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Energy efficient building through energy simulation using different insulating materials

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ABSTRACT

Simulation study has been carried out to assess energy saving potential in air conditioned buildings with application of roof and wall insulation system for a period of one year in composite climate of India. Out of total eleven cases, the first case is untreated and conventional building and is considered as reference building. The other five cases are roof treated building with five different thermal insulations without wall insulation. The remaining five cases are roof treated with similar insulations as previous five cases along with wall treated with EPS insulation from inside of the room. The minimum cooling load was observed amongst eleven cases when roof treated with Elastospray and walls treated with EPS thermal insulation. The study reveals that appropriate insulation can reduce cooling load by 30% when both the roof and walls are treated.

Key words: Energy Simulation, Thermal insulation, Power consumption, Software computation, Energy saving

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INTRODUCTION

Technical developments during the last century enable architects, engineers and construction experts to develop innovative concepts in planning and use of a vast range of construction materials for achieving functional utility of the newly developed building insulation materials and their various combinations in buildings. In India, modern buildings consume about 25 to 30 % of total energy generated. Although the present energy consumption per capita in India is a fraction of that of the most developed nations, but with its projected growth, it may lead to acceleration of environmental degradation leading to further global warming and climate change. Therefore, energy conservation in built environment is the need of the hour.

Lot of similar studies of energy simulation of building are carried out applying different methodology in various parts of the world. In Brazil, VA Scalco et.al [1] have developed different methodologies, one of the strategy is to adopt the residential buildings energy labeling scheme in which primary faces are evaluated in naturally ventilated buildings. In one of the study made by Iwaro and Mwasha [2] shows that considering the growth in population, construction sector there is a need of higher level of comfort indicating upward trend in energy demand in future which are likely to continue. An analysis study of the building energy consumption in Hong Cong (Lam & Li 1999) [3] showed that the building envelop design is directly related to the peak of cooling load (36.7%). A study made by Yu et.al [4] investigated the effects of building envelop components on cooling load which can be reduced by 11.5% by exterior wall thermal insulation alone. Bin Su [5] in one of his paper studied the effects of the passive features of building elements and materials on energy consumption. The study introduces a method for using actual energy consumption data to identify the major design problem for housing energy efficiency. Calads [6]; Karlson and Mashfegh [7] and Smeds & Wall [8] have studied the combine computer simulation with field data for energy efficient house design. Suman [9] conducted studies on energy simulation for sustainable buildings by software computing system, whereas Chapels et.al [10] studied about environmental sustainability for energy consumption in the indoor environment.

The study of climate change impact on building energy consumption has been made by Degelman [11], Frank [12] and Zmeureanu et. al [13]. Energy efficient building by passive design by Su B. [14] and energy modeling study has been described in Australian building code board (ABCD) [15]. Proofs [16] and Treloar et. al [17] made study on energy analysis adopting different methodologies. National building codes of India [18] consists of building performance characteristics to analyze the performance of the proposed design and materials in such a way that the interactions between different technical domains may be judiciously incorporated the building performance analysis and is essential at the design stage to prevent the delivery of building with unacceptable performance characteristics. The evaluation approach of design a building are i. experimental methodologies for model study; ii. Full scale study and iii. Mathematical modeling and analytical computer simulation study. Computer simulation is a suitable method for building energy analysis for studying energy efficiency in building because it can integrate the complex physical process of building, since the real scale experimental approach is time consuming and very expensive.

For energy simulation study of building a computer model TRNSYS, version 16 [19] has been used. A case study on thermal behavior has been under taken for the building located at New Delhi, which falls in the composite climatic zone of India.

1. Approach for calculating energy consumption in buildings

The energy consumption for eleven cases of a building has been determined by numerical computer simulation method. This is a complex model consisting of related parameters and of fast calculation comparing variants. In this study heat conduction transfer function methodology to predict thermal history of multi-layer slabs has been used for calculation of transient heat transfer through walls and roof of building. The long wave radiation exchange between the surfaces within the zone and conductive heat flux from the inside surface to the air approximated using the star network proposed by SEEM, A2-Bant program developed at LBL USA has been used for taking into account the effect of heat transmission through windows.

2. Building simulation tools

There are number of computer software available for energy simulation of building such as DOE-2, Energy plus from LBNL, Energy-10 developed at CANADA , TRNSYS 16, [17] developed jointly by (solar energy laboratory, University of Wisconsin- Madison, TRANS SOLAR Energie technic and centre scientifique due batiment and thermal energy system specialist, LLC and so on. The software TRNSYS has been used for energy simulation of the building for eleven specific cases considering versatility and its capability of predicting hourly temperature and of carrying thermal simulation of single as well as multi-zone building. This software has weather file containing detailed climate data of many stations covering all over the world, including more than 70 stations of India. The simulation study of single zone building has been carried out at New Delhi, falling in composite climatic zone.

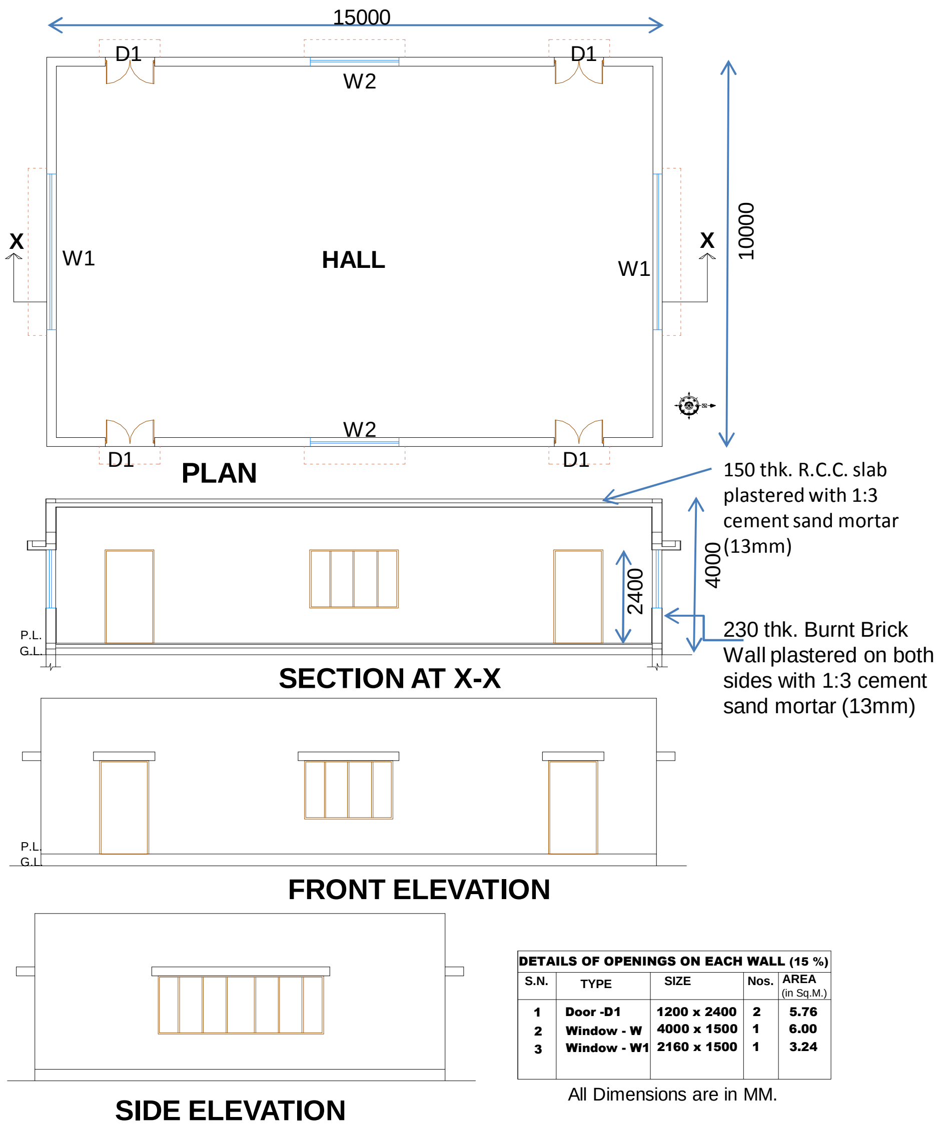
2.1 Sample building details

The single zone building under consideration is a single storey residential building rectangular in shape, the aspect ratio of the rooms is 3:2 and dimensions are 15m x 10m x 4m, all the four vertical walls facing cardinal directions (N, E, S & W) and flat horizontal roof exposed to external environment. The opening area including window is 15% of the corresponding wall area. Fig.1 shows the plan, elevation and section of the model building.

Specification of the building: (i) Wall is made up of 23.0 cm thick burnt brick wall plastered on both the side with 1:3 cm thick cement sand mortar. The total thickness of each of four walls is 0.256 m and its U-value is 2.376 W/m^{2}K. (ii) Roof is made up of 0.15 m thick heavy reinforced concrete slab inside plaster with 0.013 m thick cement mortar. The total thickness of roof is 0.163 m and its U-value is 4.023 W/m^{2}K. (iii) The floor of the building is 0.025 m marble stone laid over heavy concrete of 0.100 m and clay soil of 0.100 m thickness. The total thickness of floor is 0.225 m and its U-value is 3.29 W/m^{2}K. (iv) Windows have horizontal over hangs of 0.45 m wide on their top. The overall heat transfer coefficient of window is 5.84 W/m^{2}K. The frame area of the window is 15% of the total window area. U-value of the frame material is 2.27 W/m^{2}K.

2.2 Weather data and study location

The selected building is located at New Delhi, falls in composite zone of India as per climate zone described in Nation building code of India 2005 and the solar radiation and climate data of this station is taken as it is available in the desired format TMY2 (New Typical Meteorological year). The important data elements which are being used as input data in the software are hourly values of about 20 parameters : Extraterrestrial horizontal radiation, Diffusion horizontal radiation, global horizontal illuminance, Direct normal illuminance, Diffuse horizontal illuminance, Zenith illumance, Total sky cover, Opaque sky cover, Dry bulb temp., Dew point temp., Relative humidity, atmosphere pressure, Wind direction, wind speed, horizontal visibility, Precipitable water, aerosol optical depth, extraterrestrial, Direct normal radiation etc..



DETAILS OF OPENINGS ON EACH WALL (15 %)				
S.N.	TYPE	SIZE	Nos.	AREA (in Sq.M.)
1	Door -D1	1200 x 2400	2	5.76
2	Window - W	4000 x 1500	1	6.00
3	Window - W1	2160 x 1500	1	3.24

Fig. 1 MODAL BUILDING FOR STUDY OF ENERGY SIMULATION

3. Basic Considerations for energy efficient building

A suitable orientation of a building helps in achieving desirable thermal condition through reduction of solar heat ingress and enhancement of natural ventilation. Longer axis of the building along East-West with windows of longer size facing North and South provides advantage of solar heat in winter and minimizing it in summer. The thermal zone of a building walls are classified into four types: i. External wall separating the zone from external ambient environment, ii. Adjacent wall that separating different thermal zones iii. Internal wall within a thermal zone under consideration and iv. Boundary wall within having known external boundary conditions.

Overall heat transfer coefficient (U-value) plays an important role in energy simulation studies and it depends upon thermal conductivity and thickness of different layers of materials used in the construction of building components and inside and outside surface heat transfer coefficients of roof and wall (hi and ho). The case under consideration is a single story residential building having a big hall room.

4.1 Optical and Thermal characteristics

The common optical and thermal characteristics of single glazed window with following properties are considered for energy simulation.

Overall heat transfer coefficient, U = 5.8 W/m^{2}K
Solar transmittance = 0.855,
Frame U-value = 2.27 W/m^{2}K
Tilt of windows from horizontal = 90 degree (vertical)
Total height – 1219.2 mm
Total width – 914.4 mm
Glass height – 1079.5 mm
Glass width – 774.7 mm

4. Simulation study

All the eleven cases of the sample building model have been undertaken for simulation study. The sample building consist no adjacent or internal wall as all the four walls are external wall, each made of non-negligible mass. The solar absorptances of the walls are 0.6 on the front side and 0.6 on the back side. The convective heat transfer coefficients of walls are 11.0 KJ/hm^{2}K on the front side and outside (ho) is 64 KJ/hm^{2}K. The solar absorptance of the roof is 0.6 on the both the front side and the back side. The convective heat transfer coefficient of roof is also 11.0 KJ/hm^{2}K on the front side and 64 KJ/m^{2}K on the back side. The treatment, such as application of various layers of insulation on roof and wall are recommended practice using different insulation materials have been considered in various treated cases.

The first case has been described in table 1. It is purely untreated roof, wall and floor using convectional constructions. This case falls under category A. Category B consists of untreated wall and floor as in category A but five cases of roof treated with thermal insulation, Elastoper, Peripor, Neopor, Elastospray and styropor along with thermo create addition in all the five cases as shown in table 2. The third category C is similar to the Category B with additional thermal insulation in all four wall is EPS. Category C also consists five cases as given in table 3. In all there are eleven cases which are simulated and observations have been made for different building components i.e., wall, roof and floor for various parameters including layer, thickness, thermal conductivity, thermal capacity, density, total thickness and 'U'-value, as described in table 1, table 2 and table 3.

The results of the study are in the form of energy consumption KWH after running the simulation for whole of the year covering all the seasons. For air conditioned space, air- conditioners of cooling capacity of 60 KJ/hour has been considered for untreated case and cooling capacity of 40 Kj/h has been considered for treated cases.

The simulation by software TRNSYS of energy consumption of untreated room and the treated room with five different types of thermal insulation as described above has been carried out for a whole year. All the predicted energy consumption for all treated cases is shown in three figures. Figure 2 consists of energy consumption in untreated room and roof treated room. The energy consumption in the room with both roof and wall treated are depicted in figure 3 and figure 4 has energy consumption of the room with wall treated and untreated room. From these figures, result can be obtained in terms of energy saving by roof insulation only or by wall insulation and using both roof and wall insulation.

Table 1 Category A – Conventional Construction (untreated)

Case No.	Building Section	Layer	Thickness (m)	Thermal Conductivity (W/mK)	Thermal Capacity (KJ/kg K)	Density (Kg/m^3)	Total thickness (m)	U-value (W/m^{2}K)
Case1	Wall	Cement Pl Brick Cement Pl	0.013 0.230 0.013	0.720 0.811 0.720	0.84 0.84 0.84	2000.00 1750.00 2000.00	0.256	2.376
	Roof	Cement Pl Heavy R.C.	0.013 0.150	0.720 1.890	0.84 0.84	2000.00 2400.00	0.163	4.023
	Floor	Marble Heavy Conc Soil	0.025 0.100 0.100	2.520 1.460 1.520	0.84 0.84 1.80	2550.00 2200.00 1500.00	0.225	3.290

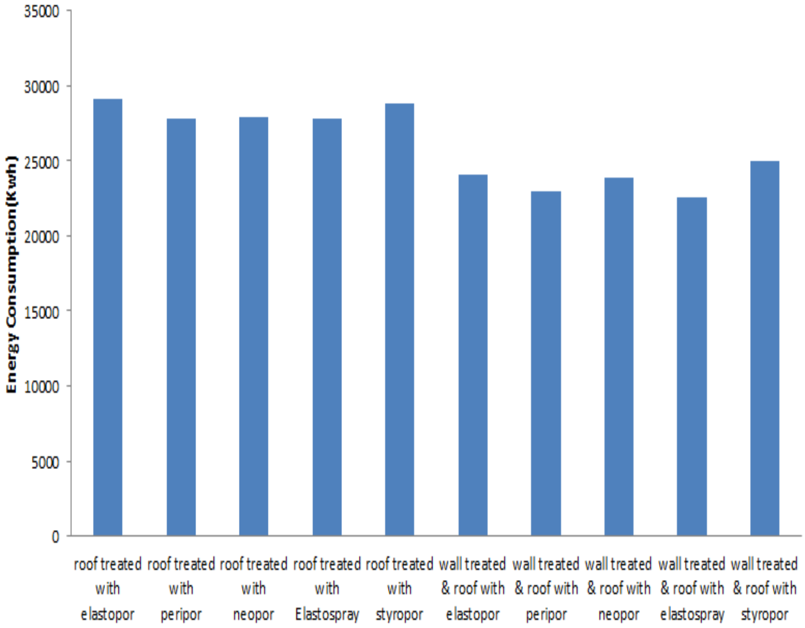


Fig. 2 Energy Consumption for roof treated and roof and wall treated buildings

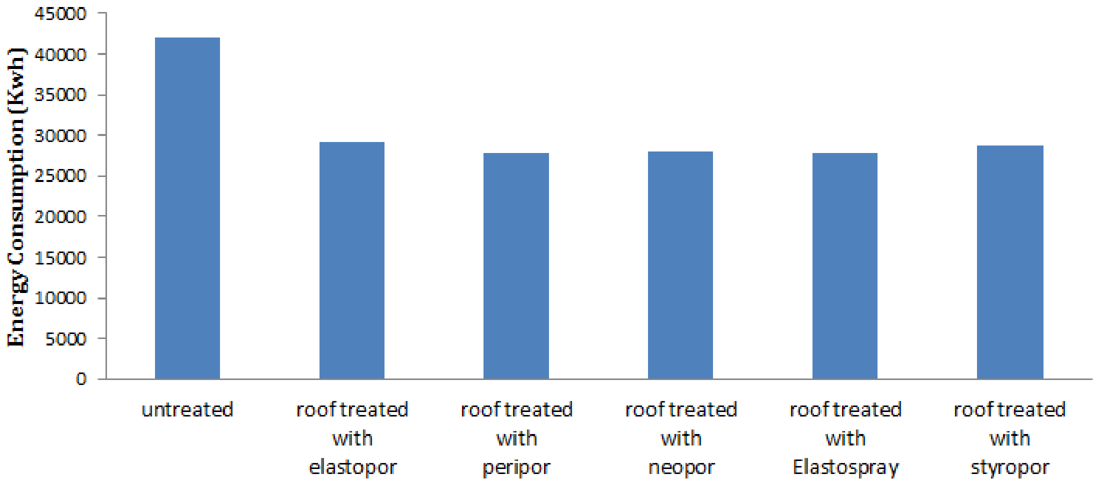


Fig. 3 Performance of roof treated building with different insulating materials

Table 2. Category B – Wall Treated Building Construction

Case No.	Building Section	Layer	Thickness (m)	Thermal Conductivity (W/mK)	Thermal Capacity KJ/kg K	Density (Kg/m^3)	Total thickness (m)	U-value (W/m^2K)
Case2	Wall	Cement Pl Brick Cement Pl	0.013 0.230 0.013	0.720 0.811 0.720	0.84 0.84 0.84	2000.00 1750.00 2000.00	0.256	2.376
	Roof	Cement Pl Heavy R. C. Elastopor Thermocrete Chinamosaic	0.013 0.150 0.050 0.100 0.003	0.720 10890 0.0249 0.230 1.030	0.84 0.84 0.84 0.84 1.00	2000.00 2400.00 44.32 752.00 2000.00	0.316	0.425
	Floor	Marble Heavy Conc Soil	0.025 0.100 0.100	2.520 1.460 1.520	0.84 0.84 1.80	2550.00 2200.00 1500.00	0.225	3.290
Case3	Wall	Cement Pl Brick Cement Pl	0.013 0.230 0.013	0.720 0.811 0.720	0.84 0.84 0.84	2000.00 1750.00 2000.00	0.256	2.376
	Roof	Cement Pl Heavy R. C. Peripor Thermocrete	0.013 0.150 0.050 0.100	0.720 10890 0.0324 0.230	0.84 0.84 0.84 0.84	2000.00 2400.00 32.60 752.00		

		Chinamosaic	0.003	1.030	1.00	2000.00	0.316	0.511
	Floor	Marble	0.025	2.520	0.84	2550.00		
		Heavy Conc	0.100	1.460	0.84	2200.00		
		Soil	0.100	1.520	1.80	1500.00	0.225	3.290
Case4	Wall	Cement Pl	0.013	0.720	0.84	2000.00		
		Brick	0.230	0.811	0.84	1750.00		
		Cement Pl	0.013	0.720	0.84	2000.00	0.256	2.376
	Roof	Cement Pl	0.013	0.720	0.84	2000.00		
		Heavy R. C.	0.150	10890	0.84	2400.00		
		Neopor	0.050	0.0319	0.84	17.50		
		Thermocrete	0.100	0.230	0.84	752.00		
		Chinamosaic	0.003	1.030	1.00	2000.00	0.316	0.508
	Floor	Marble	0.025	2.520	0.84	2550.00		
		Heavy Conc	0.100	1.460	0.84	2200.00		
		Soil	0.100	1.520	1.80	1500.00	0.225	3.290
Case5	Wall	Cement Pl	0.013	0.720	0.84	2000.00		
		Brick	0.230	0.811	0.84	1750.00		
		Cement Pl	0.013	0.720	0.84	2000.00	0.256	2.376
	Roof	Cement Pl	0.013	0.720	0.84	2000.00		
		Heavy R. C.	0.150	10890	0.84	2400.00		
		Elastospray	0.050	0.0231	0.84	43.8		
		Thermocrete	0.100	0.230	0.84	752.00		
		Chinamosaic	0.003	1.030	1.00	2000.00	0.316	0.401
	Floor	Marble	0.025	2.520	0.84	2550.00		
		Heavy Conc	0.100	1.460	0.84	2200.00		
		Soil	0.100	1.520	1.80	1500.00	0.225	3.290
Case6	Wall	Cement Pl	0.013	0.720	0.84	2000.00		
		Brick	0.230	0.811	0.84	1750.00		
		Cement Pl	0.013	0.720	0.84	2000.00	0.256	2.376
	Roof	Cement Pl	0.013	0.720	0.84	2000.00		
		Heavy R. C.	0.150	10890	0.84	2400.00		
		Styropor	0.050	0.0345	0.84	19.23		
		Thermocrete	0.100	0.230	0.84	752.00		
		Chinamosaic	0.003	1.030	1.00	2000.00	0.316	0.536
	Floor	Marble	0.025	2.520	0.84	2550.00		
		Heavy Conc	0.100	1.460	0.84	2200.00		
		Soil	0.100	1.520	1.80	1500.00	0.225	3.290

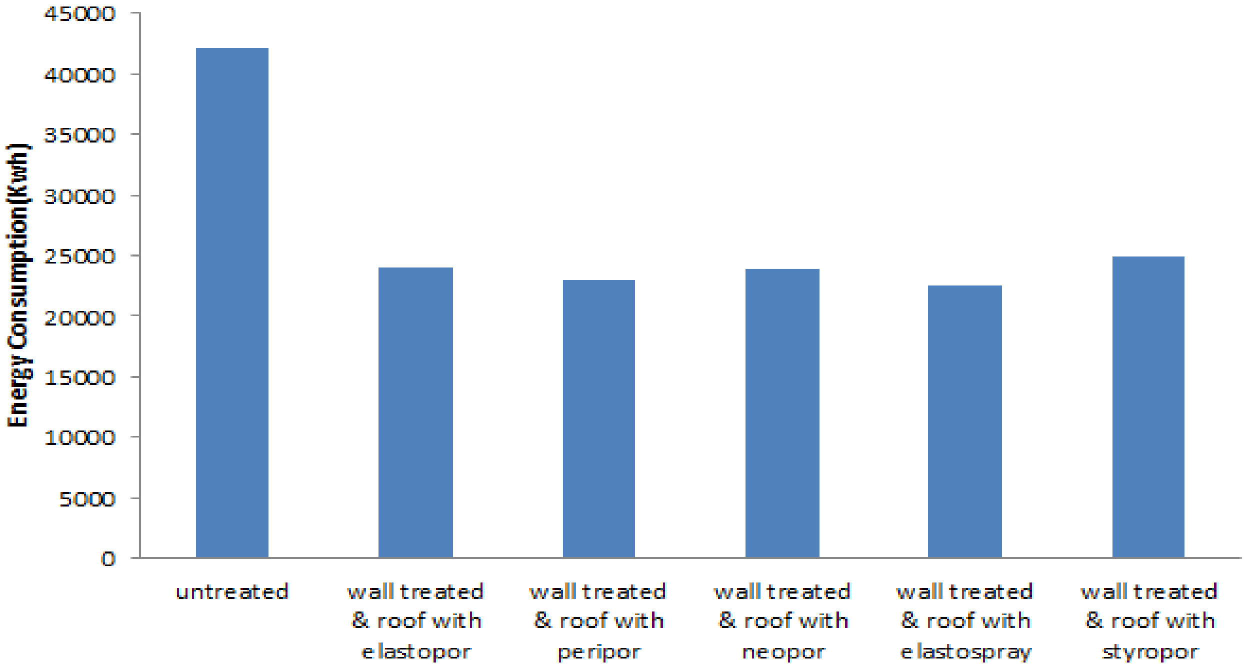


Fig. 4 Performance of wall treated with EPS and roof treated Building

Table 3 Category C –Wall and Roof treated Building Construction

Case No.	Building Section	Layer	Thickness (m)	Thermal Conductivity (W/mK)	Thermal Capacity KJ/kg K	Density (Kg/m^3)	Total thickness (m)	U-value (W/m^{2}K)
Case7	Wall	EPS	0.050	0.032	0.84	21.68		
		Cement Pl	0.013	0.720	0.84	2000.00		
		Brick	0.230	0.850	0.84	1750.00		
		Cment Pl	0.013	0.720	0.84	2000.00	0.306	0.545
	Roof	Cement Pl Heavy	0.013	0.720	0.84	2000.00		
		R. C	0.150	1.890	0.84	2400.00		
		Elastopor	0.050	0.0249	0.84	44.32		
		Thermocrete	0.100	0.230	0.84	752.00		
		Chinamosaic	0.003	1.030	1.00	2000.00	0.316	0.425
	Floor	Marble	0.025	2.520	0.84	2550.00		
		Heavy Conc	0.100	1.460	0.84	2200.00		
		Soil	0.100	1.520	1.80	1500.00	0.225	3.290
Case8	Wall	EPS	0.050	0.032	0.84	21.68		
		Cement Pl	0.013	0.720	0.84	2000.00		
		Brick	0.230	0.85	0.84	1750.00		
		Cment Pl	0.013	0.720	0.84	2000.00	0.306	0.545
	Roof	Cement Pl Heavy	0.013	0.72	0.84	2000.00		
		R. C	0.150	1.890	0.84	2400.00		
		Peripor	0.050	0.0324	0.84	32.60		
		Thermocrete	0.100	0.230	0.84	752.00		
		Chinamosaic	0.003	1.030	1.00	2000.00	0.316	0.511
	Floor	Marble	0.025	2.520	0.84	2550.00		
		Heavy Conc	0.100	1.460	0.84	2200.00		
		Soil	0.100	1.520	1.80	1500.00	0.225	3.290
Case9	Wall	EPS	0.050	0.032	0.84	21.68		
		Cement Pl	0.013	0.720	0.84	2000.00		
		Brick	0.230	0.85	0.84	1750.00		
		Cment Pl	0.013	0.720	0.84	2000.00	0.306	0.545
	Roof	Cement Pl Heavy	0.013	0.72	0.84	2000.00		
		R. C	0.150	1.890	0.84	2400.00		
		Neopor	0.050	0.0319	0.84	17.50		
		Thermocrete	0.100	0.230	0.84	752.00		
		Chinamosaic	0.003	1.030	1.00	2000.00	0.316	0.508
	Floor	Marble	0.025	2.520	0.84	2550.00		
		Heavy Conc	0.100	1.460	0.84	2200.00		
		Soil	0.100	1.520	1.80	1500.00	0.225	3.290
Case 10	Wall	EPS	0.050	0.032	0.84	21.68		
		Cement Pl	0.013	0.720	0.84	2000.00		
		Brick	0.230	0.85	0.84	1750.00		
		Cment Pl	0.013	0.720	0.84	2000.00	0.306	0.545
	Roof	Cement Pl Heavy	0.013	0.72	0.84	2000.00		
		R. C	0.150	1.890	0.84	2400.00		
		Elastospray	0.050	0.0231	0.84	43.80		
		Thermocrete	0.100	0.230	0.84	752.00		
		Chinamosaic	0.003	1.030	1.00	2000.00	0.316	0.401
	Floor	Marble	0.025	2.520	0.84	2550.00		
		Heavy Conc	0.100	1.460	0.84	2200.00		
		Soil	0.100	1.520	1.80	1500.00	0.225	3.290
Case 11	Wall	EPS	0.050	0.032	0.84	21.68		
		Cement Pl	0.013	0.720	0.84	2000.00		
		Brick	0.230	0.85	0.84	1750.00		
		Cment Pl	0.013	0.720	0.84	2000.00	0.306	0.545
	Roof	Cement Pl Heavy	0.013	0.72	0.84	2000.00		
		R. C	0.150	1.890	0.84	2400.00		
		Styropor	0.050	0.0345	0.84	19.23		
		Thermocrete	0.100	0.230	0.84	752.00		
		Chinamosaic	0.003	1.030	1.00	2000.00	0.316	0.536
	Floor	Marble	0.025	2.520	0.84	2550.00		
		Heavy Conc	0.100	1.460	0.84	2200.00		
		Soil	0.100	1.520	1.80	1500.00	0.225	3.290

DISCUSSION

It is observed from table 2 that total thickness of roof of case 2 to case 6 is same 0.316 m but U-value varies from 0.401 to 0.536 W/m^{2}K. Variation in U-value occurs mainly due to thermal conductivity of thermal insulation materials used in the section. For an example the least value of roofs section treated with Elastospray insulation is 0.401 W/m^{2}K and thermal conductivity of Elastospray is 0.0231 W/mK whereas U-value of roof treated with peripor is 0.511 W/m^{2}K and thermal conductivity of peripor is 0.032 W/mK. The properties of other materials remain same in the roof section. The roof treated with different five types of thermal insulation are also included in category C. This category consist a wall treated with EPS in all the five cases 7 to 11. Total thickness of wall is 0.306 m and U-value is 0.545 W/m^{2}K, whereas total wall thickness of untreated wall of category A is 0.256 and its U-value is 2.736 W/m^{2}K. The U-value is reduced from 2.736 to 0.545 W/m^{2}K due to additional layer of 5 cm EPS. Thermal conductivity of EPS is 0.032 W/mK. The output result of the simulation study has been taken in the form of cooling load (energy consumption) in KWH. During energy simulation of insulation treated building by the TRNSYS software, cooling capacity of air temperature has been assumed 60 KJ/hour for untreated building and for treated building, cooling capacity of air temperature has been assumed 40 KJ/hour.

The cooling load determined by simulation study for all the eleven cases have been shown in fig. 2, fig 3 and fig 4 and also in table 4. The minimum cooling load obtained out of the roof treated building is the Elastospray treated roof building. The maximum cooling load was found with styropor treated roof building. Amongst all eleven cases of untreated and treated building, the maximum cooling load was observed in untreated building. In treated buildings, where wall is treated with EPS insulation and roof is treated with Styropor has higher cooling load with other treated buildings. The least cooling load was found with the building which roof is treated with Elastospray and walls with EPS insulation. It can be also observed from fig 2, 3 and 4 that only roof insulation can reduce one third of the untreated building cooling load. The reduction in cooling load can be further enhanced by walls insulation by another 10% of the roof insulated building. The reduction in cooling load is noticed because of a building with no thermal insulation allows heat flow from outside to inside and heating load in winter from inside to outside without any barrier. To increase barrier or thermal resistance, thermal insulation use in roof, wall or floor is the best solution.

Table 4. Case wise Cooling load with different treatment of roof wall

Case No.	Description of treatment	Annual Cooling load(KWH)
Case 1	Untreated	42090
Case2	Roof treated with Elastopor	29100
Case 3	Roof treated with Peripor	27800
Case 4	Roof treated with Neopor	27800
Case 5	Roof treated with Elastospray	27770
Case 6	Roof treated with Styropor	28850
Case 7	Roof treated with EPS & Roof with Elastopor	24080
Case 8	Roof treated with EPS & Roof with Peripor	23000
Case 9	Roof treated with EPS & Roof with Neopor	23900
Case 10	Roof treated with EPS & Roof with Elastospray	22590
Case 11	Roof treated with EPS & Roof with Styropor	24980

CONCLUSION

In air conditioned buildings, insulation plays a vital role to save energy and care should be taken to well insulate these buildings whereas, in an unconditioned building, heavy insulation is not required because once heat enters into the building, the temperature remain high for longer period. It is observed from fig 2, 3 and table 1 to table 4 that the insulation with best thermal properties used in building roof and wall gives minimum energy consumption. For example, the minimum cooling load was observed amongst eleven cases when roof treated with Elastospray and walls treated with EPS thermal insulation. It can be further concluded from this study that appropriate insulation can reduce cooling load by 30% when both the roof and walls are treated. The untreated building components allow heat to flow across them without any barrier, but in hot region and cold region heat flow is resisted by good thermal insulation from outside to inside and from inside to outside respectively.

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