A Presentation
On
Study of Unsteady State Thermal Characteristics of Homogeneous and Composite Walls of Building and Insulating Materials for Passive Cooling

Ashok Babu TALANKI PUTTARANGA SETTY ¹ Saboor SHAIK ²

Department of Mechanical Engineering
National Institute of Technology Karnataka
Surathkal -575025, Mangalore, INDIA.

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1. **INTRODUCTION**

Buildings are consuming more and more power for cooling, heating and day lighting.

According to U.S. Green building council, buildings are consuming 40% of world’s power production and responsible for 40% of greenhouse gas emissions.

Global warming is due to use of fossil fuels for power production. This has to be replaced by the renewable sources of energy. Power consumption in building is to be reduced.
Fig.1.1 YEARLY GLOBAL WARMING
Fig. 1.2 ICE MELTING IN ARCTIC CIRCLE
Fig. 1.3 Solar Passive Building Design Elements

Solar-Passive Building Design

- Thermal comfort
  - Reduce energy demand of Space-Conditioning

- Visual comfort
  - Reduce energy demand of Artificial lighting

Reduction in energy consumption and GHG emission

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2. OBJECTIVES
The followings objectives have been set to explore,

1. OPTIMUM LOCATION OF INSULATION IN COMPOSITE WALL

2. OPTIMUM THICKNESS OF THE HOMGENEOUS WALL WHERE MAXIMUM THERMAL HEAT CAPACITY INCURRS

3. UNSTEADY STATE THERMAL CHARACTERISTICS OF FIVE BUILDING AND FIVE INSULATING MATERIALS AND THEIR COMPOSITE WALLS

4. THE BEST COMBINATION OF PROPOSED BUILDING AND INSULATING MATERIALS
3. UNSTEADY THERMAL RESPONSE CHARACTERISTICS
&
CYCLIC ADMITTANCE PROCEDURE
Optimum fabric thickness, $L_{opt} = 1.18251\sigma_L$
Fig. 3.2 ATTENUATION OF SINUSOIDAL WAVE

- Decrement Factor
- Decremental Timelag (6-12 hr)
Fig. 3.3 THERMAL ADMITTANCE AND TRANSMITTANCE

- ADMITTANCE
- TRANSMITTANCE

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Fig. 3.4 THE SCHEMATIC REPRESENTATION OF TIME LAG AND DECREMENT FACTOR

One Dimensional Diffusion Equation:

\[ \frac{\partial^2 T(X, t)}{\partial X^2} = \frac{\rho C_p}{k} \frac{\partial T(X, t)}{\partial t} \]  \hspace{1cm} (3.2)

With Boundary Conditions:

\[ k \left( \frac{\partial T}{\partial x} \right)_{x=0} = h_i [T_{x=0}(t) - T_i] \]  \hspace{1cm} (3.3)

\[ k \left( \frac{\partial T}{\partial x} \right)_{x=L} = h_o [T_{sa}(t) - T_{x=L}(t)] \]  \hspace{1cm} (3.4)

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Space/Time Independent Solutions (Davies M.G., 2004):

\[ T(x, t) = A \exp(x/\xi) \exp(t/\zeta) \]

\[ \xi \text{ and } \zeta \text{ are properties of system, they have units of distance and time respectively} \]

The above equation satisfies the Fourier equation if,

\[ \xi^2 = \kappa \zeta \]

Value of \( \zeta \) leads to different solutions

If \( \zeta \) is taken equal to \(-z\) (where \( z \) is real and positive)
then imposition of boundary conditions on a finite thickness slab gives “TRANSIENT SOLUTION”.

If \( \zeta \) is an imaginary number and equal to \( P/(j2\pi) \) (where \( j = \sqrt{-1} \))
then imposition of periodic convective boundary conditions on a finite thickness slab gives “PERIODIC SOLUTION” with sinusoidal excitation with Period \( P \).
The Periodic Solution (Davies M.G., 2004)

\[ T(x, t) = A \exp(x/\xi) \exp(t/\zeta) \]

**Condition to be satisfied is** \[ \xi^2 = \alpha \zeta \quad \text{Where Diffusivity } \alpha = k/\rho C_p \]

For Periodic Solution, \[ \zeta = P/(j2\pi) \]

i.e., \[ \xi^2 = \kappa \cdot (P/(j2\pi)) \]

\[ \frac{x}{\xi} = \frac{x}{\pm(\kappa P/j2\pi)^{1/2}} = \pm (i + j) \left( \frac{\pi \rho c_p x^2}{\lambda P} \right)^{1/2} = \pm (1 + j) \beta x \quad \rightarrow 3.7 \]

Where, \( \beta = \sqrt{\pi \rho c_p / \lambda P} \)

**Solution to the Fourier Equation is**, \[ T(x, t) = [A' \exp(\beta x + j \beta x) + B' \exp(-\beta x - j \beta x)] \exp(j2\pi t/P) \quad \rightarrow 3.8 \]

\[ = [A \sinh(\beta x + j \beta x) + B \cosh(\beta x + j \beta x)] \exp(j2\pi t/P) \quad \rightarrow 3.9 \]

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\[ T_0 = T_1 \cosh(z + jz) + q_1 \left( \frac{\sinh(z + jz)}{a} \right) \]

\[ q_0 = T_1 \left( \frac{\sinh(z + jz)}{a} \right) \times a + q_1 \cosh(z + jz) \]

Arranging the above terms in the Matrix form i.e.,

\[
\begin{bmatrix}
T_0 \\
q_0
\end{bmatrix} =
\begin{bmatrix}
\cosh(z + jz) & \left( \frac{\sinh(z + jz)}{a} \right) \\
\left( \frac{\sinh(z + jz)}{a} \right) \times a & \cosh(z + jz)
\end{bmatrix}
\begin{bmatrix}
T_1 \\
q_1
\end{bmatrix}
\]

Where

\[ z^2 = \frac{\pi \rho c_p X^2}{\lambda P} = \frac{\pi cr}{P} \]

\[ a^2 = j2\pi\lambda \rho c_p / P = j2\pi c/rP \]

\[ z = \text{Cyclic thickness of the slab, dimensionless but effectively in radians} \]

\[ a = \text{Characteristic Admittance of slab in W/m}^2 \text{ K} \]
Values of Hyperbolic Functions in Cartesian form:

\[ \text{cosh}(z + jz) \]

Real
\[ \cosh(z) \cos(z) \]

Imaginary
\[ j \sinh(z) \sin(z) \]

\[ \text{sinh}(z + jz)/a \]

Real
\[ \frac{[\cosh(z) \sin(z) + \sinh(z) \cos(z)]}{(a\sqrt{2})} \]

Imaginary
\[ j \frac{[\cosh(z) \sin(z) - \sinh(z) \cos(z)]}{(a\sqrt{2})} \]

\[ \text{sinh}(z + jz).a \]

Real
\[ \frac{[-\cosh(z) \sin(z) + \sinh(z) \cos(z)]}{a\sqrt{2}} \]

Imaginary
\[ j \frac{[\cosh(z) \sin(z) + \sinh(z) \cos(z)]}{a\sqrt{2}} \]
Let,

\[ A = \cosh(z) \cos(z) \]
\[ B = \sinh(z) \sin(z) \]
\[ C = \frac{\cosh(z) \sin(z) + \sinh(z) \cos(z)}{\sqrt{2}} \]
\[ D = \frac{\cosh(z) \sin(z) - \sinh(z) \cos(z)}{\sqrt{2}} \]

Then the Matrix of a single layer has the form

\[
\begin{bmatrix}
A + jB & (C + jD)/a \\
(-D + jC).a & A + jB
\end{bmatrix}
\]
Fig. 3.5 SINGLE CAPACITY CIRCUIT

\[
\begin{bmatrix}
T_e \\
q_e
\end{bmatrix} = \begin{bmatrix} 1 & r_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} m_1 & m_2 \\ m_3 & m_1 \end{bmatrix} \begin{bmatrix} n_1 & n_2 \\ n_3 & n_1 \end{bmatrix} \cdots \begin{bmatrix} 1 & r_2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix}
T_i \\
q_i
\end{bmatrix}
\]

\[
\begin{bmatrix}
T_e \\
q_e
\end{bmatrix} = \begin{bmatrix} M_1 & M_2 \\ M_3 & M_4 \end{bmatrix} \begin{bmatrix}
T_i \\
q_i
\end{bmatrix}
\]

m, n are no.of layers of the wall
M1, M2, M3 and M4 are components of the matrix

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Unsteady state Thermal Characteristics of the wall (CIBSE., 2006):

**Thermal Admittance, \( Y \).**

\[
\gamma_c = \left( \frac{q_i}{\theta_i} \right)_{t_e=0} = -M_1/M_2
\]

\[
Y = |\gamma_c|
\]

**Decrement Factor, \( f \).**

\[
f_c = -\frac{1}{UM_2}
\]

\[
f = |f_c|
\]

**Decremental time lag, \( \phi \).**

\[
\phi = \frac{12}{\pi} \arctan \left( \frac{\text{Im}(f_c)}{\text{Re}(f_c)} \right)
\]
Surface Factor, $F_c$

$$F_c = 1 - r_1 y_c$$

Surface Factor Time lag, $\Psi$.

$$\Psi = \frac{12}{\pi} \arctan \left( \frac{\text{Im}(F_c)}{\text{Re}(F_c)} \right)$$

Areal Thermal heat capacity, $\chi$.

$$\chi = \frac{t}{2\pi} \left| \frac{M_4 - 1}{M_2} \right|$$

penetration length, $\sigma_L$.

$$\sigma_L = \sqrt{2\alpha/\omega}$$

Phase velocity of thermal heat wave, $v$.

$$v = \sqrt{2\alpha \omega}$$

Optimum wall thickness, $L_{opt}$.

$$L_{opt} = 1.18251\sigma_L$$

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GRAPHICAL USER INTERFACE
COMPUTER PROGRAM
For
Unsteady State Thermal Characteristics of Homogeneous & Composite Walls
A SOFTWARE FOR UNSTEADY STATE THERMAL CHARACTERISTICS OF THE WALL

By

S. SABOOR
(Research Scholar)

Under The Guidance of
Prof. T. P. ASHOK BABU

Department of Mechanical Engineering
National Institute of Technology Karnataka
Surathkal -575025

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4. RESULTS & DISCUSSIONS
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Building material</th>
<th>Code</th>
<th>( k ) (W/mK)</th>
<th>( \rho ) (kg/m³)</th>
<th>( C_p ) (J/kgK)</th>
<th>( \alpha ) (m²/s)</th>
<th>( \sigma_L ) (m)</th>
<th>( v ) (m/s)</th>
<th>( L_{opt} ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Laterite Stone*</td>
<td>BM1</td>
<td>1.369</td>
<td>1000</td>
<td>1926.1</td>
<td>7.11x10⁻⁷</td>
<td>0.139</td>
<td>1.016x10⁻⁵</td>
<td>0.165</td>
</tr>
<tr>
<td>2.</td>
<td>Burnt brick</td>
<td>BM2</td>
<td>0.811</td>
<td>1820</td>
<td>880</td>
<td>5.06x10⁻⁷</td>
<td>0.118</td>
<td>8.578x10⁻⁶</td>
<td>0.139</td>
</tr>
<tr>
<td>3.</td>
<td>Mud brick</td>
<td>BM3</td>
<td>0.75</td>
<td>1731</td>
<td>880</td>
<td>4.92x10⁻⁷</td>
<td>0.116</td>
<td>8.459x10⁻⁶</td>
<td>0.137</td>
</tr>
<tr>
<td>4.</td>
<td>Reinforced brick</td>
<td>BM4</td>
<td>1.10</td>
<td>1920</td>
<td>840</td>
<td>6.82x10⁻⁷</td>
<td>0.137</td>
<td>9.959x10⁻⁶</td>
<td>0.161</td>
</tr>
<tr>
<td>5.</td>
<td>Fly ash brick*</td>
<td>BM5</td>
<td>0.360</td>
<td>1700</td>
<td>857</td>
<td>2.47x10⁻⁷</td>
<td>0.082</td>
<td>5.993x10⁻⁶</td>
<td>0.097</td>
</tr>
<tr>
<td>6.</td>
<td>Saw dust</td>
<td>IM1</td>
<td>0.051</td>
<td>188</td>
<td>1000</td>
<td>2.71x10⁻⁷</td>
<td>0.086</td>
<td>6.278x10⁻⁶</td>
<td>0.102</td>
</tr>
<tr>
<td>7.</td>
<td>Rice husk</td>
<td>IM2</td>
<td>0.051</td>
<td>120</td>
<td>1000</td>
<td>4.25x10⁻⁷</td>
<td>0.102</td>
<td>7.862x10⁻⁶</td>
<td>0.127</td>
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<tr>
<td>8.</td>
<td>Coir board</td>
<td>IM3</td>
<td>0.038</td>
<td>97</td>
<td>1000</td>
<td>3.91x10⁻⁷</td>
<td>0.103</td>
<td>7.541x10⁻⁶</td>
<td>0.122</td>
</tr>
<tr>
<td>9.</td>
<td>Jute felt</td>
<td>IM4</td>
<td>0.042</td>
<td>291</td>
<td>880</td>
<td>1.64x10⁻⁷</td>
<td>0.067</td>
<td>4.883x10⁻⁶</td>
<td>0.079</td>
</tr>
<tr>
<td>10.</td>
<td>Jute fiber</td>
<td>IM5</td>
<td>0.067</td>
<td>329</td>
<td>1090</td>
<td>1.86x10⁻⁷</td>
<td>0.071</td>
<td>5.201x10⁻⁶</td>
<td>0.084</td>
</tr>
<tr>
<td>11.</td>
<td>Cement plaster</td>
<td>P</td>
<td>0.721</td>
<td>1762</td>
<td>840</td>
<td>4.87x10⁻⁷</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4.1: Thermal properties and Optimum thickness values of Building and Insulating materials

(* Experimentally calculated thermal properties)

Where,  \( k \) = Thermal conductivity,  \( \rho \) = Density,  \( C_p \) = Specific heat capacity,  \( \alpha \) = Thermal diffusivity,  \( \sigma_L \) = Penetration length,  \( v \) = Phase velocity of thermal heat wave,  \( L_{opt} \) = Optimum fabric thickness.

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<table>
<thead>
<tr>
<th>CODE</th>
<th>$U$ (W/m²K)</th>
<th>$f$</th>
<th>$\phi$ (h)</th>
<th>$Y$ (W/m²K)</th>
<th>$Y_{TL}$ (h)</th>
<th>$F$</th>
<th>$\Psi$ (h)</th>
<th>$\chi$ (J/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM1</td>
<td>3.165</td>
<td>0.563</td>
<td>5.44</td>
<td>5.26</td>
<td>1.12</td>
<td>0.398</td>
<td>1.99</td>
<td>79818</td>
</tr>
<tr>
<td>BM2</td>
<td>2.401</td>
<td>0.549</td>
<td>5.95</td>
<td>4.61</td>
<td>1.38</td>
<td>0.488</td>
<td>1.72</td>
<td>71789</td>
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<tr>
<td>BM3</td>
<td>2.29</td>
<td>0.554</td>
<td>5.95</td>
<td>4.48</td>
<td>1.43</td>
<td>0.505</td>
<td>1.67</td>
<td>69884</td>
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<tr>
<td>BM4</td>
<td>2.84</td>
<td>0.601</td>
<td><strong>5.26</strong></td>
<td>4.87</td>
<td>1.27</td>
<td>0.452</td>
<td>1.82</td>
<td>74096</td>
</tr>
<tr>
<td>BM5</td>
<td>1.37</td>
<td>0.401</td>
<td><strong>8.15</strong></td>
<td>3.72</td>
<td>1.69</td>
<td>0.599</td>
<td><strong>1.34</strong></td>
<td>57782</td>
</tr>
<tr>
<td>IM1</td>
<td>0.244</td>
<td>0.610</td>
<td>6.17</td>
<td>0.774</td>
<td>2.79</td>
<td>0.927</td>
<td>0.276</td>
<td>12172</td>
</tr>
<tr>
<td>IM2</td>
<td>0.244</td>
<td><strong>0.779</strong></td>
<td><strong>4.30</strong></td>
<td>0.605</td>
<td>2.88</td>
<td>0.944</td>
<td>0.218</td>
<td>9465</td>
</tr>
<tr>
<td>IM3</td>
<td>0.184</td>
<td>0.760</td>
<td>4.53</td>
<td>0.48</td>
<td>2.93</td>
<td><strong>0.956</strong></td>
<td><strong>0.173</strong></td>
<td>7539</td>
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<tr>
<td>IM4</td>
<td>0.202</td>
<td><strong>0.400</strong></td>
<td><strong>8.75</strong></td>
<td>0.819</td>
<td>2.71</td>
<td>0.922</td>
<td>0.288</td>
<td>12372</td>
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<tr>
<td>IM5</td>
<td>0.316</td>
<td>0.438</td>
<td>8.20</td>
<td>1.178</td>
<td>2.59</td>
<td><strong>0.886</strong></td>
<td><strong>0.415</strong></td>
<td>18030</td>
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</tbody>
</table>

**Table 4.2: Unsteady state thermal characteristics of Building and Insulating materials**

Where, $Y =$ Thermal Admittance, $f =$ Decrement Factor, $\phi =$ Time lag, $F =$ Surface Factor, $\Psi =$ Surface Factor Time lag and $\chi =$ Areal Thermal heat capacity.

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### Table 4.3: Composite wall configuration and Thickness

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Configuration</th>
<th>Thickness of the wall from outside to inside (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>A</td>
<td>0.015P+0.2BM+0.015P</td>
</tr>
<tr>
<td>2.</td>
<td>B</td>
<td>0.015P+0.02IM+0.2BM+0.015P</td>
</tr>
<tr>
<td>3.</td>
<td>C</td>
<td>0.015P+0.1BM+0.02IM+0.1BM+0.015P</td>
</tr>
<tr>
<td>4.</td>
<td>D</td>
<td>0.015P+0.2BM+0.02IM+0.015P</td>
</tr>
</tbody>
</table>

**Figure 4.1: Configurations of Composite walls**

**BM: Building Material  IM: Insulating Material  P: Plaster**

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Figure 4.2: Optimum fabric thickness of building and insulating materials
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Figure 4.3: Decrement factor and time lag of building materials

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Figure 4.4: Decrement factor and time lag of insulating materials

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Figure 4.5: Surface factor and it’s time lag of building and insulating materials

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Figure 4.6: Effect of insulation location on decrement factor and its time lag of BM1
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Figure 4.7: Effect of insulation location on decrement factor and it’s time lag of BM2

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Figure 4.8: Effect of insulation location on decrement factor and it’s time lag of BM3
Figure 4.9: Effect of insulation location on decrement factor and it’s time lag of BM4

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Figure 4.10: Effect of insulation location on decrement factor and it’s time lag of BM5
5. CONCLUSIONS
The composite wall with insulation placed at the mid centre plane of the wall and insulation placed at outer surface of the wall are the recommended composite walls for higher time lag and lower decrement values respectively.

Fly ash brick with the jute felt insulation located at the mid centre plane of the wall and fly ash brick with the coir board insulation located at the outer surface are the recommended combinations for higher time lag and lower decrement factors respectively.
Decrement factors of the fly ash brick (0.4) and jute felt (0.4) are the least among all the studied building and insulating materials, respectively. Time lags of the fly ash bricks (8.15h) and jute felt (8.75h) are the highest among all the studied building and insulating materials. Hence these two materials are more effective at suppressing temperature swings.

From the results it is observed that, Building materials are slow responsive to short wave radiation due to their lower surface factors and higher surface factor time lags whereas insulating materials are fast responsive to short wave radiation due to their higher surface factors and lower surface factor time lags. Hence the insulating materials should not be exposed to short wave radiation.

Among all the studied building and insulating materials, Fly ash bricks and jute felt can store large amount of heat energy at smaller wall thickness. Hence they are recommended for energy and material savings.
6. REFERENCES
REFERENCES:


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Go Green

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