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THERMAL PERFORMANCE OF AN INSULATED AND WINDOW AREA OPTIMIZED HOUSE

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Abstract

Space heating and cooling inside the building consume a lot of energy. Energy efficient buildings can reduce this energy consumption. Thermal insulators reduce the heat flow into and out of the buildings. Providing air gap and optimizing window area also reduce the cooling load. Present work is the comparison of thermal performance of an uninsulated and an insulated & window area of a house occupied during summer. The indoor air temperature is much lesser for summer season in case of house with insulation on inside and smaller window area as compared to an uninsulated house. The maximum indoor air temperature difference for insulated house as compared to uninsulated house is 5.73°C, 5.65°C, 2.96°C, 3.23°C and 3.08°C for the months from May to September respectively. There are energy savings for an insulated house as compared to an uninsulated house for the summer season. The total energy savings for the summer season are 4514 units. There are money savings also for the insulated house for the summer season. The total money savings for the summer season are Rs. 22574. The carbon dioxide (CO_2) emission is also reduced for the insulated house for each month of the summer season. Total reduction in carbon dioxide emission for the summer season is 7078 kg. The thermal performance of an insulated and window area optimized house is better than an uninsulated house. In addition to the better human comfort the insulated house also offers money and energy savings. Also the insulated house is environment friendly.

Keywords: Energy efficient buildings, Thermal insulation, Cooling load, Indoor air temperature.

1. Introduction

The total energy consumption in India is rising. The growth rate of energy consumption in India was highest amongst the major economies at 7.1% in 2014-15 [1]. The total energy consumption in India in 2015 was 770 million tonnes of oil

Nomenclatures

a	Coefficient of room air temperature
A_r	Area of roof, m^2
A_{wa}	Area of wall, m^2
A_{wi}	Area of window, m^2
B_1	Runge-Kutta coefficient one
B_2	Runge-Kutta coefficient two
B_3	Runge-Kutta coefficient three
B_4	Runge-Kutta coefficient four
C	Carbon dioxide emission reduction, kg
C_{ef}	Carbon dioxide emission factor, kg/kWh
C_{ra}	Specific heat of room air, kJ/kg K
E_s	Energy savings, kWh
F_d	Losses in distribution
F_t	Losses in transmission
h	Interval of time, h
h_i	Film co-efficient of indoor air, W/m^2-K
h_o	Film co-efficient over the building, W/m^2-K
I_t	Total incident solar load, W/m^2
K_1	Thermal conductivity of cement layer, W/m-K
K_2	Thermal conductivity of cement concrete layer, W/m-K
K_3	Thermal conductivity of brick layer, W/m-K
K_4	Thermal conductivity of air layer, W/m-K
K_5	Thermal conductivity of wood layer, W/m-K
M_{ra}	Mass of room air, kg
M_s	Money saved, Rs.
N	Number of air changes per hour, h^{-1}
Q_{qt}	Total heat gain, kJ/s
Q_{lt}	Total heat loss, kJ/s
Q_{net}	Net heat loss, kJ/s
Q_r	Heat gain through roof, kJ/s
Q_v	Heat loss due to ventilation, kJ/s
Q_{wa}	Heat gain through wall, kJ/s
Q_{wi}	Heat gain through window, kJ/s
R	Cost of energy, Rs./kWh
T_a	Current dry bulb temperature, °C
T_{ira}	Insulated roof room air Temperature, °C
T_{ra}	Current room air temperature, °C
T_{sa}	Solar-air temperature, °C
T_{sa_r}	Solar-air temperature of roof , °C
T_{sa_wa}	Solar-air temperature for wall, °C
T_{sa_wi}	Solar-air temperature for window, °C
T_{ura}	Uninsulated roof room air Temperature, °C
U_{ir}	Overall heat transfer coefficient for insulated roof, W/m^2-K
U_{iw}	Overall heat transfer coefficient for insulated window, W/m^2-K
U_r	Overall heat transfer coefficient for roof, W/m^2-K
$u(t)$	Function of time comprising time dependent terms
U_{ur}	Overall heat transfer coefficient for uninsulated roof, W/m^2-K
U_{uw}	Overall heat transfer coefficient for uninsulated window, W/m^2-K
V_{ra}	Volume of room air, m^3

Greek Symbols

α	Surface absorptance for solar radiation.
τ	Transmissivity of glass
δ_1	Thickness of cement layer, m
δ_2	Thickness of cement-concrete layer, m
δ_3	Thickness of brick layer, m
δ_4	Thickness of air layer, m
δ_5	Thickness of wood layer, m
ρ_{ra}	Density of room air, kg/m^3
$\varepsilon\delta R/h_o$	Longwave radiation factor.

equivalent [2]. Residential buildings consume a large amount of energy of total energy consumption [3]. An increase in building energy consumption of 700% may be experienced in India by 2050 in comparison to the year 2005 [4]. Major energy consumption in this sector is in space heating and cooling. This large amount of energy consumption in space heating and cooling can be decreased by applying energy efficient technology and building design. Energy efficiency in buildings is main concern for governments now a day [5]. Techniques like improving the building envelope, better ventilation and using environment friendly technologies can decrease the energy consumption in buildings [6]. The building envelope can be improved by utilizing thermal insulators as the building materials. Thermal insulators reduce the heat flow because of its large thermal resistance. Thermal insulation can reduce the energy consumption in buildings by 20-40% [7]. Utilizing movable insulation can decrease the heating and cooling load of buildings [8]. The thermal insulation can aid in achieving energy efficiency [9]. Air spaces can also be used as insulation layers. The optimum air space thickness is around 20 mm [10]. Also the thermal storage of the building materials should be considered while designing the energy efficient buildings for winters and summers [11].

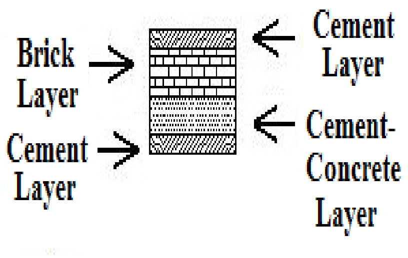
Thermal storage is suitable where the diurnal variation of ambient temperature is more than 10 K [12]. In regions with severe hot summers the time lag in heat transfer from outside to inside can be increased using a material with higher thermal mass. Higher thermal mass can delay or reduce the peak indoor load [13, 14]. Furthermore natural ventilation utilization can increase the indoor air quality and the thermal comfort in summers without any energy expenditure [15]. Passive cooling can also be used to cool the buildings. This is because a passive house is the most energy efficient [16]. Passive cooling can be used for thermal comfort and to reduce energy expenditure in India [17]. Passive design of buildings can reduce the world energy consumption by 2.35% [18]. Passive technologies like optimization of windows and insulating the buildings etc. can be utilized to make the buildings energy efficient. The energy efficient buildings are also environment friendly. The environmental effect occurs during processing of raw materials, construction, life cycle and demolition of the buildings [19]. But the most significant environmental effect occurs during the life cycle of the buildings [20, 21]. Electricity is consumed in cooling the buildings with the help of air conditioners. In India the main source of electricity generation is coal. Coal mining is harmful to the environment and it causes air and water pollution [22]. In India 1710.3 million metric tons of carbon dioxide is emitted due to residential sector [23]. Therefore the energy efficient buildings can reduce the environmental effect as it causes a reduction in energy consumption during life cycle of the buildings. Additionally the energy efficient buildings should be designed after considering parameters like solar heat gain in summer season, heat loss in winter season and ventilation in transitional season [11].

In south Asia mostly masonry houses with reinforced cement concrete roof are built [24]. In summers these houses have high roof temperature and longer heat retaining capacity which affects the indoor air temperature. The solar air temperature of roof is reported around 62°C at various places [11]. This causes the indoor air temperature to exceed 40°C [25]. This high indoor temperature is very uncomfortable to live in. Thermal insulation can be utilized to reduce the heat transferred through a concrete roof [26].

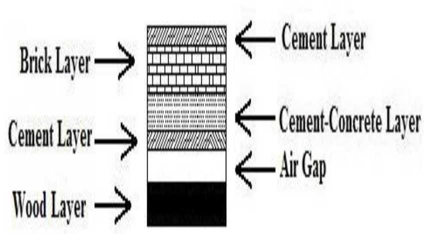
The state of Punjab in India comes under severe hot summer zone. Summer season here lasts for around five months from May to September. Hot and dry summers last for May & June, humid summer season exists for July & August and in September both the temperature and humidity are high. Large variation in outside temperature causes huge fluctuation in indoor temperature. The effect of these climatic conditions can be negated by using insulating materials and optimizing the window area. In the present work the combined effect of insulation and window area optimization for a house is evaluated. Also the performance of an uninsulated house and the same house with insulation on inside and with reduced window area is compared by parameters like indoor air temperature, energy savings, money savings and carbon dioxide emission reduction computed from solar irradiation, ambient air temperature, thermal conductivities of various materials and film coefficients of inside and outside air etc.

The construction of two types of houses considered for the study is shown in Fig. 1. The first house is made from common construction material (Figs. 1(a), (b) and (c)) and the second house is the same house except an insulation layer of wood and air gap (Figs. 1(d), (e) and (f)) employed inside and reduced window area. The optimum thickness of wooden layer insulation on inside of the insulated house is 0.06 m in the present investigation. The common house construction material in India is a composite brick and cement-concrete. The exterior wall consists of brick layer with plaster on inside and outside. The roof has a layer of cement and concrete, a layer of brick on the upper side and layer of cement on the outer and inner surface. The thermal performance of these types of houses is not good for extreme hot climate [25].

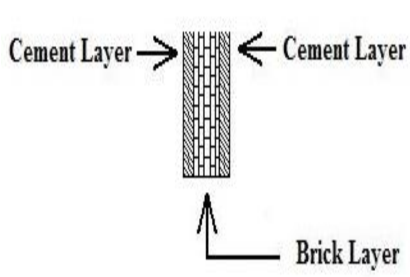
In the present work this common house made up of cement, concrete and bricks are compared with an insulated and window area optimized house. An actual house was used for the study. The indoor air temperature was measured as well as calculated analytically with Microsoft Excel software for the month of June for the uninsulated house and the two were compared. The schematic sketch for measuring the indoor air temperature for the month of June is given in Fig. 2. Mercury in glass thermometer with an accuracy of ± 0.07°C was used for measuring air temperature. After getting satisfactory results from the analytical method for the month of June, it was used for calculating the indoor air temperature for all the cases. Various dimensions and properties of the house, construction materials and insulation layer are listed in Table 1. The construction of roof of the uninsulated and insulated houses is shown in Figs. 1(a) and (d) respectively. The construction of walls for the uninsulated and insulated houses is shown in Figs. 1(b) and (e). The window area without optimization and with optimization is shown in Figs. 1(c) and (f). The window area of the house is decreased after optimization to reduce the inflow of heat during the severe sunshine. The optimized window area was obtained by varying the area to get minimum indoor air temperature. The position of the windows was not changed as the windows are already well placed in east and west direction of the house under study. This is due to the fact that there is no space available for windows on the north and south side of the house because of construction on these sides. The thermal performance of the two houses is compared. Further energy and money savings were calculated. Furthermore the carbon dioxide emission reduction was computed from the energy savings. The carbon dioxide emission factor for thermal power plant was taken as 0.98 kg/kWh [27, 28]. The transmission and distribution loss factor for electricity In India are taken as 0.4 and 0.2 respectively [29].



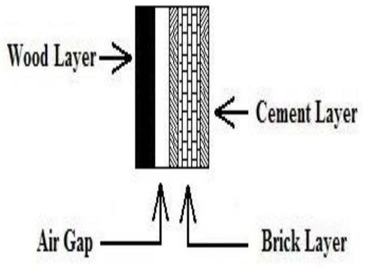
(a) House roof without insulation layer.



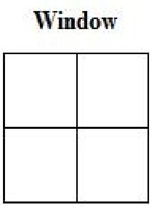
(d) House roof with insulation layer.



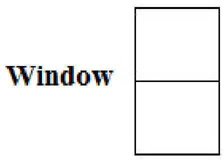
(b) House wall without insulation layer.



(e) House wall with insulation layer.



(c) Window area without optimization.



(f) Window area optimized.

Fig. 1. Roof, walls and window area of two types of houses.

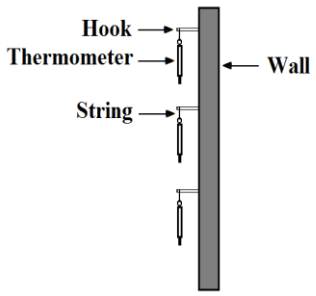


Fig. 2. Schematics of indoor air temperature measurement setup.

Table 1. Parameters used for the analysis.

Parameter	Value
Area of the house	54 m^2
Height of the ceiling	3 m
Dimensions of window	1 m × 1.5 m
h_o	22.8 W/m^2K
h_i	6 W/m^2K
K_1	0.721 W/mK
K_2	1.58 W/mK
K_3	0.798 W/mK
K_4	0.027 W/mK
K_5	0.072 W/mK
R	6 Rs./kWh
δ_1	0.01 m
δ_2	0.12 m
δ_3	0.04 m
δ_4	0.02 m
δ_5	0.06 m
ρ_{ra}	1.14 kg/m^3
τ	0.86
Absorptance of wall and roof surface	0.4
Absorptance of window glass	0.1

2. Methods for computing indoor air temperature, energy savings, money savings and carbon dioxide reduction

In this section analytical methods for computing various parameters like solar air temperature, total heat gain, total heat loss, indoor air temperature, energy savings, money savings and carbon dioxide reduction are presented. The various methods used are as follows: -

2.1. Solar air temperature

The solar-air temperature is computed from (Eq. (1)) the ambient air temperature, surface absorptance for solar radiation, total incident solar load, outside air film coefficient and long wave radiation factor [29]. The ambient air temperature was noted down and the other parameters were taken from available literature.

$$T_{sa} = T_a + \alpha \frac{I_t}{h_o} - \frac{\varepsilon \delta R}{h_o} \tag{1}$$

2.2. Overall heat transfer coefficient

The overall heat transfer co-efficient for uninsulated roof and insulated roof is given by Eqs. (2) and (3) respectively. It is reciprocal of sum of thermal resistances of inside & outside air, inside and outside layer of cement, brick layer and cement-concrete layer for uninsulated roof. In case of the insulated roof the thermal resistances of the air gap and the wooden layer are also added to the resistances of the uninsulated roof. The overall heat transfer co-efficient for uninsulated wall and insulated wall is given by Eqs. (4) and (5) respectively. It is reciprocal of sum of thermal resistances of inside & outside air, inside and outside layer of cement and brick layer uninsulated wall. In case of the insulated wall the thermal resistances of the air gap and the wooden layer are also added to the resistances of the uninsulated wall. The overall heat transfer coefficients calculated in this section are used to calculate the heat transfer from roof & wall for uninsulated and insulated house.

$$U_{ur} = \frac{1}{\frac{1}{h_i} + \frac{\delta_1}{K_1} + \frac{\delta_2}{K_2} + \frac{\delta_3}{K_3} + \frac{\delta_1}{K_1} + \frac{1}{h_o}} \quad (2)$$

$$U_{ir} = \frac{1}{\frac{1}{h_i} + \frac{\delta_1}{K_1} + \frac{\delta_2}{K_2} + \frac{\delta_3}{K_3} + \frac{\delta_4}{K_4} + \frac{\delta_5}{K_5} + \frac{\delta_1}{K_1} + \frac{1}{h_o}} \quad (3)$$

$$U_{uw} = \frac{1}{\frac{1}{h_i} + \frac{\delta_1}{K_1} + \frac{\delta_3}{K_3} + \frac{\delta_1}{K_1} + \frac{1}{h_o}} \quad (4)$$

$$U_{iw} = \frac{1}{\frac{1}{h_i} + \frac{\delta_1}{K_1} + \frac{\delta_3}{K_3} + \frac{\delta_1}{K_1} + \frac{\delta_4}{K_4} + \frac{\delta_5}{K_5} + \frac{1}{h_o}} \quad (5)$$

2.3. Indoor air temperature

The buildings gain heat through roof, wall and window and heat is lost due to ventilation. Total heat gain by the building is given by Eq. (6) and total heat loss by the building is given by Eq. (7). Total heat gain is the sum of heat gain from roof given by Eq. (8), heat gain from the walls given by Eq. (9) and heat gain from the windows given by Eq. (10) [29]. Total heat loss from the building is equal to heat loss by ventilation and is given by Eq. (11) [22]. Heat gain from roof is calculated from the solar air temperature for roof, room air temperature, area of roof and overall heat transfer coefficient for roof. Heat gain from wall is determined from the solar air temperature for wall, room air temperature, area of wall and overall heat transfer coefficient for wall. Heat gain from window is the sum of heat transmitted through glass and heat conducted in due to solar air temperature of the window. Heat loss due ventilation is computed from inside and outside air temperature, number of air charges, density of room air, volume of room air and specific heat of room air. All these heat gains and losses are used to calculate the net heat gain by the house. The net heat gain by the house is given Eq. (12) which is the difference of total heat gain and total heat loss.

$$Q_{gt} = Q_r + Q_{wa} + Q_{wi} \tag{6}$$

$$Q_{lt} = Q_v \tag{7}$$

$$Q_r = U_r * A_r (T_{sa\_r} - T_{ra}) \tag{8}$$

$$Q_{wa} = U_{wa} * A_{wa} (T_{sa\_wa} - T_{ra}) \tag{9}$$

$$Q_{wi} = A_{wi} * \tau * I_t + U_{wi} * A_{wi} (T_{sa\_wi} - T_{ra}) \tag{10}$$

$$Q_v = \frac{\rho_{ra} * V_{ra} * C_{ra} * N * (T_{ra} - T_a)}{3600} \tag{11}$$

$$Q_{net} = Q_{gt} - Q_{lt} \tag{12}$$

The net heat gain is useful in computing the indoor air temperature of the house by heat balance. Heat balance for the house is given by Eq. (13) showing that net heat gain by the house is equal to heat gain by the air inside the house.

$$M_{ra} * C_{ra} \left(\frac{dT_{ra}}{dt} \right) = Q_{net} \tag{13}$$

Substituting the values of all the heat gain and loss terms in Eq. (13), we get Eq. (14) which can be written as Eq. (15) or Eq. (16).

$$M_{ra} * C_{ra} \left(\frac{dT_{ra}}{dt} \right) = U_r * A_r (T_{sa\_r} - T_{ra}) + U_{wa} * A_{wa} (T_{sa\_wa} - T_{ra}) + A_{wi} * \tau * I_t + U_{wi} * A_{wi} (T_{sa\_wi} - T_{ra}) - \frac{\rho_{ra} * V_{ra} * C_{ra} * N * (T_{ra} - T_a)}{3600} \tag{14}$$

or

$$\frac{dT_{ra}}{dt} = f\,(T_{ra}, u(t)) \tag{15}$$

or

$$\frac{dT_{ra}}{dt} = a\,T_{ra} + u(t)) \tag{16}$$

The solution of Eq. (16) for indoor air temperature can be obtained by Runge-Kutta fourth order method for the next hour [29]. The solution for indoor air temperature is given by Eq. (17) below.

$$T_{ra}(t+1) = T_{ra}(t) + \left(\frac{B_1 + 2B_2 + 2B_3 + B_4}{6} \right) * h \tag{17}$$

Runge-Kutta coefficients [29] used in Eq. (17) were computed from the following expressions (Eqs. (18) - (21)).

$$B_1 = \left(aT_{ra}(t) + \mathrm{u}(t) \right) * h \tag{18}$$

$$B_2 = \left(a(T_{ra}(t) + \frac{B_1}{2}) + \mathrm{u}(t) \right) * h \tag{19}$$

$$B_3 = \left(a(T_{ra}(t) + \frac{B_2}{2}) + \mathrm{u}(t)\right) * h \qquad (20)$$

$$B_4 = \left(a(T_{ra}(t) + B_3) + \mathrm{u}(t)\right) * h \qquad (21)$$

2.4. Energy savings

The energy savings for the insulated house is given by Eq. (22). It is the product of difference of room temperature in uninsulated & insulated houses and mass and specific heat of room air.

$$E_s = \frac{M_{ra} * C_{ra}(T_{ura} - T_{ira})}{3600} \qquad (22)$$

2.5. Money savings

Money savings are obtained from Eq. (23) by multiplying the energy savings for insulated house with cost of energy.

$$M_s = E_s * R \qquad (23)$$

2.6. Reduction in carbon dioxide emission

The reduction in carbon dioxide emission due to the energy saving potential of the insulated house is given by Eq. (24) [29]. It is obtained from energy savings by multiplying carbon dioxide emission factor and losses (transmission & distribution).

$$C = C_{ef} * (1 + F_d + F_t) * E_s \qquad (24)$$

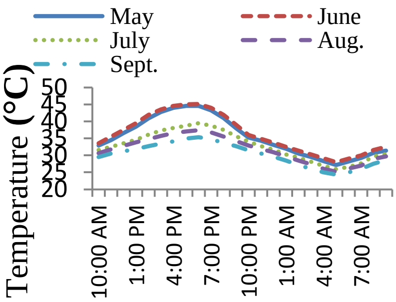
3. Results and Discussion

The parameters like solar air temperature, various heat interactions, indoor air temperature, optimized window area, energy savings, money savings and reduction in carbon dioxide emission computed from various equations are presented in the following sections: -

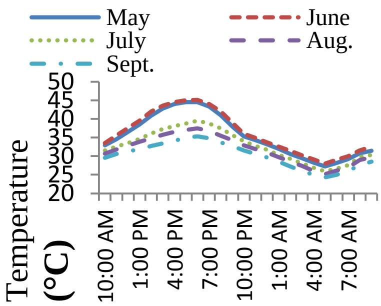
3.1. Solar air temperature

The solar air temperature variation for roof, wall and window from May to September is given in Figs. 3(a), (b) and (c) respectively. The solar air temperature is same for roof, wall and window for uninsulated & insulated house as it is the outside temperature. The solar air temperature is more during the day as compared to that in the evening or night. This is because of solar irradiance during the day which also increases the ambient air temperature as the time progresses. The solar air temperature during evening or night is lesser because of no solar irradiance which also decreases the ambient air temperature with passage of time. The solar air temperature for roof, wall and window from May to September increases from 10 am to 6 pm due to daytime. It decreases from 6 pm to 5 am due to evening and night time. Then it increases again from 5 am to 9 am due to sunrise. The solar air temperature is higher for roof as compared to wall and window for all the months because of longer time of solar irradiance on roof as compared to wall and window. It is slightly higher for wall than that for window due to more absorptance for solar radiation of wall material.

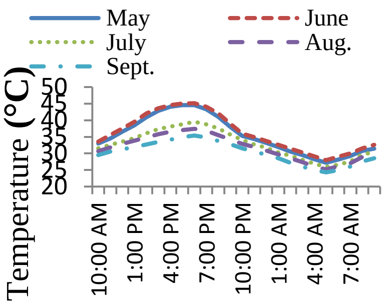
The maximum solar air temperature occurs around 6 pm in the evening for roof, wall and window for all the months. It is slightly higher for June as compared to May for roof, wall and window because of somewhat higher ambient air temperature in June. The solar air temperature for August is higher than September and lesser than July for roof, wall and window. This is because ambient air temperature is slightly lesser in September and slightly higher July as compared to August. The solar air temperature is higher for May and June than that for July to September due to higher ambient air temperature and solar irradiance in May and June. The maximum solar air temperature for roof is around 61.6°C, 62.2°C, 53.3°C, 51.4°C and 49.9°C for the month of May to September respectively. Its maximum value for wall is around 46.8°C, 47.8°C, 41.2°C, 39.8°C and 37.8°C for the month of May to September respectively. In case of window it has maximum value around 44.5°C, 45.1°C, 39.5°C, 37.4°C and 35.3°C for the month of May to September respectively.



(a) Solar air temperature variation for roof.



(b) Solar air temperature variation for wall.



(c) Solar air temperature variation for window.

Fig. 3. Solar air temperature for roof, wall and window for summer season.

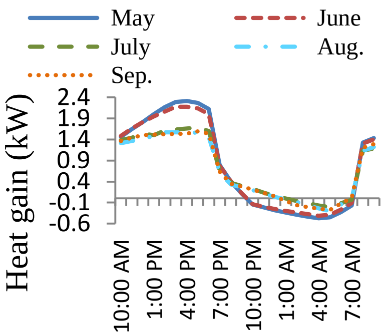
3.2. Heat interactions

The results of various heat interactions like heat gain from roof, wall and window and heat loss due to ventilation for uninsulated and insulated & window area optimized house are presented in Fig. 4. The heat gain from roof, wall and window for uninsulated house (Figs. 4(a), (b) and (c)) is much higher than that for insulated house (Figs. 4(f), (g) and (h)) from May to September during the daytime. This is due to less overall heat transfer co-efficient for the insulated house for roof and wall because of which less heat is transferred to the house. In case of window due to smaller area of window after optimization lesser amount of solar radiation enters the house. Due to the same reason the heat loss from roof, wall and window is more during the night for uninsulated house as compared to insulated & window area optimized house from May to September.

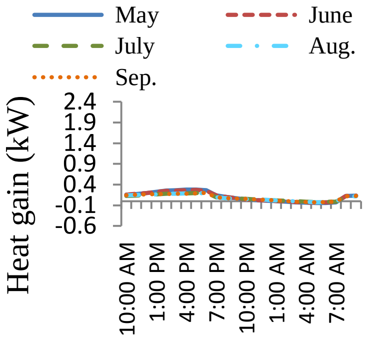
In the uninsulated house the heat gain during the day and heat loss during night for roof, wall and window is more for May and June as compared to July-September. The heat gain is more in May and June because of higher solar air temperature in May and June. The heat loss in the night is more in May and June because of higher indoor air temperature due which higher temperature difference exists between inside and outside. In the insulated house the heat gain during the day for wall and window is more for May and June because of higher solar air temperature in May and June. The heat for roof during the day is almost same for all the months because of lesser overall heat transfer coefficient for roof. Heat loss for the insulated house during the night is almost same for all the months for roof, wall and window because of insulation and window area optimization.

Heat gain due to ventilation during the day is slightly more in insulated house (Fig. 4(d)) in comparison to uninsulated house (Fig. 4(i)) for May to September. This is because the indoor air temperature is less in case of insulated house as compared to uninsulated house which causes more temperature difference in inside and outside of house. The heat loss due to ventilation during the night is almost same for the uninsulated and the insulated house for all the months during summers. The net heat gain during the day and net heat loss during the night is more for the uninsulated house (Fig. 4(e)) as compared to the insulated & window area optimized house (Fig. 4(j)) for all the months of summers. This is because of the insulation for roof & wall and smaller area for the window after optimization.

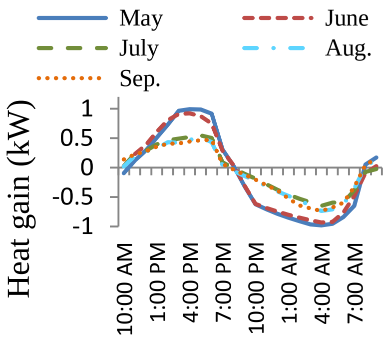
The net heat interaction for the insulated and the window area optimized house is very less due the reason already explained. The reduction in heat gain due to insulation and window area optimization is about 48% and 52% respectively. Therefore very less fluctuation in indoor air temperature occurs in the insulated house during the day and night as the heat gain or heat loss is very less. Hence insulated house is more comfortable to live in throughout the day and the night.



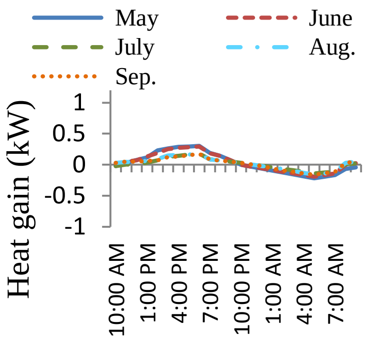
(a) Heat gain from roof for uninsulated house.



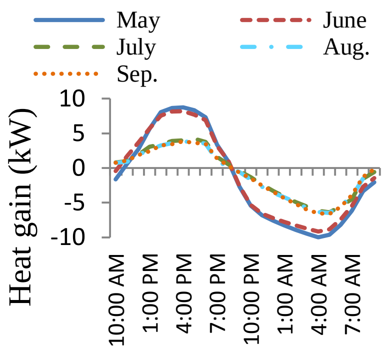
(f) Heat gain from roof for insulated house.



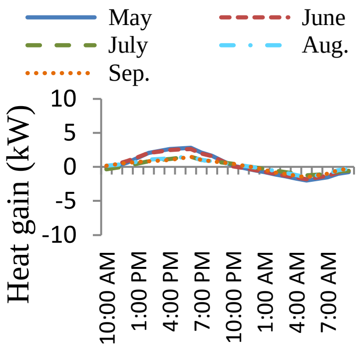
(b) Heat gain from wall for uninsulated house.



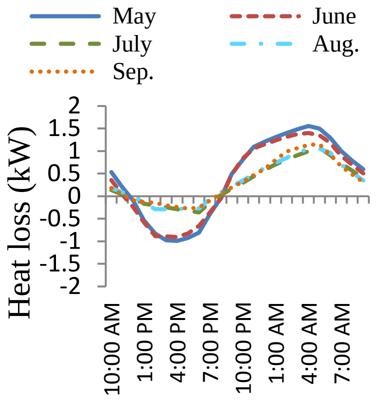
(g) Heat gain from wall for insulated house.



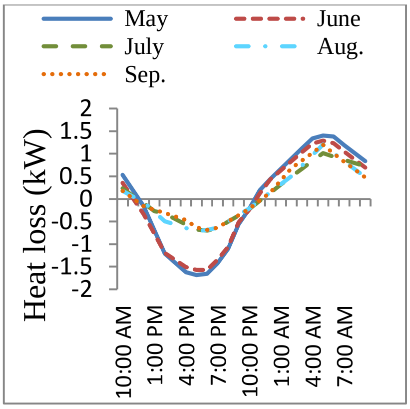
(c) Heat gain from window for uninsulated house.



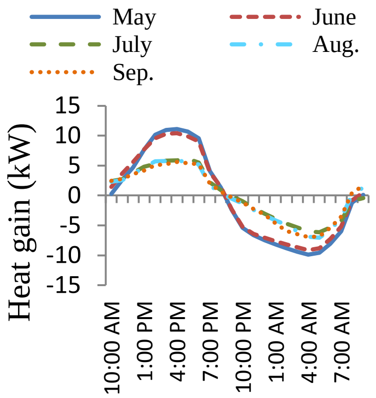
(h) Heat gain from window for insulated house.



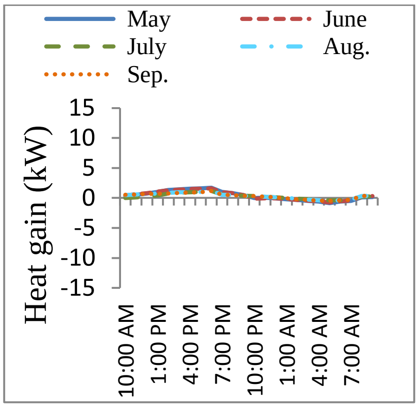
(d) Heat loss due to ventilation for uninsulated house.



(i) Heat loss due to ventilation for insulated house.



(e) Net heat gain for uninsulated house.



(j) Net heat gain for insulated house.

Fig. 4. Various heat interactions for two types of houses for summer season.

3.3. Optimized window area

The window area was varied in the Eq. (14) to get the minimum value of indoor air temperature (Fig. 5) for the month of June. Indoor air temperature decreases with reduction in window area due to lesser heat inflow through the window. The optimum value of window area is taken as 1.5 m^2 as below this there will be problem in day lighting as lesser sunlight will enter the house due to reduced window area. The value of optimized area is then applied to all the months to compute the indoor air temperature.

3.4. Indoor air temperature

The indoor air temperature measured and calculated analytically for the uninsulated house for the month of June is presented in Fig. 6. The indoor air temperature in both the cases is almost same during the day. The analytically computed indoor air temperature is slightly higher than measured value during 6 pm to 10 pm.

The comparison of indoor air temperature computed analytically in a house made from common construction material and same house with an air gap & a wooden layer on inside and smaller window area for the summer season is shown in Fig. 7 and Tables 2 and 3. The indoor air temperature is much lesser in case of house with insulation on inside and smaller window area for the whole day and night except from 5 am to 9 am in the morning. During 5 am to 9 am the indoor air temperature is slightly higher in the insulated houses. Lesser amount of net heat gets transferred inside due to insulation layer which reduces the overall heat transfer coefficient for most of the day and night. This reduces the indoor air temperature in insulated house. Due to same reason the air temperature is slightly higher in insulated house in the morning as the heat transfer is lesser from inside to outside due to lesser heat transfer coefficient.

The reduction in indoor air temperature due to insulation and window area optimization is about 48% and 52% respectively. The indoor air temperature increases as the day progresses and decreases in the night due to higher solar air temperature and higher amount of net heat gain in the day and lesser solar air temperature and net heat loss during night for the uninsulated and insulated house. The variation in the indoor air temperature is much higher for the uninsulated house as compared to the insulated house. The difference in indoor air temperature is more for the month of May and June due to higher outside temperature. The difference in indoor temperature is slightly lesser for the month of July to September as the outside temperature decreases for these months. The maximum indoor air temperature difference for insulated house as compared to uninsulated house is 5.73°C, 5.65°C, 2.96°C, 3.23°C and 3.08°C for the months from May to September respectively.

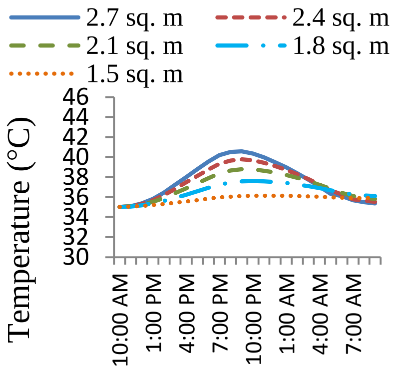


Fig. 5. Window area optimization for the insulated house in June.

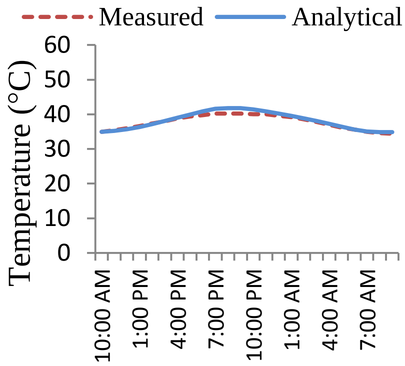
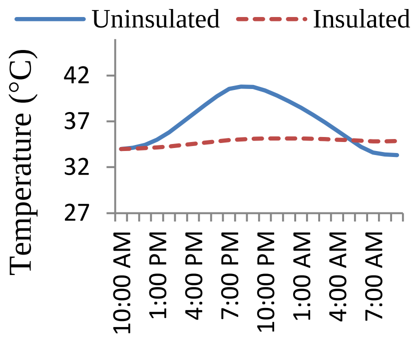


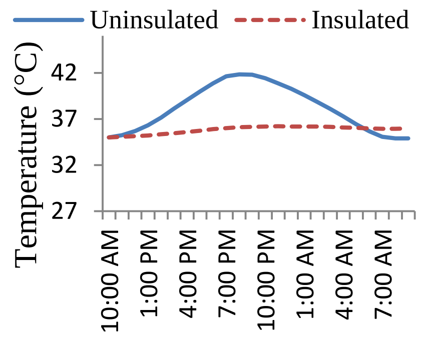
Fig. 6. Indoor air temperature for uninsulated house in June.

3.5. Energy savings

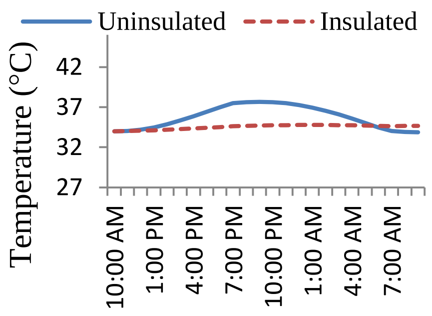
There are energy savings in an insulated and window area optimized house (Fig. 8(a) and Table 4) as compared to an uninsulated house for the summer season. This is because of lesser indoor air temperature existing in case of an insulated house. The energy savings are more for the month of May and June and lesser for the months of July, August and September. This is because of more indoor temperature difference for the insulated house as compared to uninsulated house for the months of May and June. The amount of energy savings from the month May to the month of September are 1170, 1240, 652, 762 and 690 units respectively. The maximum energy saving for the insulated house is for the month of June due to maximum indoor air temperature difference for this month as compared to an uninsulated house. The total energy savings for the summer season is 4514 units.



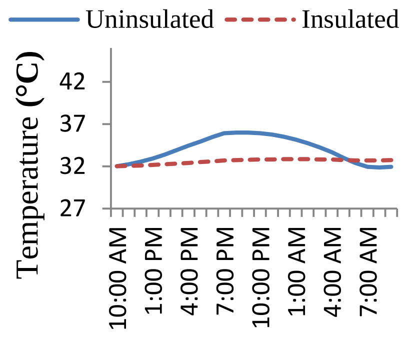
(a) Indoor temperature variation in May.



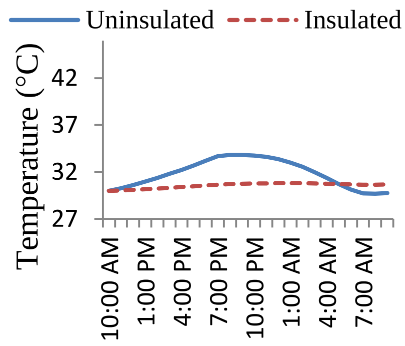
(b) Indoor temperature variation in June.



(c) Indoor temperature variation for two houses in July.



(d) Indoor temperature variation for two houses in August.



(e) Indoor temperature variation for two houses in September.

Fig. 7. Indoor air temperature for two types of houses for summer season.

Table 2. Indoor air temperature variation from May to July.

Time	May		June		July	
	T_{ura} (°C)	T_{ira} (°C)	T_{ura} (°C)	T_{ira} (°C)	T_{ura} (°C)	T_{ira}(°C)
10:00 AM	34	34	35	35	34	34
11:00 AM	34.12	34.04	35.22	35.05	34.05	34.03
12:00 PM	34.45	34.1	35.64	35.11	34.2	34.07
1:00 PM	34.99	34.17	36.24	35.19	34.46	34.12
2:00 PM	35.8	34.27	37.05	35.3	34.85	34.19
3:00 PM	36.78	34.4	37.98	35.42	35.35	34.26
4:00 PM	37.79	34.54	38.93	35.55	35.87	34.34
5:00 PM	38.8	34.68	39.85	35.69	36.41	34.43
6:00 PM	39.75	34.83	40.73	35.83	36.98	34.53
7:00 PM	40.54	34.97	41.46	35.97	37.49	34.62
8:00 PM	40.78	35.05	41.7	36.05	37.63	34.67
9:00 PM	40.75	35.11	41.67	36.1	37.67	34.7
10:00 PM	40.39	35.14	41.32	36.13	37.62	34.74
11:00 PM	39.83	35.15	40.78	36.14	37.49	34.76
12:00 AM	39.2	35.14	40.17	36.14	37.26	34.77
1:00 AM	38.49	35.13	39.5	36.13	36.95	34.78
2:00 AM	37.72	35.1	38.78	36.11	36.56	34.77
3:00 AM	36.89	35.07	38.02	36.08	36.1	34.76
4:00 AM	36.01	35.02	37.21	36.04	35.59	34.74
5:00 AM	35.09	34.96	36.37	35.98	35.03	34.71
6:00 AM	34.25	34.9	35.6	35.93	34.48	34.67
7:00 AM	33.6	34.84	35.04	35.89	34.05	34.64
8:00 AM	33.39	34.85	34.86	35.9	33.92	34.65
9:00 AM	33.34	34.86	34.84	35.92	33.87	34.68

3.6. Money savings

Money savings also attainable for the summer season (Fig. 8(b) and Table 4) because of energy savings for an insulated and window area optimized house. The money savings are more for the month of May and June due to more energy savings for these months. The money savings are slightly lesser for other months. The value of money savings from the month of May to the month of September are 5851, 6200, 3261, 3810 and 3452 Rs. respectively. The maximum savings are for the month of June due to more energy savings for this month. The total money savings for the summer season are Rs. 22574.

3.7. Reduction in Carbon dioxide emission

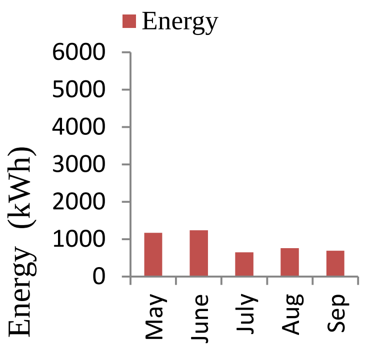
Reduction in carbon dioxide emission (Fig. 8(c) and Table 4) is achievable for each month of the summer season for an insulated and window area optimized house. This is because of energy savings for each month of the summer season in an insulated house. Which in turn will reduce the carbon dioxide emission as lesser amount of energy is spent for cooling the house. The value of carbon dioxide emission reduction for the months from May to September is 1835, 1944, 1022, 1195 and 1082 kg respectively. The total amount of carbon dioxide emission reduction for the summer season is 7078 kg.

Table 3. Indoor air temperature variation from August to September.

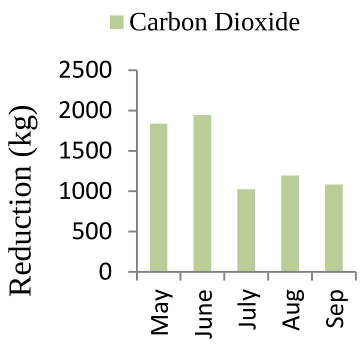
Time	August		September	
	T_{ura} (°C)	T_{ira} (°C)	T_{ura} (°C)	T_{ira} (°C)
10:00 AM	32	32	30	30
11:00 AM	32.25	32.05	30.26	30.05
12:00 PM	32.55	32.1	30.61	30.11
1:00 PM	32.91	32.16	30.98	30.17
2:00 PM	33.37	32.24	31.38	30.24
3:00 PM	33.9	32.32	31.8	30.31
4:00 PM	34.42	32.41	32.23	30.39
5:00 PM	34.94	32.5	32.69	30.48
6:00 PM	35.46	32.59	33.21	30.57
7:00 PM	35.91	32.68	33.69	30.66
8:00 PM	36	32.73	33.81	30.71
9:00 PM	36	32.77	33.83	30.74
10:00 PM	35.92	32.8	33.76	30.78
11:00 PM	35.75	32.82	33.61	30.8
12:00 AM	35.49	32.83	33.37	30.81
1:00 AM	35.15	32.84	33.02	30.81
2:00 AM	34.74	32.83	32.55	30.8
3:00 AM	34.25	32.82	31.99	30.78
4:00 AM	33.67	32.79	31.38	30.75
5:00 AM	33.01	32.75	30.72	30.71
6:00 AM	32.39	32.71	30.14	30.67
7:00 AM	31.95	32.68	29.73	30.63
8:00 AM	31.88	32.69	29.68	30.65
9:00 AM	31.94	32.72	29.77	30.68

Table 4. Energy savings, money savings and carbon dioxide reduction.

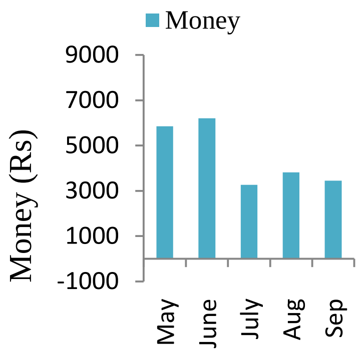
	E_s (kWh)	M_s (Rs.)	C (kg)
May	1170	5851	1835
June	1240	6200	1944
July	652	3261	1022
Aug	762	3810	1195
Sep	690	3452	1082
Total	4514	22574	7078



(a) Energy savings.



(c) Carbon dioxide emission reduction.



(b) Money savings.

Fig. 8. Energy savings, money savings and carbon dioxide emission reduction for house with insulation layer and reduced window area.

4. Conclusions

In the present work performance of an uninsulated house is compared with an insulated and window area reduced house. Following conclusions are drawn.

- The solar air temperature is highest for the month of June for roof, wall and window and is same for the uninsulated and insulated and window area optimized house.
- The net heat gain for the uninsulated house is very high as compared to the insulated and window area optimized house for the month of May to September.
- The thermal comfort of an insulated and window area optimized house is better than an uninsulated house. In addition to the human comfort provided, the insulated house provides the energy and the money savings. Also the insulated house is friendlier to the environment.
- The indoor air temperature is lesser in the insulated and window area optimized house as compared to the uninsulated house. The maximum indoor

air temperature difference for the insulated house in comparison to the uninsulated house is 5.73°C, 5.65°C, 2.96°C, 3.23°C and 3.08°C for the month of May to September respectively.

- Energy savings can be obtained for the insulated and window area optimized house as compared to the uninsulated house for the summer season. The amount of energy savings for the months from May to September are 1170, 1240, 652, 762 and 690 units respectively. The total energy savings for the summer season are 4514 units.
- Money can be saved for the insulated and window area optimized house for the summer season. The value of money savings for the months from May to September are 5851, 6200, 3261, 3810 and 3452 Rs. respectively. The total savings for the summer season are Rs. 22574.
- Reduction in carbon dioxide emission can be achieved for each month of the summer season. The reduction in carbon dioxide emission for the months from May to September is 1835, 1944, 1022, 1195 and 1082 kg respectively. The total amount reduction in carbon dioxide emission for the summer season is 7078 kg.

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