THERMAL RESPONSE OF A NON AIR CONDITIONED BUILDING BY USING INSULATION OF VARIOUS THICKNESSES AT THE DIFFERENT POSITIONS OF THE WALLS AND ROOF AT COLD STATIONS OF INDIA

Jindal Nikhil*, Jha Ranjana and Baghel Sarita

School of Applied Sciences, Netaji Subhas Institute of Technology, Dwarka, New Delhi (INDIA)

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ABSTRACT

The performance of a non air-conditioned building has been analyzed for cold climatic regions of India by using various thicknesses of insulation at different positions of the walls and roof i.e. on the external surface and the inner surface of the walls and in the middle of the walls. Single zone isolated building, having dimensions of 4m x 4m x 3m, and with south facing window 2 m x 1.6 m size, has been analyzed in this study. The periodic solution of the heat conduction equation describing the heat transmission through the different building components, floor, walls and roof has been adopted. Ambient temperature and total solar radiation intercepted by the building envelope have been represented through Fourier series. Traditional construction with 220 mm Burnt Clay Brick (BCB) wall, plastered 15 mm on both side without insulation and with insulation at different positions like internal and external surface of walls and in between the walls have been analyzed. It has been observed that thermal comfort for the three stations considered in this study can not be ensured in the month of January if the building is traditional (non- insulated).

Key Words: Thermal comfort, Thermal insulation, Numerical simulation, Non air conditioned building

NOMENCLATURE

\( A \) area of the fabric \( (\text{m}^2) \)
\( A_F \) area of the floor \( (\text{m}^2) \)
\( C \) heat transfer coefficient for air exchange \( (W\ K^{-1}) \)
\( C_{in} \) infiltration coefficient
\( C_v \) ventilation coefficient
\( c \) specific heat \( (J\ kg^{-1}\ K^{-1}) \)
\( h \) convective heat transfer coefficient \( (W\ m^{-2}\ K^{-1}) \)
\( I \) radiation flux \( (W\ m^{-2}) \)
\( L \) thickness \( (m) \)
\( k \) thermal conductivity \( (W\ m^{-1}\ K^{-1}) \)
\( M \) thermal mass \( (J\ K^{-1}) \)
\( N_i \) number of air exchanges per hour
\( Q \) rate of heat flow across any fabric surface \( (W) \)
\( \dot{q} \) rate of heat flow across any surface per unit area \( (W\ m^{-2}) \)
\( T \) temperature \( (^{\circ}\text{C}) \)
\( t \) time \( (\text{sec}) \)

*Author for correspondence

ACH Air changes per hour
\( Q, S \) as defined by Eq (3) (see mathematical modeling)
\( U \) conduction transmittance \( (W\ m^{-2}\ K^{-1}) \)
\( V \) volume of room \( (m^3) \)
\( X \) coefficient matrix of order 13 x 13
\( Y \) column matrix of order 13 x 1

Greek letters
\( \rho \) density \( (kg\ m^{-3}) \)
\( \alpha \) absorptivity (dimensionless)
\( \omega \) angular frequency, \( \omega = 2\pi/86,400 \) rad s\(^{-1}\)

Subscripts
\( a \) air
\( d \) door
\( f \) floor
\( i \) inside surface
\( n \) nth harmonic
\( o \) outside surface
\( r \) room
\( v \) ventilation
\( w \) wall
\( WN \) window
INTRODUCTION

To have a cost effective design of a building, an optimum thickness of insulation is required. Increasing energy demand and consciousness all over the world for global warming has been made it imperative that energy sources should be used in effective ways. Insulation is an economically viable option to reduce energy consumption in buildings. The environment is getting benefited indirectly if the energy consumption is reduced. Climatic conditions are the major factors governing the heating/cooling load requirements of the buildings. The average ambient temperature of a particular region and thermal conductivity of insulation plays an important role to decide the optimum thickness of the insulation material. Increased amount of thickness of the insulating material decreases air pollution and increases energy saving simultaneously. By using insulation, the thermal comfort inside the buildings can be assured.

Thermal comfort can be defined as the condition of mind which expresses satisfaction with the thermal environment. Artificial heating systems are required if a building can not provide thermally comfortable indoor spaces. The demand of energy increases due to heating as well as cooling requirements inside the building to provide the thermal comfort. Energy cost saving is very important in a country like India and to reduce the CO$_2$ and SO$_2$ emissions in the environment as well. The external walls and roof of a building are the interface between outdoor environment and indoor temperature of the building. These components of the building can be used as the most effective way of controlling the indoor temperature of the building with the integration of insulation of various thicknesses.

In India, Energy Conservation Building Code (ECBC- 2007) has been enforced to save the heating and cooling energy in built environment with the inclusion of specific values of thermal transmittance of walls, roof, glazing area and thermal insulation.

The purpose of insulation is to provide a continuous thermal barrier to minimize heat flow through the walls, ceiling and floor. By using insulation, energy cost can be reduced for heating and cooling and at the same time it provides indoor comfort in the building.

In this study, expressions for time variation of room temperature inside the building have been obtained with the help of periodic solution of heat conduction equation. To get direct solar gain, a window is provided on south wall. The mathematical expressions can be used for any type of climate zone and building as the expressions completely depends on an exact energy balance. The calculations have been performed for two types of climatic zones i.e. cold and cloudy and cold and sunny.

The thermal performance of the building is determined by the thermal properties of the material used in its construction characterized by its ability to absorb or emit solar heat in addition to the overall U-value of the corresponding components including insulation of various thicknesses placed at different positions of the building. The optimum thickness and position of the insulation used has been determined for three cold stations of India i.e. Srinagar, Shimla and Shillong. The best performance has been achieved by placing the insulating material close to the point of entry of heat flow i.e. on the outer surface of the building which is having many advantages also.

From the economic point of view thickness of the thermal insulation involves the initial cost of the insulating material and the ongoing value of energy savings over the service lifetime of the insulation.

In most studies, the optimum thickness of insulation was estimated mainly on the heating and cooling loads of the building in consideration and the other parameters like cost of insulating material, efficiency of heating and cooling systems. Bolatturk A.$^1$, Yu J. et al.$^2$ and Ucar A. et al.$^3$ estimated the heating and cooling energy requirements by the degree time concept (degree days or degree hours) which is applied under static conditions. Many researchers carried out studies by taking the proper amount of thermal insulation in the building envelope which helps to reduce cooling and heating demands of the building as well as CO$_2$ and SO$_2$ emissions to the atmosphere. Dombayci$^4$ focused on the reduction of CO$_2$, SO$_2$ and other greenhouse gasses by applying an optimum thickness of
thermal insulation on the external walls of the building. The concept of air gaps in the building with optimum thickness of insulation material on the building was introduced by Mahlia and Iqbal in Maldives. They used different insulation materials and optimum thickness and air gaps on the building walls. It had been observed in the study that without an air gap in the building walls, the fibre glass-urethane material had the greatest life cycle savings and the most economical insulating material. By considering time lag and decrement factor for various wall orientation including optimum location and distribution of insulation on a wall for both summer and winter weathers in Turkey by Ozel and Pihatli, the best performance was observed when one insulation layer was placed on outer, second within and the third on the innermost surface of the walls. Al- Sallal et al also investigated the most suitable location to apply insulation for the roof and walls. The numerical model was deployed for different types of walls and roof configurations during typical day of summer and winter. He also compared two types of roof insulation polystyrene and fiberglass and found that the payback period was shorter for cold climates. Several researchers studied that the optimum thickness of thermal insulation should be used on the external surface of the walls for different climatic conditions. Farhan et al, Al-Khawa, Daouas et al, Ahmed and M. Bojic et al investigated the role of thermal insulation in energy saving by reducing the rate of heat transfer and determining the optimum thickness of the insulation for a particular climatic condition. Bolatturk selected 16 cities from four climatic zones of Turkey where in the research consideration were taken for the various parameters like optimum insulation thickness, energy savings and payback periods for various fuels like coal, natural gas, fuel oil, liquified petroleum gas, electricity and polystyrene insulating material were considered. It was observed that optimum insulation thickness vary between 2 to 17 cm, energy savings vary between 22% and 19% and pay back periods vary between 1.3 and 4.5 years depending upon the climate of cities and the type of fuel. By taking different base temperature for Turkey’s warmest zone, heating and cooling degree hours were calculated for the optimum thickness of thermal insulation. Architectural design properties such as air infiltration rate, glazing type and glazing area considering long term and current outdoor temperature, Kaynakli investigated the variations of annual energy requirement of the buildings. The optimum insulation thickness for Bursa varied between 5.3 to 12.4 cm. depending on fuel type. Five different fuels and four different insulation materials were considered for the study for various cities in Turkey. Al-Khawa, Ozel, Kontoleon et al and many other researchers used sol-air temperature to study the optimum insulation thickness by calculating heating and cooling degree days. Al- Sanea et al discussed a dynamic heat transfer model based on a finite volume and an economic model based on life cycle cost.

The effect of insulation location and the associated energy performance for residential buildings with six characteristics wall configurations for six different US cities having different climates was studied by Kossecka and Kosnay. They observed that material used for exterior wall and climate play an important role on the thermal performance of the buildings. Al-Sanea et al developed a techno economic model based on time dependent method for estimating optimum distribution of insulation over various components of air conditioned building located in various cities of different climatic conditions. It was observed that insulation over the roof provides the maximum savings whereas on south oriented wall least. Yumrutas et al and Daouas analyzed two types of walls (brick/brick and stone/brick sandwich walls) and two types of insulating materials (expended polystyrene and rock wool) to determine the most economical combination of wall and insulating materials. It was found that expended polystyrene and stone/brick sandwich wall structure give the best performance. Expended polystyrene was found to be the most profitable insulating material in Tunisia.
MATERIAL AND METHODS

Mathematical modeling
A single zone isolated house of dimensions 4m x 4m x 3m has been taken for the analysis. The analysis is based on the time dependent analysis of heat flow through various building components. The heat flows through the walls, roof and ground by conduction. The heat flux associated with each mode is calculated for all possible components. The associated heat fluxes are determined from the nature of heat transfer. The direct gain of heat is available inside the room through the window placed on south wall. The convective heat transfer is taking place between the inside room air and the ambient air in the form of ventilation and infiltration. The heat flux, from each mode contributing towards room temperature, is calculated and summed over all the modes of heat gain. All heat fluxes are calculated on an hourly heat balance basis for each surface of the building. The rate of increase in internal energy of the room air is equal to sum over all the modes of heat gain. This results in an energy balance equation in terms of a Fourier series of harmonics for each variable. Climatic conditions are used for two representative days one of a summer month (June) and one of a winter month (January).

To carry out this study few hypothesis are made:

1. Heat flow through different layers of walls and roof is assumed to be unidirectional i.e. in perpendicular direction to the wall face.
2. Temperature distribution (internal and external) on each wall is considered to be uniform.
3. The door and window is supposed to be closed.
4. The convection is natural and the flow is laminar.
5. Optimization is done by considering heat gain through the opaque walls, roof and window.

Heat flux through walls and roof
The well known conduction equation for heat flow through a solid is given as

\[
 k \frac{\partial^2 T}{\partial x^2} = \rho c \frac{\partial T}{\partial t} \tag{1}
\]

As the room temperature is determined by the solar radiation and ambient temperature, at any time, and as both the variables are varying periodically and hence expressible in terms of Fourier coefficients, so the room temperature is also varying periodically with the same frequency. By using the appropriate boundary conditions, the solution of Eq. (1) can be written in the matrix form as

\[
\begin{bmatrix}
 T_{in} \\
 \dot{q}_{in}
\end{bmatrix}
 =
\begin{bmatrix}
 A_n & B_n \\
 D_n & A_n
\end{bmatrix}
\begin{bmatrix}
 T_{on} \\
 \dot{q}_{on}
\end{bmatrix}
\]

The values of matrix elements \( A_n, B_n \) and \( D_n \) are dependent upon the thermophysical properties of the building components and are determined as:

\[
 A_n = \cosh(\alpha_n L) \\
 B_n = -\frac{\sinh(\alpha_n L)}{k\alpha_n} \\
 D_n = -k\alpha_n \sinh(\alpha_n L)
\]

Where \( \alpha_n = \sqrt{\frac{\text{inopc}}{k}} \)

If the fabric is multilayered, Eq. (1) gets modified to

\[
\begin{bmatrix}
 T_{in} \\
 \dot{q}_{in}
\end{bmatrix}
 =
\begin{bmatrix}
 P_n & Q_n \\
 R_n & S_n
\end{bmatrix}
\begin{bmatrix}
 T_{on} \\
 \dot{q}_{on}
\end{bmatrix}
\]

where

\[
\begin{bmatrix}
 P_n & Q_n \\
 R_n & S_n
\end{bmatrix} =
\begin{bmatrix}
 1 & -1/h_i \\
 0 & 1
\end{bmatrix}
\begin{bmatrix}
 A_n^1 & B_n^1 \\
 D_n^1 & A_n^1
\end{bmatrix}
\times
\begin{bmatrix}
 A_n^2 & B_n^2 \\
 D_n^2 & A_n^2
\end{bmatrix}
\begin{bmatrix}
 A_n^3 & B_n^3 \\
 D_n^3 & A_n^3
\end{bmatrix}
\begin{bmatrix}
 1 & -1/h_o \\
 0 & 1
\end{bmatrix}
\]

Here \( P, Q, R \) and \( S \) are again dependent upon thermophysical properties of different layers, and the order in which various layers are arranged in the direction in which the heat flows.

The value of \( \dot{q}_{in} \) is obtained by solving Eq. (2) for \( \dot{q}_{in} \) and is

\[
\dot{q}_{in} = A \frac{S_n T_{in} - T_{on}}{Q_n} \tag{4}
\]
When the solar radiation falls on the inner surface as well as on the outer surface of the fabric specially in the case of direct solar gain, the boundary conditions applied to Eq. (1) get modified and one finds an expression for \( q_n \), similar to Eq. (4), here the respective temperature are replaced by their corresponding solar values with an additional term, i.e.

\[
\dot{Q}_n = A_F \left( \frac{S_n}{Q_n} \right) \left( T_{in} + \frac{\alpha I_{in}}{h_i} \right) + A\alpha I_{in} \quad \text{eqn. 5}
\]

**Heat flux through the floor**

The floor has been treated as a semi-infinite medium, the solution of Eq. (1) with suitable boundary conditions for the floor gives the expression for the heat flux, i.e.

\[
\dot{Q}_n = A_F \frac{S_n}{Q_n} \left( T_{in} + \frac{\alpha I_{in}}{h_i} \right) + A_F \alpha I_{in} \quad \text{eqn. 6}
\]

Where, \( n \neq 0 \), \( S_n = 1.0 \), and \( Q_n = -\frac{1}{h_i} + \frac{1}{k\alpha_n} \).

And for \( n = 0 \), i.e. steady condition, \( S_n = 0 \). The heat flux through each mode has been calculated. Solar radiation and ambient temperature which are time varying function and can be expressed in terms of Fourier series as

\[
f(t) = \sum_{n=-\infty}^{+\infty} f_n \exp(in\omega t) \quad \text{eqn. 7}
\]

As discussed above, the heat flux transmitted through the walls and roof can be expressed as

\[
\dot{Q} = A \sum_{n=-\infty}^{+\infty} \left( S_n \left( T_{in} + \frac{\alpha I_{in}}{h_i} \right) - T_{in} \right) \left( \frac{\alpha I_{in}}{h_i} \right) \exp(in\omega t) + A \sum_{n=-\infty}^{+\infty} \left( \alpha I_{rn} \right) \exp(in\omega t) \quad \text{eqn. 8}
\]

Where \( S_n \) and \( Q_n \) are dependent upon the thermophysical properties of walls and roof materials.

The energy flux through the floor is obtained as

\[
\dot{Q} = A_F \sum_{n=-\infty}^{+\infty} \frac{S_n}{Q_n} \left( T_{rn} + \frac{\alpha I_{in}}{h_i} \right) \exp(in\omega t) + A_F \sum_{n=-\infty}^{+\infty} \left( \alpha I_{in} \right) \exp(in\omega t) \quad \text{eqn. 9}
\]

Hourly calculations have been done for the direct gain through the glazing.

**Heat gain due to infiltration and ventilation**

The heat gain due to infiltration of air from ambient into room has been calculated from the expression

\[
\dot{Q} = C_{inf} \sum_{n=-\infty}^{+\infty} (T_{rn} - T_m) \exp(in\omega t) \quad \text{eqn. 10}
\]

The expression for ventilation heat gain is given as

\[
\dot{Q} = \sum_{n=-\infty}^{+\infty} C_v (T_{rn} - T_m) \exp(in\omega t)
\]

\[
= \sum_{m=-\infty}^{+\infty} \sum_{n=-\infty}^{+\infty} C_{vm} (T_{rn} - T_m) \exp\left\{i(n+m)\omega t\right\} \quad \text{eqn. 11}
\]

Where it has been assumed that the ventilation term \( C_v \) is a time varying factor and it is expressed in terms of Fourier coefficients as

\[
C_v = \sum_{m=-\infty}^{+\infty} C_{vm} \exp(\omega t)
\]

**Heat conduction through glazing and door**

Heat conduction through the glazing and the door has been expressed in terms of their respective U-values, i.e.

\[
\dot{Q} = A_U \sum_{n=-\infty}^{+\infty} (T_{rn} - T_m) \exp(in\omega t) \quad \text{eqn. 12}
\]

Room air temperature has been calculated by the net amount of heat gain/loss by the room air through all its components. It has been expressed in the form of energy balance equation as

\[
M_i \frac{d}{dt} \left[ \sum_{n=-\infty}^{+\infty} T_{rn} \exp(i\omega t) \right] = \sum_{j=2}^{6} \dot{Q}_j \quad \text{eqn. 13}
\]

where \( i \) corresponds to Equations (8) to (12). Considering the harmonics from \( n = -6 \) to \( n = +6 \) only, and by comparing coefficients of different harmonic frequencies, Eq. (13) gives
13 Equations which can be written in the form of a matrix as
\[ X_{3 \times 13} T_{m_{3 \times 1}} = Y_{3 \times 1} \]
or
\[ T_{m_{3 \times 1}} = X_{3 \times 13}^{-1} Y_{3 \times 1} \]  
(14)
Solution of Eq. (14) determines the different harmonic components of the room air temperature, and these can be combined together to give the hourly variation of room temperature, i.e.
\[ T(t) = \sum_{n=6}^{16} T_m \exp(in\omega t) \]  
(15)

**Input data**

In this study, two types of buildings have been analyzed i.e. conventional building and insulated building. In conventional building, the wall consists of 220 mm Burnt Clay Brick (BCB) and 15 mm plaster on both sides; the roof, a four layered component, consists of 15 mm plaster in the inner surface, 100 mm RCC (Reinforced Cement Concrete), 80 mm mudphuska (mixture of clay and rice husk) and 25 mm broken tiles on outer surface. In the case of insulated building, a layer of Expanded Polystyrene (EPS) of various thickness has been taken on the outer surface, inner surface and in between the walls and in the case of roof, mudphuska has been replaced by a layer of Expanded Polystyrene (EPS) of various thickness. The floor consisting of 100 mm RCC has been considered for both types of buildings. The dimensions of building under consideration are 4 m x 4 m x 3m, with one window in south wall having size of 2 m x 1.6 m (20% of the floor area). Single glazed, clear glass window is taken for conventional building and double glazed, low-e, window is taken for insulated building. The overall heat transfer coefficients for outer and inner surfaces are 23 W m\(^{-2}\) K\(^{-1}\) and 8.29 W m\(^{-2}\) K\(^{-1}\) respectively. The absorptance values for walls and roof are taken 0.4 and 0.7 respectively. The ventilation rates for conventional building and for insulated building are 1.0 ACH and 0.5 ACH respectively (ACH: air change per hour). Metrological hourly data like monthly mean hourly ambient temperature and solar radiation for the three stations under consideration have been taken from Bansal and Minke.\textsuperscript{23-26} Standard values of thermo-physical properties of the materials used in this problem are given in Table 1.

**Table 1: Thermo-physical properties of the building material used in this study**

<table>
<thead>
<tr>
<th>S/N</th>
<th>Material</th>
<th>Specific heat (J kg(^{-1}) K(^{-1}))</th>
<th>Density (kg m(^{-3}))</th>
<th>Conductivity (W m(^{-2}) K(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Burnt Clay Brick (BCB)</td>
<td>880</td>
<td>1820</td>
<td>0.81</td>
</tr>
<tr>
<td>2.</td>
<td>RCC</td>
<td>880</td>
<td>2280</td>
<td>1.58</td>
</tr>
<tr>
<td>3.</td>
<td>Plaster</td>
<td>840</td>
<td>1762</td>
<td>0.72</td>
</tr>
<tr>
<td>4.</td>
<td>Broken tiles</td>
<td>880</td>
<td>1820</td>
<td>0.81</td>
</tr>
<tr>
<td>5.</td>
<td>Mudphuska</td>
<td>880</td>
<td>1622</td>
<td>0.52</td>
</tr>
<tr>
<td>6.</td>
<td>Insulation (Expanded polystyrene)</td>
<td>1340</td>
<td>34</td>
<td>0.035</td>
</tr>
</tbody>
</table>

Srinagar (Latitude 34°05’N; Longitude 74°50’E; Altitude 1586m), Shillong (Latitude 25°34’N; Longitude 91°53’E; Altitude 1500m) and Shimla (Latitude 31°06’N; Longitude 77°10’E; Altitude 2202m) have been taken for this study. January and June, the coldest and the hottest months of India have been chosen for calculations.

**RESULTS AND DISCUSSION**

The optimum thickness of the insulating material i.e. expanded polystyrene has been
calculated to ensure the thermal comfort inside a building (i.e. room temperature 20 ± 2°C) at the three different cities of cold regions of India. The results have been obtained in terms of hourly variation of room temperature for a typical winter and summer day for Shimla, Shillong and Srinagar. Non insulated as well as insulated building with variable thickness of insulation has been analyzed. The analysis is performed for two months i.e. January and June where January represents the winter season while June represents the summer season in India.

**Shimla**

The study of the effect of insulation has been performed for January and June months where the climatic conditions are cold and cloudy. Fig. 1(a) is showing the variation of ambient temperature and inside room temperature for a conventional building i.e. without insulation. At Shimla, during the summer month of June, the ambient temperature varies from 16.2°C to 24.3°C. A conventional building, at this station and in this month, shows room temperature variation from 22°C to 24.8°C. The inside room temperature achieved for the non insulated building is almost in the comfortable indoor temperature range. Hence it is concluded that in the summer season, comfortable indoor temperature can be achieved for a conventional building, while in the month of January, the inside room temperature varies from 6°C to 8.9°C which is very low for human thermal comfort. So in the winter month, a conventional building cannot ensure thermal comfort inside the building.

When insulation is applied on the four walls and on the roof, the inside temperature gets enhanced. Enhancement of the room temperature depends upon the thickness of insulation. Thickness of insulation is varied from 8 cm to 14 cm in steps of 2 cm. Fig. 1(b) shows the results for different thickness of insulation when insulation was applied on the inner surface of the walls and on the roof. It is seen that for the thickness of 8 cm, the room temperature varies from 14.6°C to 19.7°C with the temperature swing of 5.1°C. When the thickness is increased to 14 cm, the room temperature increases significantly and the variation in room temperature is from 22.1°C to 27.8°C with a temperature swing of 5.7°C. It is evident that the temperature swing is very high when insulation is placed on the inner surface of the walls.

Fig. 1(c) shows that there is not much fluctuation in the inside room temperature, when the insulation of variable thickness is placed in the middle of the walls. The swing in inside room temperature is about 1.0°C during day and night. For the insulation thickness of 10 cm, the desired comfortable temperature range can be achieved where the inside room temperature is ranging from 19.1°C to 20.3°C. For the insulation thickness of 14 cm, the room temperature between 23.8°C to 25.0°C is achieved.

The results are shown in Fig. 1(d) when insulation is applied on the outer surface of walls and on the roof. The room temperature variation is from 16°C to 17.3°C for 8 cm of insulation thickness. For the insulation thickness of 10 cm, the inside room temperature varies from 19.1°C to 20.3°C which lies in the comfortable room air temperature range. It can be seen from the graph that the swing in the indoor temperature is very less i.e. 1°C (approx) when insulation is used on the outer surface of the walls.

It is observed that when the insulation is placed on the outer surface of the walls or in the middle of the walls, the room temperature swing is very less about 1°C (approx). When it is applied on the inner surface of the walls, the room temperature swing is about 5°C (approx). As less temperature swing is preferable to human thermal comfort so positioning of the insulation is recommended on the outer surface of the walls or within the walls. The comfortable room temperature is achieved for the insulation thickness of 10 cm on the outer surface or in the middle of the walls and on roof for Shimla.
Fig. 1(a): Time variation of room temperature for a non insulated building at Shimla for January and June months, ACH = 1.0

Fig. 1(b): Time variation of room temperature for an insulated building at Shimla in January for various insulation thickness applied on inner surface of the walls, ACH = 0.5

Fig. 1(c): Time variation of room temperature for an insulated building at Shimla in January for various insulation thickness applied in the middle of the walls, ACH = 0.5
Shillong

Shillong is a cold and cloudy station located in the eastern region of India. Non insulated and well insulated building with variable thickness of insulation i.e. 5cm, 6cm, 7cm and 8 cm on different positions of the walls and on the roof have been analyzed. It has been observed that for the non insulated building in the month of June, the inside room temperature is ranging from 17.4°C to 23.7°C and without using insulation, the comfortable temperature is achieved. While in the month of January where the difference in maximum and minimum ambient temperature is about 12°C, the inside room temperature varies from 10.2°C to 13.5°C. Hence, to achieve comfortable room temperature, insulation is required for the winter season. Depending upon the climatic conditions of Shillong, insulation of variable thickness at different positions of the wall has been analyzed. The results for a conventional building are shown in Fig. 2(a). When the insulation is used on the inner surface of the walls and roof, the results are shown in Fig. 2(b). It is observed that for the insulation thickness of 5 cm, the variation in room temperature is 16°C to 20.4°C. For this insulation thickness comfortable temperature is not achieved. The room temperature ranges between 17.2°C to 21.8°C for the insulation thickness of 6 cm. When the insulation thickness is increased by another one cm i.e. 7 cm, the room temperature varies from 18.4°C to 23.2°C. And for 8 cm insulation thickness, the inside room temperature is ranging between 19.6°C to 24.6°C. It is observed that the temperature swing is around 5°C when the insulation is placed on the inner surface of the walls which is fairly high for human thermal comfort.

It has been observed that there is not much difference in maximum and minimum temperature inside the room when the insulation is used in the middle of the walls and on the roof. The temperature swing is only about 1°C throughout the day and night for all the thickness of insulation. Fig 2(c) is showing the results for various thickness of insulation used in this study. It is evident that the comfortable room temperature is achieved for the insulation thickness of 7 cm.

The results are shown in the Fig. 2(d) for various insulation thickness placed on the outer surface of the walls. It has been observed that the room temperature is varying between 19.8°C to 21°C for the insulation thickness of 7 cm with a temperature swing of about 1°C which is the comfortable temperature for human thermal comfort.
Fig. 2(a) : Time variation of room temperature for a non insulated building at Shillong for January and June months, ACH = 1.0

Fig. 2(b) : Time variation of room temperature for an insulated building at Shillong in January for various insulation thickness applied on inner surface of the walls, ACH = 0.5

Fig. 2(c) : Time variation of room temperature for an insulated building at Shillong in January for various insulation thickness applied in the middle of the walls, ACH = 0.5
Fig. 2(d): Time variation of room temperature for an insulated building at Shillong in January for various insulation thickness applied on outer surface of the walls, ACH = 0.5

For Shillong, it is observed that when 7 cm of insulation thickness is applied either on outer surface or in the middle of the walls and on the roof, one can achieve the comfortable room temperature with a low temperature swing of about 1°C.

Srinagar

Srinagar is a cold and cloudy station in the top of North India. Insulated and Non-insulated buildings have been analyzed for a typical day of the months January and June. In the month of June, the ambient temperature is ranging between 14.4°C to 29°C. For a conventional building in this month, the room temperature varies from 22.8°C to 26.3°C. It is evident that in the summer month a conventional building can ensure the comfortable room temperature inside the building. While in the month of January when the ambient temperature is ranging between -2.3°C to 4.4°C, a non-insulated building shows the room temperature variation from 1.5°C to 4.4°C which is much below the comfortable room temperature. So, insulation of optimum thickness should be used in order to maintain the comfortable room temperature in winter months. Fig. 3(a) shows the variation of room temperature for a conventional building in the month of June and January.

Fig. 3(a): Time variation of room temperature for a non insulated building at Srinagar for January and June months, ACH = 1.0
Fig. 3(b) : Time variation of room temperature for an insulated building at Srinagar in January for various insulation thickness applied on inner surface of the walls, ACH = 0.5

Fig. 3(c) : Time variation of room temperature for an insulated building at Srinagar in January for various insulation thickness applied in the middle of the walls, ACH = 0.5

Fig. 3(d) : Time variation of room temperature for an insulated building at Srinagar in January for various insulation thickness applied on outer surface of the walls, ACH = 0.5;
For the month of January, the variation in room temperature is analyzed for variable thickness of insulation at different position of the walls and on the roof. Five different thickness of insulation i.e. 8 cm, 10 cm, 12 cm, 14 cm and 16 cm have been used to calculate the room temperature. When the insulation is applied on the inner surface of the walls and on roof, Fig. 3 (b) shows that as the insulation thickness is increased, the inside room temperature is increased. It has been observed that for 8 cm of insulation thickness, the room temperature varies from 10.6°C to 15.8°C. When the insulation thickness is increased to 16 cm, the variation in room temperature is from 19.7°C to 25.4°C. It is observed that the temperature swing inside the building is about 6°C when the insulation is applied on the inner surface of the walls which is not preferable. Fig. 3(c) shows the variation of inside room temperature when the insulation is placed between the walls. The swing in room temperature is only about 1°C for all the thickness of the insulation used. But the comfortable room temperature is achieved for the insulation thickness of 14 cm in January whereas the average ambient temperature is about 2°C. The results are shown in Fig. 3(d) when the insulation is placed at the outer surface of the walls. The comfortable room temperature is achieved for the insulation thickness of 14 cm with a temperature swing of about 1°C. So for this particular thickness the comfortable room temperature can be achieved throughout the whole day for the winter season. It is observed that for Srinagar one can achieve the comfortable room temperature inside the building when 14 cm thickness of insulation is used on either the outer surface of the walls or in the middle of the walls with a low temperature swing.

CONCLUSION

For all the three stations considered, the temperature swing inside the room is fairly high for a non insulated building. The insulation layer causes a substantial temperature drop across its thickness. The optimum insulation thickness and location reduces temperature swing and magnitude of heat inside the room. The results obtained can be concluded that the insulation on walls and roof reduces the impact of low temperatures during the winter period, thus enabling the thermal comfort to be achieved. Under optimum conditions, the presence of insulation when applied either on external surface of the walls or in the middle of the walls significantly reduce the temperature swing inside the building hence provide a higher level of indoor comfort for the occupants.

With insulation on the external surface of the walls or in the middle of the walls, it can be concluded that

a) For Shimla, 10 cm of insulation thickness provides a comfortable room temperature inside the building where the climatic condition is cold and cloudy.

b) For Shillong, 7 cm thickness of insulation ensures the thermal comfort for the occupants with a low temperature swing.

c) For Srinagar where the climatic condition is same as that of Shimla and Shillong but the ambient temperature is very low, 14 cm of insulation thickness provides the room temperature which is in the comfortable range.

REFERENCES


