from the nearest weather station of the selected location to perform analysis. The latitudinal position helps in determining the amount of solar radiation for that particular location.

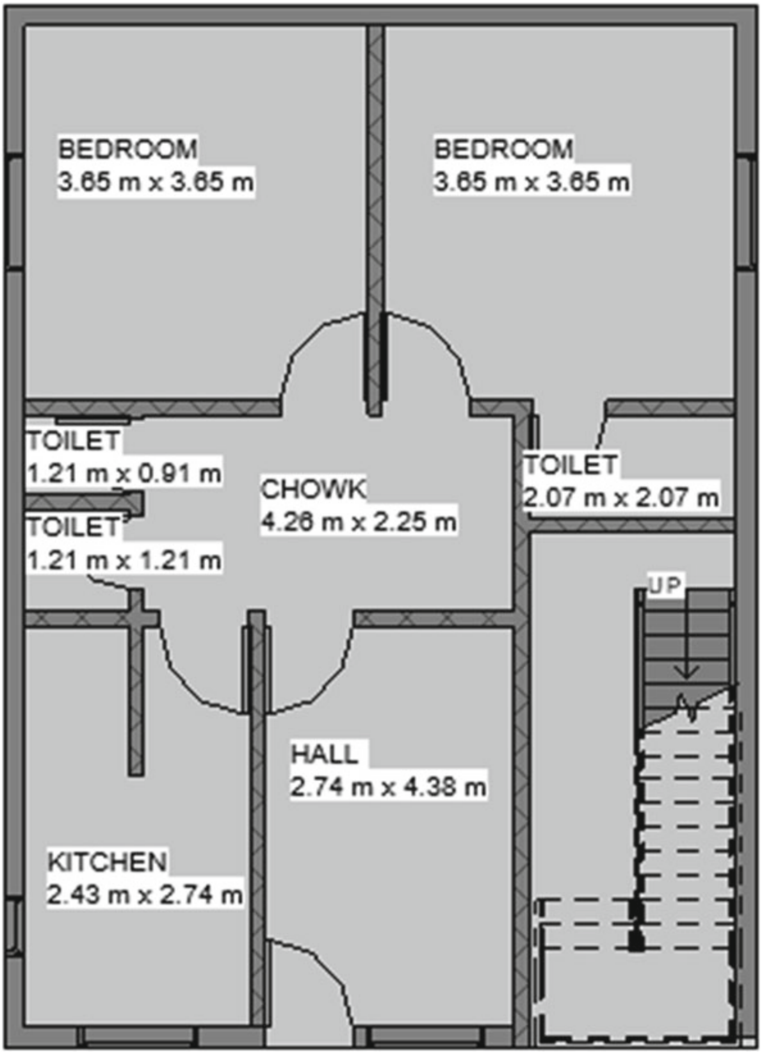

Fig. 1 2D plan of ground floor

2.4 Selection of Materials Using Nanotechnology Testing

The selection of the new material for the wall infill is one of the major factors in optimizing the structure and making it as economic as possible. So, to make the wall infill economic, we started to test the materials by recycling the waste material [12]. Finally, sludge, industrial waste, fly ash, and basalt fiber are taken as the experimental infill materials. These materials are easily available and are very economical in nature. So now the extensive testing has to be done to check if they can meet the strength and other standards.

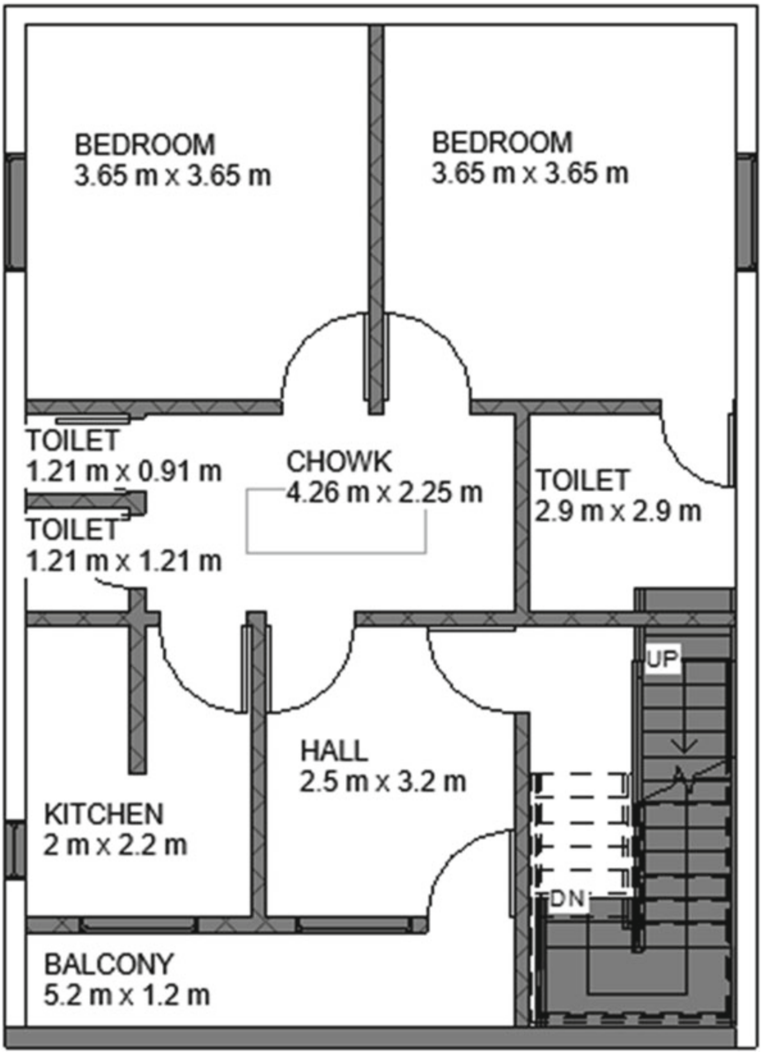

Fig. 2 2D plan of I and II floors

2.4.1 FTIR Analysis

For the detailed composition of these materials, we have done FTIR and SEM analysis in the nanotech laboratory. The FTIR spectroscopy uses mid-infrared rays to extract information about the functional groups in the substance [14]. The sample absorbs the infrared rays and emitted spectrum, and the position and magnitude of this spectrum is the fingerprint of the molecule. This method is faster and the results are acquired in a fraction of seconds. This test helped to know the major chemical groups in the

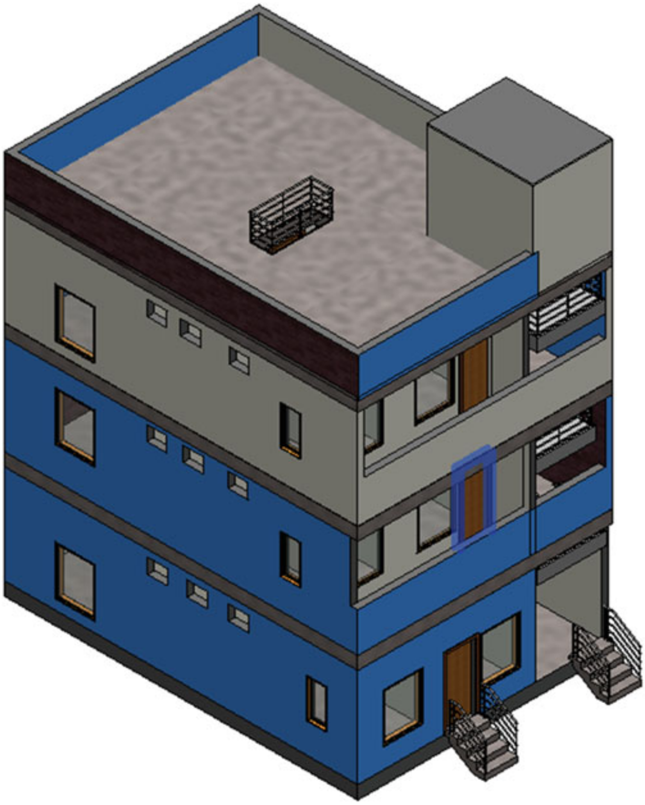

Fig. 3 Isometric view

material which will help us to know the reactions which can happen. This helped to know the durability and life of the material used and these results are compared with the standard compounds such as cement as this material is replacing the cement. The test results which are shown in Table 1 helped us to consider the industrial waste as it has similar results compared to the calcined clay, which is used previously in the industry.

2.4.2 SEM Analysis

It is done using the electron beam to magnify the image. This helped us to texture and magnify the images of the compounds. This also helped to know about the elemental composition of the samples. These results as shown in Tables 2, 3 and 4, where when compared with the composition of the cement and other standard material we can get the basic characteristics of the samples.

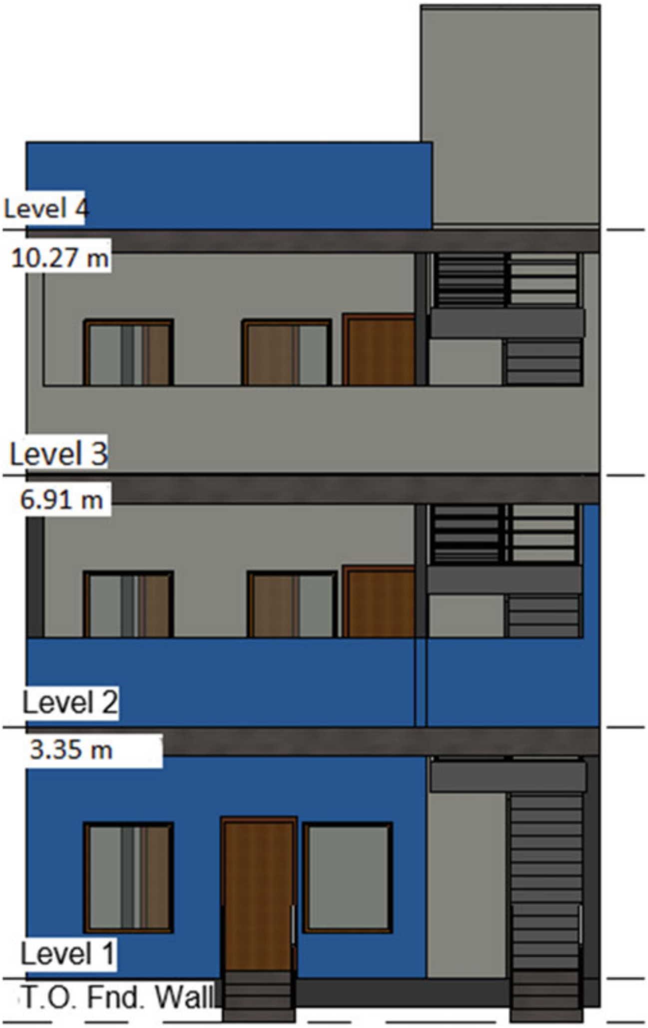

Fig. 4 Elevation

Table 1 The result of FTIR analysis

Sample	Absorption (cm^{-1})	Appearance	Group	Compound class
Sludge	561.29	Strong	C–I stretching	Halo compound
	3278.99	Strong, sharp	C–H stretching	Alkyne
Industrial waste	416.62	Strong	C–I stretching	Halo compound
	3500.80	Medium	N–H stretching	Primary amine
Sisal fibre	1024.20	Strong	C = C bending	Alkene
	1595.13	Strong	N–O stretching	Nitro compound

Table 2 SEM analysis results for sisal fibre

Element	At. No	Mass [%]	Mass Norm. [%]	Atom [%]
C	6	51.47	51.47	60.25
O	8	42.23	42.23	37.12
Ca	20	1.92	1.92	0.67
K	19	1.35	1.35	0.49

Table 3 SEM analysis results for industrial waste

Element	At. No	Mass [%]	Mass Norm. [%]	Atom [%]
O	8	60.79	55.12	73.55
Ca	20	28.20	25.57	13.62
S	16	21.06	19.10	12.72
Fe	26	0.15	0.14	0.05

Table 4 SEM analysis results for sludge

Element	At. No	Mass [%]	Mass Norm. [%]	Atom [%]
O	8	35.66	52.19	68.06
Ca	20	9.80	14.35	7.47
Si	14	8.97	13.13	9.76
Mg	12	4.97	7.27	6.24

These materials are then cast for physical testing, which will help us in comparing the compressive strength, thermal conductivity, and various other properties. The mix ratio which has the optimum values will be considered. These properties are then compared with the standards so that the results satisfy the required strength and help in optimizing the energy consumption.

3 Results and Discussion

This section explains how the heating and cooling load values change on introducing a new infill material and the differences in the load values between the results obtained by analyzing using conventional materials and infill material. These values indicate the amount of heat that is to be added or to be removed from the rooms to maintain a comfortable room temperature and to reduce the usage of electrical appliances. These heating and cooling load values can be used to optimize the building design which tells us about the number of ventilations and open spaces that should be provided in the building. The three locations for which the analysis is performed are mentioned below along with the load values, model history, and benchmark comparison obtained.

Table 5 The building summary (Agar)

Inputs	Conventional material	Infill material
Area (m^2)	54.56	54.56
Volume (m^3)	444.58	444.58
Results of calculation		
Total load peak cooling (W)	11,220.47	9786.53
Month and hour for peak cooling	5/21 17:00	5/21 17:00
Sensible load peak cooling (W)	11,003.17	9598.33
Maximum cooling latent load (W)	217.29	188.20
Maximum heating load (W)	2263.39	2841.44
Checksums		
Cooling load density (W/m^2)	205.65	205.65
Heating load density (W/m^2)	41.48	41.48

3.1 Agar

The building summary has been obtained after analyzing the building for the energy analysis. Table 5 explains the calculations of different load values such as peak heating load, peak cooling load, sensible load, and latent load for the Agar city. In this table, the outputs are obtained for the conventional material which is simple cement mortar and the infill material which is a mortar mixture of fly ash and calcined clay.

Figs. 5 and 6 show the benchmark comparison of the building in Agar city for different materials in the building. From these figures, it is seen that a benchmark comparison for power consumption is given for a year. In Agar location, the benchmark comparison for conventional material is 981 kWh/m^2/year, and for the infill material is 756 kWh/m^2/year. Here, for the building in which the infill material is used, the power consumption per year is comparatively less than the building in which conventional material is used.

3.2 Delhi

The building summary has been obtained after analyzing the building for the energy analysis. Table 6 explains the calculations of different load values such as peak heating load, peak cooling load, sensible load, latent load for Delhi city. In this table, the outputs are obtained for the conventional material which is simple cement mortar, and the infill material which is a mortar mixture of fly ash and calcined clay.

Figs. 7 and 8 show the benchmark comparison of the building in Delhi city for different materials in the building. From these figures, it is seen that a benchmark comparison for power consumption is given for a year. In the Delhi location, the

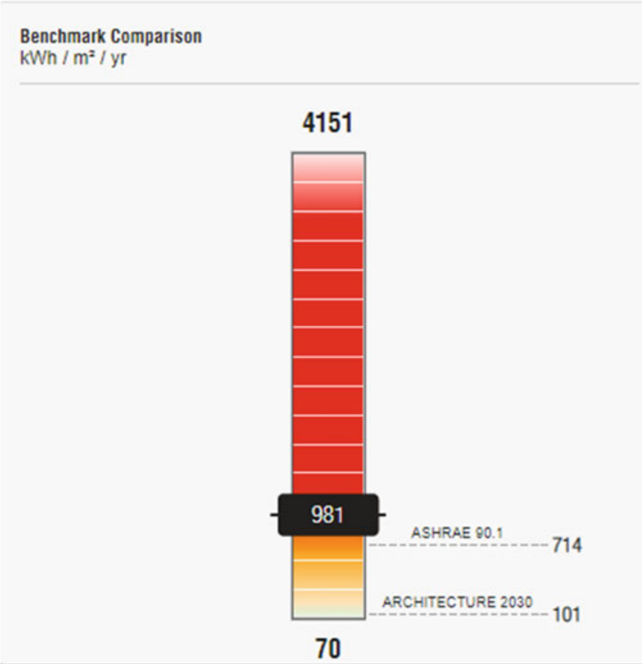

Fig. 5 Benchmark comparison for conventional material (Agar)

benchmark comparison for conventional material is 1025 kWh/m^2/year, and for the infill material is 750 kWh/m^2/year. Here, for the building in which the infill material is used, the power consumption per year is comparatively less than the building in which conventional material is used.

3.3 Chennai

The building summary has been obtained after analyzing the building for the energy analysis. Table 7 explains the calculations of different load values such as peak heating load, peak cooling load, sensible load, and latent load for Chennai city. In this table, the outputs are obtained for the conventional material which is simple cement mortar, and the infill material is a mortar mixture of fly ash and calcined clay.

Figs. 9 and 10 show the benchmark comparison of the building in Chennai city for different materials in the building. From these figures, it is seen that a benchmark comparison for power consumption is given for a year. In Chennai location, the benchmark comparison for conventional material is 978 kWh/m^2/year, and for the infill material is 601 kWh/m^2/year. Here, for the building in which the infill material

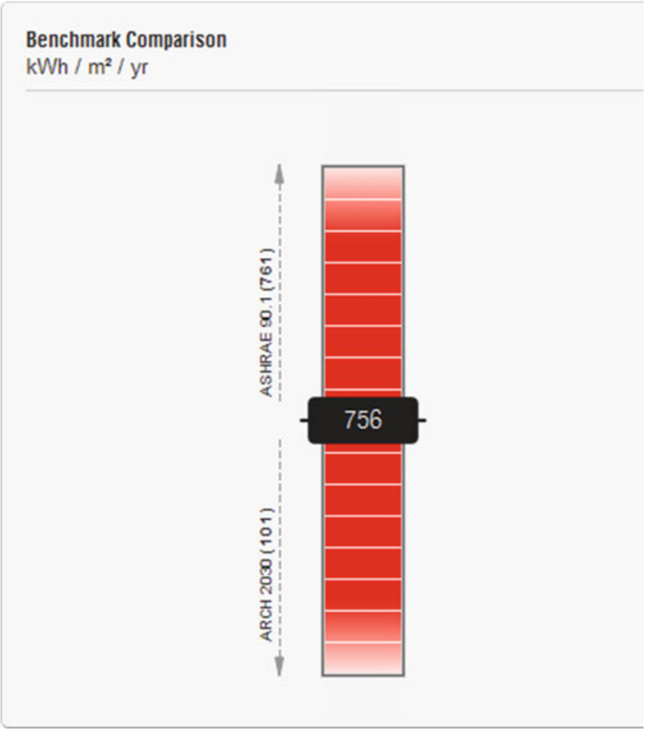

Fig. 6 Benchmark comparison for infill material (Agar)

is used, the power consumption per year is comparatively less than the building in which conventional material is used. As the same materials have been checked for three different locations, it is feasible to use infill material in place of conventional material in construction so as to decrease the power consumption of the building. Table 8 compares the various load parameters like peak cooling load, peak heating load, sensible load, and latent load among Agar, Delhi, and Chennai city. In this table, the comparison of the important results has been done for the conventional material and infill material.

From the values obtained from the analysis performed, a trend can be observed from load values obtained. Due to the introduction of new infill material, the cooling loads demand of the building are decreased while the heating loads demand has increased. From the test conducted for thermal conductivity of the new infill material, it was observed that there was an increase in thermal conductivity which concludes that more heat can be transmitted in the spaces inside the building which therefore decreases the energy demand for the building; therefore, the cooling load demand for the building also decreases for all the three locations. From the above table, it can also be observed that the heating load demand for the building has increased due to the introduction of new infill material; therefore, that indicates there is a need

Table 6 The building summary (Delhi)

Inputs	Conventional material	Infill material
Area (m^2)	54.56	54.56
Volume (m^3)	444.58	444.58
Results of calculation		
Total load peak cooling (W)	37,473.00	33,430.00
Month and hour for peak cooling	5/21 17:00	5/21 17:00
Sensible load peak cooling (W)	38,400.00	32,903.00
Maximum cooling latent load (W)	927.00	527.00
Maximum heating load (W)	19,853.00	23,874.00
Checksums		
Cooling load density (W/m^2)	299.94	299.94
Heating load density (W/m^2)	158.91	158.91

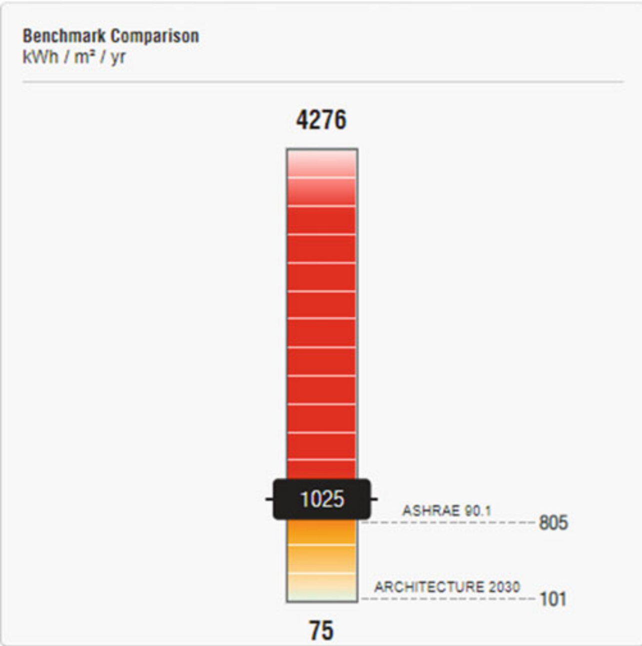

Fig. 7 Benchmark comparison for conventional material (Delhi)

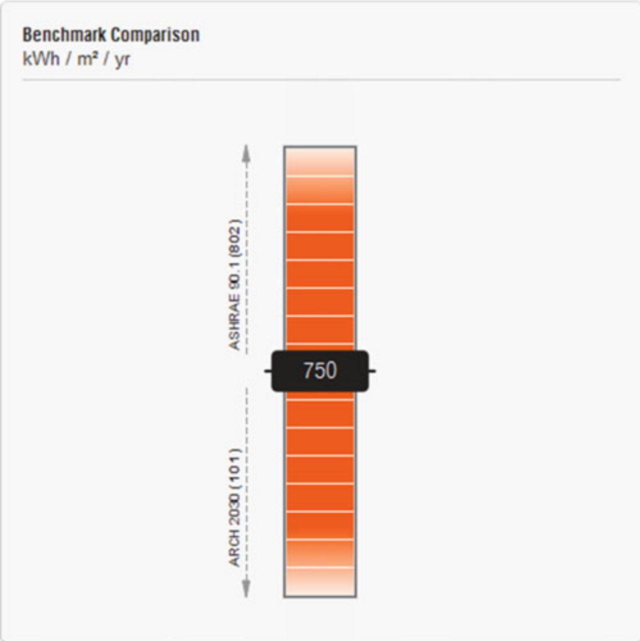

Fig. 8 Benchmark comparison for infill material (Delhi)

Table 7 The building summary (Chennai)

Inputs	Conventional material	Infill material
Area (m^2)	54.56	54.56
Volume (m^3)	444.58	444.58
Results of calculation		
Total load peak cooling (W)	32,879.00	28,051.00
Month and hour for peak cooling	5/21 17:00	5/21 17:00
Sensible load peak cooling (W)	30,363.00	26,067.00
Maximum cooling latent load (W)	2515.00	527.00
Maximum heating load (W)	673.00	1165.00
Checksums		
Cooling load density (W/m^2)	263.17	263.17
Heating load density (W/m^2)	5.39	5.39

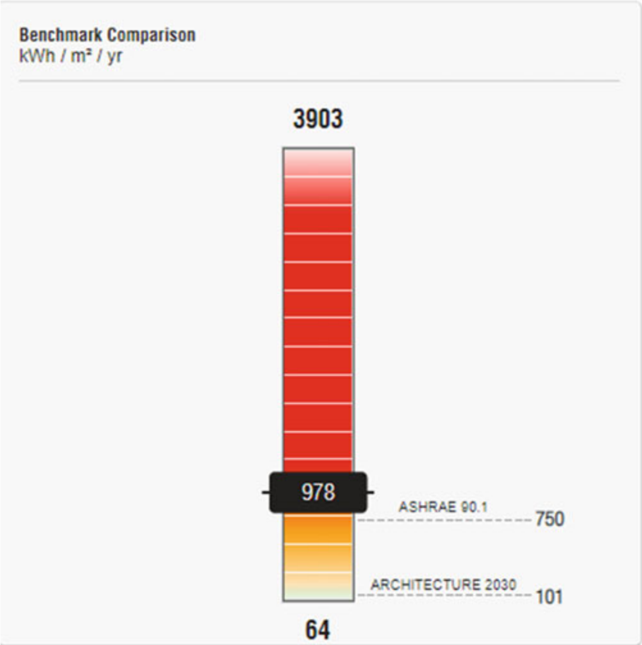

Fig. 9 Benchmark comparison for conventional material (Chennai)

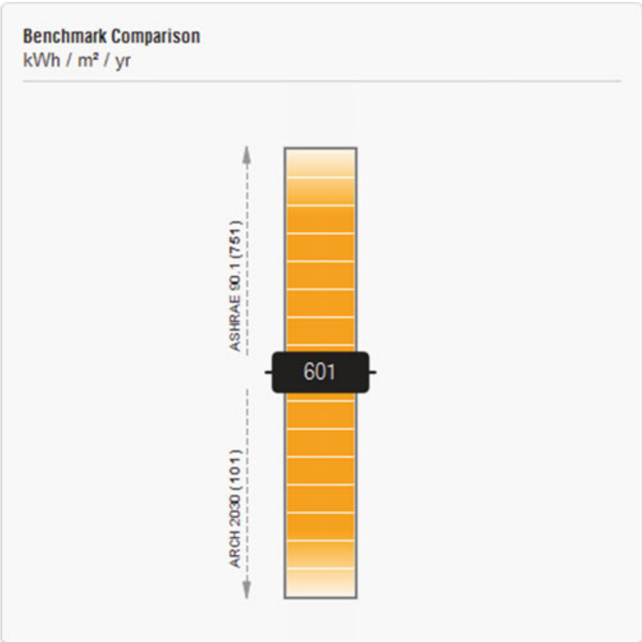

Fig. 10 Benchmark comparison for infill material (Chennai)

Table 8 The comparison of results

I. Parameters	II. Agar		III. Delhi		IV. Chennai	
	V. Conventional material	VI. Infill material	VII. Conventional material	VIII. Infill material	IX. Conventional material	X. Infill material
XI. Maximum cooling XII. Total load (W)	11,220.47	9786.53	37,473.00	33,430.00	32,879.00	28,051.00
XIII. Sensible load peak cooling (W)	11,003.17	9598.33	38,400.00	32,903.00	30,363.00	26,067.00
XIV. Maximum cooling latent load (W)	217.29	188.20	927.00	527.00	2515.00	1984.00
XV. Maximum cooling latent load (W)	2263.39	2841.44	19,853.00	23,874.00	673.00	1165.00

to provide wider window openings and ventilation for the heat to pass through the building. This increase in the peak heating load and decrease in the peak cooling load for the new infill material makes the material feasible and helpful to be used in the construction of the building to optimize it.

4 Conclusion

In this research, an investigation is done to find out the variations in the energy consumptions and energy requirements on the basis of the factors such as ventilation, openings, wall materials, thermal properties, etc. for three different locations. The analysis is done using Autodesk INSIGHT and the values obtained from the analysis show that there is significant potential for reducing the building's energy usage model. The orientation of the building also played a major role in determining the energy requirement of a particular section of a building. Before reaching a conclusion, it is also necessary to determine the usage or the purpose for which the building is being designed. When the building usage is such that it needs continuous thermal energy then it might be suitable to provide more thermal energy for the building. On the other hand, a building that does not require continuous thermal energy, a continuous supply of thermal energy might not be suitable. In the end the impact of thermal ability of the walls are taken into consideration because its impact is more in warm climatic conditions where the radiations coming from Sun are stored in the wall materials and is transmitted inside when necessary.

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