Thermal Performance Evaluation of Mud House for Ghaziabad Composite Climate

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Abstract

In this paper, we discussed about performance parameter like (Energy saving, Heat transfer rate and Total annual cost) in Mud wall building by selecting a proper insulating material and optimum thickness of insulation. Thermal conductivity and cost of insulation material are important factors that should be considered for selection of insulation material. At optimum insulation thickness, the cost of heating/ cooling to obtain comfort condition is minimum. So it is necessary to save the energy by using optimum insulation thickness. This work has been analyzed by MAT LAB Programming. Mud has high specific heat capacity, which reduces the thermal gradient of Mud house so that heat transfer rate for Mud wall construction has less value as compared to other types of construction. It is observed that room air temperature of Mud house is less in summer and higher in winter season as compared to other types of construction. Transfer of heat across the boundary of Mud wall construction has been calculated by using Degree-Days Method. As a result, it can be concluded that the overall energy saving of 54 % has been suggested by using mud insulation as compared to other insulation material and the optimum insulation of Mud wall has been found as 67 mm.

Keywords - Energy Saving, Thermal Conductivity, Mud Insulation, Optimum Insulation Thickness, Heat Transfer Rate.

Introduction

Energy saving means to efforts made to decrease energy consumption. Energy saving can be done by using efficient energy sources, in addition with decreased energy consumption or reduced consumption from conventional energy sources. Some of the energy saving can be achieved by using suitable insulation thickness in building walls. In residential application, the most effective method of energy saving is to use proper insulation material. Day by day energy consumption rate has gradually increased due to Technological development, population growth, urbanization and industrial growth. Population growth means energy consumption has increased due to more building construction. It is necessary to save the energy due to inadequate energy resources, higher price of fuels and environmental pollution coming from burning of fuels. The energy conservation is achieved by the application of thermal insulation in buildings. Energy conservation supports the eco-friendly environment by providing energy saving in the terms of money.

The heat transfer from outer envelope of building can be reduce by using thermal insulation. Thermal insulation is the best method to make heat proof house. An insulated home is more comfortable as the temperature remains stable over changes of weather. It keeps the temperature of building cool in summers and warm in winters. It is very necessary to preserve the temperature of the house independent from atmospheric temperature for energy saving. If the thermal conductivity of wall material is less, then less insulation will be required for a given extent of cooling and more operating volume will be available. The main purpose of Insulation is to decreases fuel consumption, unwanted emissions from the burning of fossil fuels and increases thermal comfort by reducing heat losses from building wall boundary. Initial

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investment due to addition of insulation will increased, but at the same time it reduces running cost of space heating or cooling. Insulation is a single investment process throughout the life time of a building to reduce energy consumption.

The purpose of the present paper is to show the performance of Mud wall construction on the basis of Energy saving, Heat transfer rate and total annual cost. To fulfill the outline of the present paper, a literature review followed with the scope of paper is given as follows. Author optimized the insulation thickness for wall by using the life cycle cost analysis. In his study, transmission load was estimated by using the degree-days concept. Generalized charts for selecting the optimum insulation thickness as a function of degree days and wall thermal resistance are prepared (Hasan *et al.,* 1999). The effects of insulation on the energy saving in Iranian building has been study by author. For this purpose, an integrative modeling is used for simulation of the energy consumption in buildings (Farhanieh *et al.,* 2006). Embodied energy of raw materials, manufacturing and associated CO2,SO2 and Nox contents have been estimated for a double- glazed, timber framed window containing an inert gas filled cavity (Weir *et al.,* 1998). In this paper, the optimum thickness of insulation for some insulating materials used in order to reduce the rate of heat flow to the buildings in hot countries has been determined.. Important factor that affects the optimum thickness of insulation is the solar radiation energy flowing into the house. In this paper, a solar radiation calculation is done (Mohammed *et al.,* 2004). The authors investigated the optimum insulation thickness for the three coldest cities of Turkey by using the degree -days values. Their study was based on the life cycle cost analysis (Comakli *et al.,* 2003). The heating and cooling degree-hours for the two main cities in Greece, namely Athens and Thessaloniki, using hourly dry bulb temperature has been determined (Papakostas *et al.,* 2005). The authors obtained the optimum location and distribution of insulation for all wall orientations in both summer and winter by consideration of maximum time lag and minimum decrement factor. The investigation was carried out by using an implicit finite difference method for multilayer walls during typical summer and winter days in Elazig, Turkey (Ozel *et al.,* 2007). In this paper, the author determined the optimum insulation thickness under steady periodic conditions. Estimated loads are used as inputs to a life-cycle cost analysis in order to determine the optimum thickness of the insulation layer. The optimum insulation thickness is calculated, based on the estimated cooling transmission loads (Daouas *et al.,* 2010). The author determined the optimum insulation thickness for different degree-days (DD) regions of Turkey (Izmir, Bursa, Eskisehir & Erzurum) for a lifetime of N years. In this study, the optimum insulation thickness for a given building envelope was determined by considering the thermal conductivity and price of the insulation material, average temperature in the region, fuel price for the heating and the present worth factor (PWF) (Sisman *et al.,* 2007). The environment impact of optimum insulation thickness has been investigated by author. In the calculations, coal was used as the fuel source and the Expanded Polystyrene (EPS) as the insulation material (Dombayci *et al.,* 2007). The author developed correlation between thermal conductivity and the thickness of selected insulation materials for building wall (Mahlia *et al.,* 2007). A new analytical method, which provides close-formed solutions for both transient indoor and envelope temperature changes in building, had developed by author. Time-dependent boundary temperature is presented as Fourier Series (Lu *et al.,* 2006). In this paper, thermal performance of vault roof passive house has been investigated. Vault roof passive house has low embodied energy and act as eco-friendly. The embodied energy of passive house situated at solar energy park of IIT Delhi, New Delhi(India) is less as compared to red brick construction. The author was determine heating and cooling load by using fourth order Runge Kutta numerical method (Chel *et al.,* 2009) . The author had calculated annual energy saving potential of a adobe structures before and after integration of earth to air heat exchanger(EAHE).The author developed thermal model of adobe structures and energy balance equations were solved by fourth order Runge–Kutta numerical technique (Chel *et al.,* 2009). Embodied energy of adobe house at solar energy park situated at IIT Delhi, New Delhi(India) had calculated by author (Shukla *et al.,* 2009). The author developed a model to estimate daylight factor . The daylight factor model was found in good agreement with experimental value of daylight factor (Chel *et al.,* 2009). In this paper, the author determined the optimum insulation thickness for building construction. During analysis, it is assumed that heat losses occurred from external walls. P1-P2 method is used to determine the optimum insulation thickness. By using the optimization model, optimum insulation thicknesses, energy saving and payback period for exterior walls of buildings are calculated for electricity tariff (Kayseri *et al.,* 2013). The author explain the influence of insulation location on the heat transfer through the building envelope in the climatic conditions of Elazığ, Turkey. The author also uses an implicit finite difference method for determination of energy saving and optimal insulation thickness (Ozel *et al.,* 2014). This study mainly focused on a environmental impacts for sustainable building constructions. As a result, sustainable building construction has less impact on environment in the term of greenhouse gas emission and energy usage, during the lifecycle of the building (Shoubi *et al.,* 2015) .

As can be seen from the literature survey, most of the authors studies about optimum insulation thicknesses were carried out for only one type of wall, usually brick walls. Conversely, there are many incidences of stone, concrete wall and mud wall construction in India. In general, most of the authors have calculated the optimum insulation thickness and Energy saving for region of Turkey and China. In this study, I have been analyse insulation of existing our conventional house of mud and agricultural waste in India. The thermal characteristic of mud wall construction was not often informed and compared with alternative type of building in the literature. Hence the present work based on thermal performance in the term of Energy saving of mud wall construction.

Mathematical models for annual energy source consumption

Heat gain from buildings occurs through surface of external East facing wall, West facing wall, North facing wall, South facing wall, wooden window, roof, human occupants, lighting load, infiltration, wooden doors and heat loss occurs from ventilation. In the Ghaziabad climate, the cooling period is longer than the heating period. Energy Saving for different month of year has been calculated by MAT LAB programming. In general cooling is required for eight months and rest of the four months, heating is required. During the summer season, cross ventilation is better option for cooling of the Mud house without any external cooling agent. The transient heat conduction equations through room air can be written as follow,

$$M_a C_a \frac{dT_r}{dt} = \sum Q_{gain} - Q_{loss} \qquad (1)$$

M_a is isothermal mass of surface, C_a is specific heat of air , T_r is indoor temperature , t is time, Q_{gain} is heat energy gained by air per second , Q_{loss} is heat energy lost by air per second .

$$Q_{gain} = Q_{wall} + Q_{roof} + Q_{window} + Q_{door} + Q_{floor} + Q_{human\ occupants} + Q_{lighting\ load} + Q_{infiltration}$$

$$Q_{loss} = Q_{ventilation} \qquad (2)$$

Q_{wall} is heat energy gained by air across wall per second , Q_{roof} is heat energy gained by air across roof per second , Q_{window} is heat energy gained by air across window per second, Q_{door} is heat energy gained by air across door per second, Q_{floor} is heat energy gained by air across floor per second, Q_{human} occupant is heat energy gained by air across human occupant per second, $Q_{infiltration}$ is heat energy gained by air across infiltration per second and $Q_{ventilation}$ is heat energy losses by ventilation per second.

The heat gain through wall per second is written as

$$Q_{wall} = UA(T_s - T_r) \qquad (3)$$

U is overall heat transfer coefficient, A is area of wall, T_s is solar-air temperature and T_r is the room air temperature.

$$(UA)_{wall} = \left(\frac{1}{h_o} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \cdots + \frac{1}{h_i}\right) x A_{wall} \quad (4)$$

h_o is the outside convective heat transfer coefficient, L is the thickness of the layer, K is the thermal conductivity and h_i is the inside convective heat transfer coefficient.

The governing equation of Solar-air temperature on any inclined/ pitch Roof surface can be written as

$$t_{solar-air} = t_a + \left(\frac{I\alpha}{h_0}\right) \quad (5)$$

Where $t_{solar-air}$ is the solar air temperature of roof surface t_a is ambient air temperature, I is total solar radiation on earth surface, α is the absorptivity of wall surface and h_o is the outside convective heat transfer coefficient.

The heat gain through roof per second is written as

$$Q_{roof} = (UA)_{roof}\left(t_{solar-roof} - t_r\right) \quad (6)$$

The sensible transmission of heat across window is written as

$$Q_w = U_w.A_w\left(t_{solar-air} - t_r\right) \quad (7)$$

Where Q_w is heat load through window, A_w is the area of windows.

The solar heat gain through window glass is written as

$$Q_{W-Solar} = \alpha\tau.A_w.I_s \quad (8)$$

Where α is the mean absorptivity, τ is the transmissivity and Is is the average value of solar radiation on wall

$$I_S = I.Cos60^0 \quad (9)$$

Heat gain per second due to lighting load

$$Q_L = N_L W \cdot U_f \quad (10)$$

Where Q_L is the heat gain due to lighting load (tube lights), W is the wattage per tube light and U_f is the use factor.

Heat gain per second due to fan motor is written as

$$Q_F = N_F W_i \cdot (1 - \eta_e) \quad (11)$$

Where N_F is the number of fan in the room, W_i is the input wattage of fan and η_e is the efficiency of fan (equipment).

Heat gain due to infiltration is written as

$$Q_{inf} = m C_p dt,$$

$$m = V_0 \rho,$$

V_0= ACH X Volume of Room/3600 (12)

Where m is the mass flow rate of air, C_p is the specific heat and dt is the temperature difference, ρ is the density and ACH is air change hour.

The heat gain/loss per second through ground is written as

$$Q_{floor} = (UA)_{floor}(T_r - T_b) \qquad (13)$$

The heat gain per second through wooden door is written as

$$Q_{door} = N_d.(UA)_{door} \cdot dt \qquad (14)$$

Where N_d is the number of door.

The thermal energy loss/gain per second due to ventilation of room air to atmosphere can be written as follows:

$$Q_{Ventilation} = \frac{\rho_a V_a C_a N(T_r - T_a)}{3600} = 0.33NV_a(T_r - T_a) \qquad (15)$$

N is air change number per hour, ρ_a is air density , *Va* is air volume in the room.

Total heat accumulated inside the room =

$$Q_{gain} - Q_{loss} = Q_{NE} + Q_{SE} + Q_{NW} + Q_{SW} + Q_W + Q_{W-Solar} + Q_{Roof} + Q_L + Q_0 + Q_F + Q_{Inf} + Q_{Door} + Q_{Window} + Q_{Ground} - Q_{Ventilation} \qquad (16)$$

Optimum insulation thickness for Mud wall construction

Optimum insulation thickness depend on number of parameter, which are thermal conductivity of insulation, cost of insulation, heating value of fuel, Degree-Days value, thermal resistance and coefficient of performance of cooling system. Degree-Days value has substantial effect on optimum insulation thickness of insulation. At optimum insulation thickness, energy saving has extreme value so it is important to determine the value of optimum insulation thickness. When Mud dung slurry is taken as insulation, then optimum insulation thickness of mud wall has been found as 67 mm.

Thermal Performance parameter of Mud wall construction

Mud house have generally thick walls and high thermal mass. The mud wall reduces heat transfer as compared to brick wall due to high thermal mass. Basically mud wall house act as a thermal buffer i.e it kept inside temperature of home less as compared to brick wall room temperature. Mud wall construction reducing fluctuation of indoor temperature during summer and winter.

There are following parameters which are used for evaluation of Mud house:

1) Energy Saving
2) Total annual cost
3) Heat transfer rate

(1) Energy Saving

Energy saving is defined as the amount of total saving cost, when the building boundary has been insulated by proper insulation material at its optimum thickness. Energy consumption rate has regularly increasing due to industrial development, urbanization, population progression and technology development. Energy saving can be achieved by reducing energy consumption. Building sector is the significant energy consumer with respect to other sector. Day by day, the cost of fuel increase and its amount is limited, so it is compulsory to reduce the consumption of fuels. For comfort condition of room temperature, energy sources are required. The energy saving is achieved by application of thermal insulation in building. Energy saving has maximum value at optimum insulation thickness.

It is realized from Table 1. that the highest and lowest energy is required for January and March month

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respectively. For heating load of 286 Kwh and cooling load of 307 Kwh energy has been saved for mud wall construction. The Heating and Cooling load in the the term of energy consumption for different month of year 2014 is represented in Table 1. The energy required per year without insulation for mud house is 1079Kwh. The energy required per year in presence of mud dung slurry insulation for mud house is 485Kwh. The energy saving has been analyzed which is 55 % by mud wall construction in presence of mud dung slurry insulation.

Table 1: Energy Saving in Mud wall construction in different month for LPG fuel as heating and electricity as cooling sources.

S. No	Month	Energy potential (Kwh) With insulation	Energy potential (Kwh) Without insulation	Energy Saving (kwh)	% Energy Saving
01	January(H)	51	133	82	14
02	February(H)	43	107	64	11
03	March(C)	24	45	21	4
04	April(C)	40	81	41	7
05	May(C)	48	100	52	9
06	June(C)	46	94	48	8
07	July(C)	39	78	39	7
08	August(C)	37	73	36	6
09	September(C)	35	69	34	6
10	October(C)	33	65	32	5
11	November(H)	41	100	59	10
12	December(H)	49	130	81	14

The difference of heating load with and without insulation gives the heating energy saving. In this analysis, mud dung slurry insulation is used over building envelope of mud house. Yearly heating/cooling Energy conservation potential of Mud house in Ghaziabad is as shown in Table 2.

Table 2: Yearly heating/cooling Energy conservation potential of Mud house in Ghaziabad

Heating Load without insulation (HL) (Kwh/Year)	Cooling Load without insulation (CL) (Kwh/Year)	Heating Load with insulation (HLW) (Kwh/Year)	Cooling Load with insulation (CLW) (Kwh/Year)	Heating Energy Saving = (HL-HLW) (Kwh/Year)	Cooling Energy Saving = (CL-CLW) (Kwh/Year)
471(KW)	608	184	301	287	307

(2) Total Annual Cost

Total annual cost is the sum of insulation cost and fuel cost. For decreasing the heat transfer across the boundary of wall, insulation thickness has increased. When the insulation thickness has been increased, then heat transfer and fuel cost decreases. But increasing the thickness of insulation means increases the cost of insulation. For minimize the total annual cost, the thickness of insulation has optimized. At optimum insulation thickness, energy saving is maximum and total annual cost in minimum. Total annual cost for mud house at different thickness of insulation (Mud dung slurry insulation) is as shown in Table 3.

Table 3: Total annual cost for mud wall constructions when mud dung slurry is taken as insulation.

S. No.	Thickness of insulation(m)	Annual cost(Rs)			Energy Saving(E_s)
		Fuel cost	Insulation cost	Total cost	
01	0	1722	0	1722	0
02	0.02	943	100	1043	679
03	0.04	649	200	849	873
04	0.06	495	300	795	927
05	0.067	457	335	792	930
06	0.08	400	400	800	922
07	0.10	335	500	835	886
08	0.12	289	600	889	833
09	0.14	253	700	953	768

The optimum insulation thickness for mud wall construction is 0.067 m when mud dung insulation is used. From the above Table 3., it is detected that Energy saving will gradually increase up to optimal thickness and after that energy saving will decrease. Therefore insulation thickness is more advantageous at Optimum insulation thickness.

(3) Heat Transfer Rate

Mud has high specific heat capacity, which reduces the thermal gradient of mud houses so heat transfer rate for Mud wall construction has less value as compared to Brick wall construction. Heat transfer rate for Mud wall construction and Brick wall construction is represent in Table 4.

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Table 4 : Heat transfer rate in Mud wall construction with Brick wall construction for different month of year

Month of the year	Heat transfer load for Mud wall(w/m^2)	Heat transfer load for Brick wall(w/m^2)
January	17.25	17.62
February	25.62	23.07
March	22.79	24.05
April	31.92	46.65
May	36.59	57.54
June	37.05	57.31
July	34.11	44.61
August	32.4	42.03
September	31.47	40.76
October	26.79	34.71
November	24.99	25.35
December	17.42	17.74

It is visualized from Table 4. that the heat transfer rate across the boundary of wall is higher for Brick wall construction. The heat storing capacity of Mud wall construction has higher value so thermal comfort is achieved at low cost. In May month, heat transfer rate is highest and in month January, heat transfer rate is less for both type of construction. The retaining of heat for Mud wall construction has higher value so less heat is transfer for mud wall construction

Result and Discussion

In summer or winter season, there is large variation of atmospheric temperature due to variation of solar radiation. But for Mud wall construction, the room air temperature is almost uniform and less then atmospheric temperature due to some specific properties of mud (i.e thermal mass, low thermal conductivity and high thermal heat capacity) . Figure 1 illustrations the variation of fuel cost, insulation cost and total annual cost in accordance with various thickness of insulation for Mud wall construction, when Mud dung slurry is selected as an insulation material. When insulation thickness increases, then heat transfer rate decreases through wall boundary. Therefore less fuels is required to maintain the thermal comfort. But this decrease of fuel cost is not just sufficient to overcome the increases of insulation thickness. There is thickness value of insulation at which total increase of insulation cost is just equal to reduction of fuel cost. That thickness is known as optimum insulation thickness.

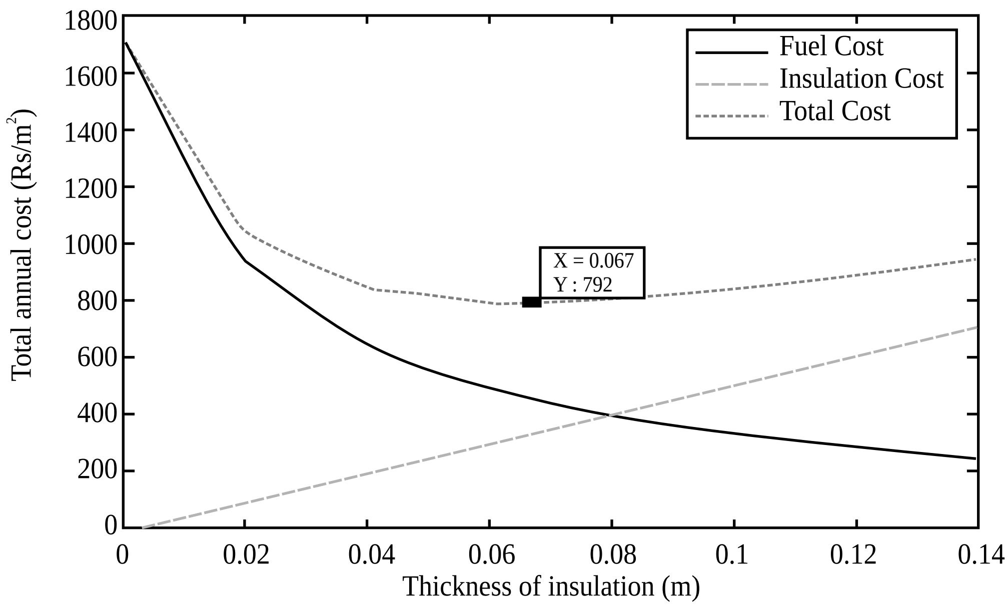

Figure 1: Total annual cost for Mud wall constructions versus insulation thickness when Mud dung slurry is taken as an insulation

The variation of insulation cost linearly in nature. Total cost is sum of insulation and fuel cost. The insulation thickness at which the total cost is minimum is taken as the optimum insulation thickness. As a result, the optimum insulation thickness and total cost is 0.067 m and Rs 792 respectively, when Mud dung slurry is used as the insulation material.

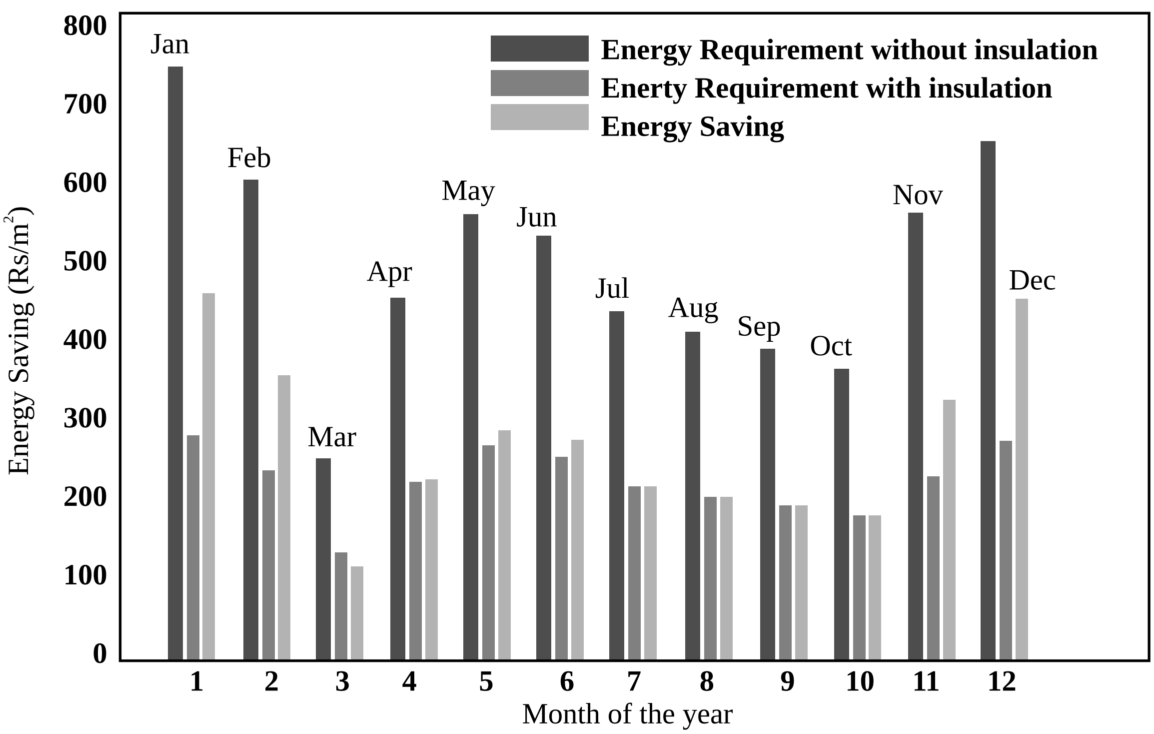

Figure 2: Comparison of energy saving for Mud house

Figure 2 shows the requirement of Energy for different month of year for Mud wall construction with and without insulation and energy saving. Energy saving is calculated as the difference between energy cost without insulation and energy cost with optimum insulation thickness. It is observed that the highest and lowest energy is required for January and March month respectively. As a result, the maximum and minimum energy requirement value is 731 Rs/m2 and 250 Rs/m2 respectively without insulation for January and March month. The maximum and minimum energy requirement value is 279 Rs/m2 and 133 Rs/m2 respectively with insulation for January and March month. It is observed from Figure 2 , that the highest and lowest energy saving is obtained for January and March month respectively. As a result, the maximum and minimum energy saving value is 452 Rs/m2 and 117 Rs/m2 respectively for January and March month. This mud house is an environment and sustainable option for inhabited buildings particularly in rural areas of India for thermal comfort condition without much investment of money since people of rural regions does not effort of energy cost to run air conditioner/air heater during summer and winter season respectively.

Conclusion

Based on the results presented in this paper, the following conclusions have been drawn.

1. The maximum energy saving is 54 % at optimum insulation thickness of 67 mm.
2. It has been found that cooling load potential reduces by 307 kW in the presence of mud insulation material.
3. From the analysis on monthly basis, from January to December 2014, it has been found that the potential of energy conservation is 594 kWh/Year.
4. The parameter having the most substantial effect on optimizing the insulation thickness is insulation cost.

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