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3416

Investigation of Dynamic Thermal Parameters of Various Insulation Filled Bricks Exposed to Periodic Thermal Variations for Energy Efficient Stuffed Bricks Design

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CONTENTS

1. INTRODUCTION

Fig.1.1 YEARLY GLOBAL WARMING

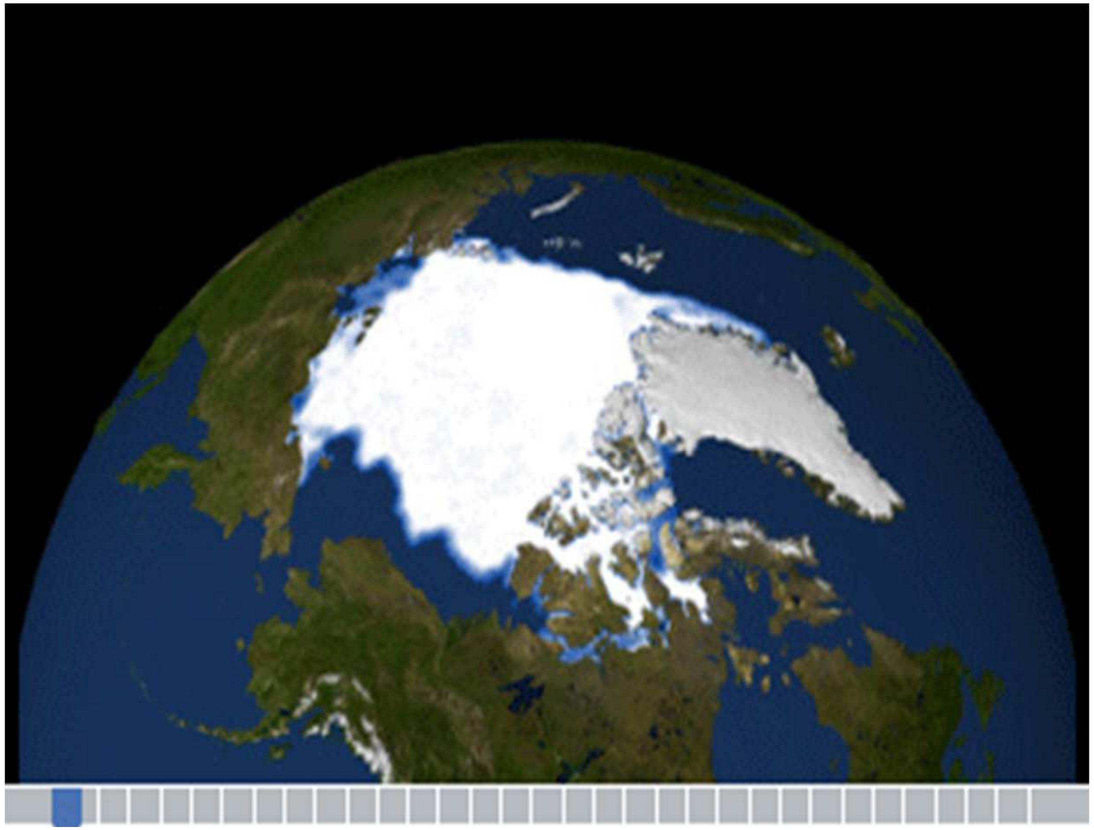


Fig.1.2 ICE MELTING IN ARCTIC CIRCLE

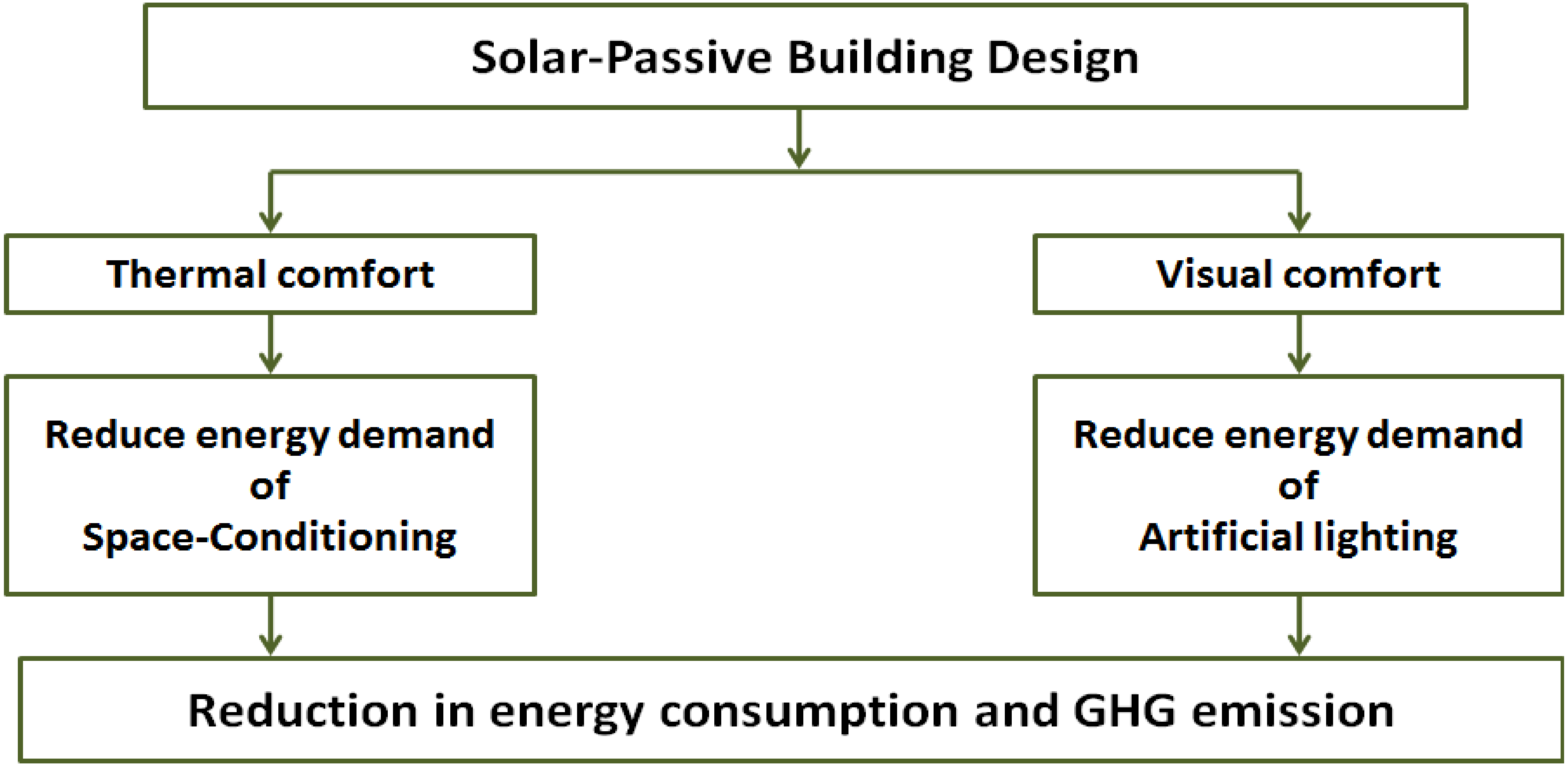


Fig.1.3 Solar Passive Building Design Elements

2. OBJECTIVES

1. **ENERGY EFFICIENT STUFFED BRICK AND INSULATION MATERIALS.**

2. **UNSTEADY STATE THERMAL CHARACTERISTICS OF FIVE BRICK MATERIALS.**

3. **THE EFFECT OF INSULATION FILLS IN STUFFED BRICKS ON UNSTEADY STATE THERMAL CHARACTERISTICS.**

4. **OPTIMUM INSULATION LAYERS IN STUFFED BRICKS**

3. UNSTEADY THERMAL RESPONSE CHARACTERISTICS & CYCLIC ADMITTANCE PROCEDURE

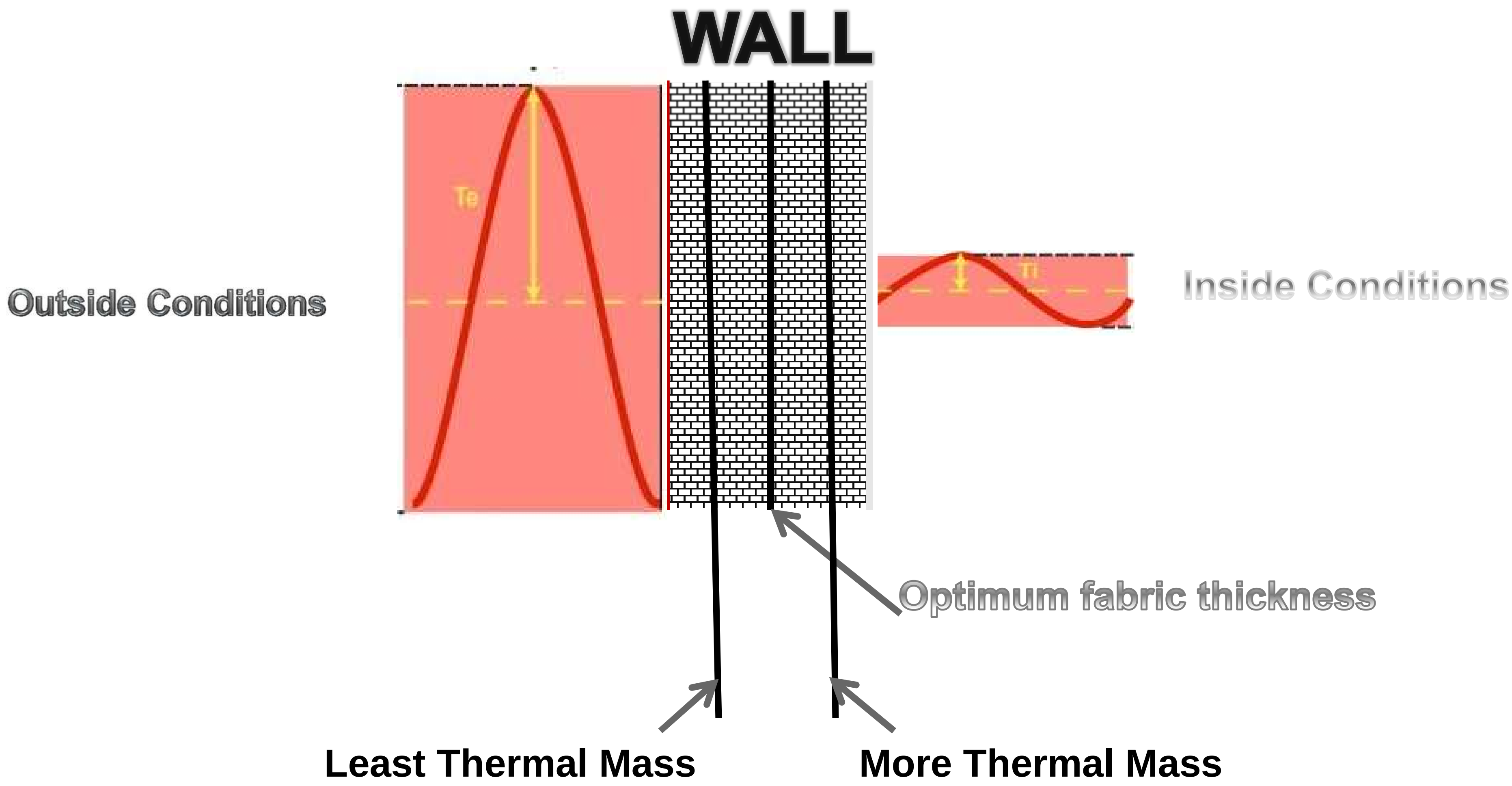
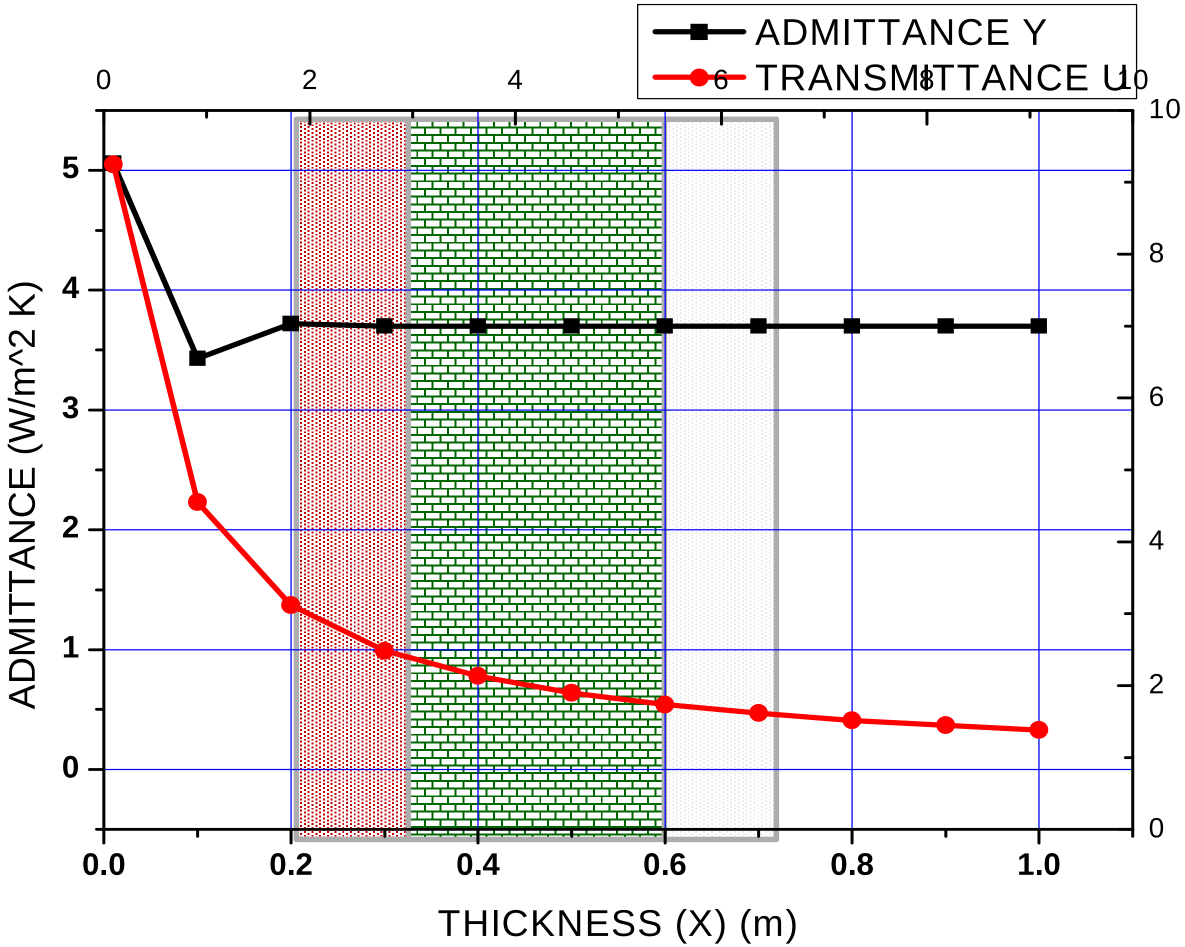


Fig. 3.1 THERMAL MASS

THERMAL INSULATION AND THERMAL MASS



- **THERMAL TRANSMITTANCE (U)**
- **THERMAL ADMITTANCE (Y)**

Fig. 3.2 THERMAL TRANSMITTANCE AND ADMITTANCE

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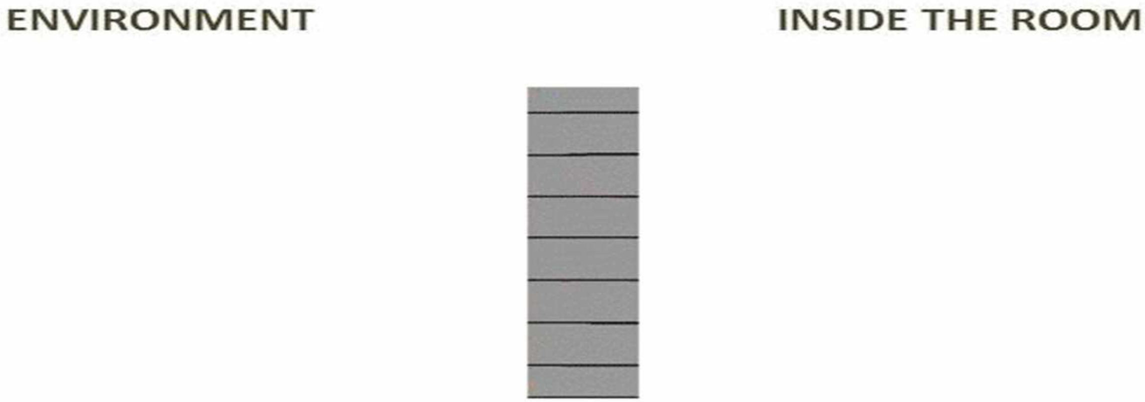

Fig. 3.3 DECREMENT FACTOR AND TIME LAG

- **Decrement Factor**
- **Decremental Time lag (6-12 h)**

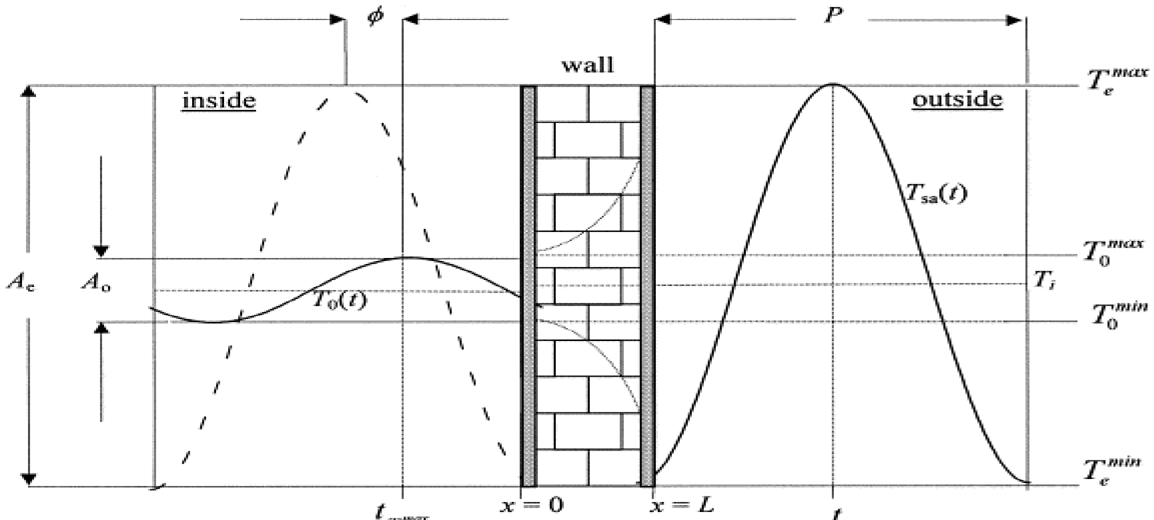

Fig. 3.4 THE SCHEMATIC REPERESENTATION OF TIME LAG AND DECREMENT FACTOR

One Dimensional Diffusion Equation:

$$\frac{\partial^2 T(X,t)}{\partial X^2} = \frac{\rho Cp}{k}\frac{\partial T(X,t)}{\partial t} \longrightarrow \textbf{3.1}$$

With Boundary Conditions:

$$k\left(\frac{\partial T}{\partial x}\right)_{x=0} = h_i[T_{x=0}(t) - T_i] \longrightarrow \textbf{3.2}$$

$$k\left(\frac{\partial T}{\partial x}\right)_{x=L} = h_0[T_{Sa}(t) - T_{x=L}(t)] \longrightarrow \textbf{3.3}$$

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

$$T(x,t) = A\exp(x/\xi)\exp(t/\zeta) \quad (3.4)$$

ξ and ζ are properties of system, they have units of distance and time respectively

The above equation Satisfies the Fourier equation if ,

$$\xi^2 = \kappa\zeta \quad (3.5)$$

Value of ζ leads to different solutions

If ζ 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 ζ is an imaginary number and equal to P/(j2π) (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)

$$\mathbf{T(x,t) = Aexp(x/\xi)exp(t/\zeta)}$$

Condition to be satisfied is $\xi^2 = \alpha\,\zeta$ $\quad$ *Where Diffusivity* $\alpha, = k/\rho Cp$

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

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

$$\frac{x}{\xi} = \frac{x}{\pm(\kappa P/j2\pi)^{1/2}} = \pm(i+j)\left(\frac{\pi\rho c_p x^2}{\lambda P}\right)^{1/2} \rightarrow \quad 3.6$$

$$= \pm(1+j)\beta x$$

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

Solution to the fourier Equation is ,

$$T(x,t) = [A' exp(\beta x + j\beta x) + B' exp(-\beta x - j\beta x)]exp(j2\pi t/P) \rightarrow \quad 3.7$$

$$= [Asinh(\beta x + j\beta x) + Bcosh(\beta x + j\beta x)]exp(j2\pi t/P) \rightarrow \quad 3.8$$

$$\mathbf{T_0 = T_1 \cosh(z + jz) + q_1 \left(\sinh(z + jz)\right)/a} \quad (3.9)$$

$$\mathbf{q_0 = T_1 \left(\sinh(z + jz)\right) \times a + q_1 \cosh(z + jz)} \quad (3.10)$$

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

$$\begin{bmatrix} \mathbf{T_0} \\ \mathbf{q_0} \end{bmatrix} = \begin{bmatrix} \mathbf{\cosh(z + jz)} & \mathbf{\left(\sinh(z + jz)\right)/a} \\ \mathbf{\left(\sinh(z + jz)\right) \times a} & \mathbf{\cosh(z + jz)} \end{bmatrix} \begin{bmatrix} \mathbf{T_1} \\ \mathbf{q_1} \end{bmatrix} \quad (3.11)$$

Where

$z^2 = \pi \rho c_p X^2 / \lambda P = \pi c r / P$ $\quad$ $\mathbf{a^2 = j2\pi\lambda\rho c_p / P = j2\pi c / rP}$

z= Cyclic thickness of the slab, dimensionless but effectively in radians

a= Characteristic Admittance of slab in W/m^2 K

Values of Hyperbolic Functions in Cartesian form:

$$\underline{\boldsymbol{cosh(z+jz)}}$$

Real $\boldsymbol{cosh(z)\,cos(z)}$

Imaginary $\mathbf{j}\,\boldsymbol{sinh(z)\,sin(z)}$

$$\underline{\mathbf{sin}\boldsymbol{h(z+jz)}/\mathbf{a}}$$

Real $\mathbf{[cosh(z)\,sin(z)+sinh(z)\,cos(z)]/(a\sqrt{2})}$

Imaginary $\mathbf{j\,[cosh(z)\,sin(z)-sinh(z)\,cos(z)]/(a\sqrt{2})}$

$$\underline{\mathbf{sin}\boldsymbol{h(z+jz)}\mathbf{.\,a}}$$

Real $\mathbf{[-\,cosh(z)\,sin(z)+sinh(z)\,cos(z)].\,a/\sqrt{2}}$

Imaginary $\mathbf{j\,[cosh(z)\,sin(z)+sinh(z)\,cos(z)].\,a/\sqrt{2}}$

Let,

$$\boldsymbol{A = cosh(z)\,cos(z)} \quad \text{(3.12)}$$

$$\boldsymbol{B = sinh(z)\,sin(z)} \quad \text{(3.13)}$$

$$\boldsymbol{C = [cosh(z)\,sin(z) + sinh(z)\,cos(z)]/(\sqrt{2})} \quad \text{(3.14)}$$

$$\boldsymbol{D = [cosh(z)\,sin(z) - sinh(z)\,cos(z)]/(\sqrt{2})} \quad \text{(3.15)}$$

Then The Matrix of a single layer has the form

$$\begin{bmatrix} \mathbf{A + jB} & \mathbf{(C + jD)/a} \\ \mathbf{(-D + jC).\,a} & \mathbf{A + jB} \end{bmatrix} \quad \text{(3.16)}$$

Outside Conditions | Inside Conditions

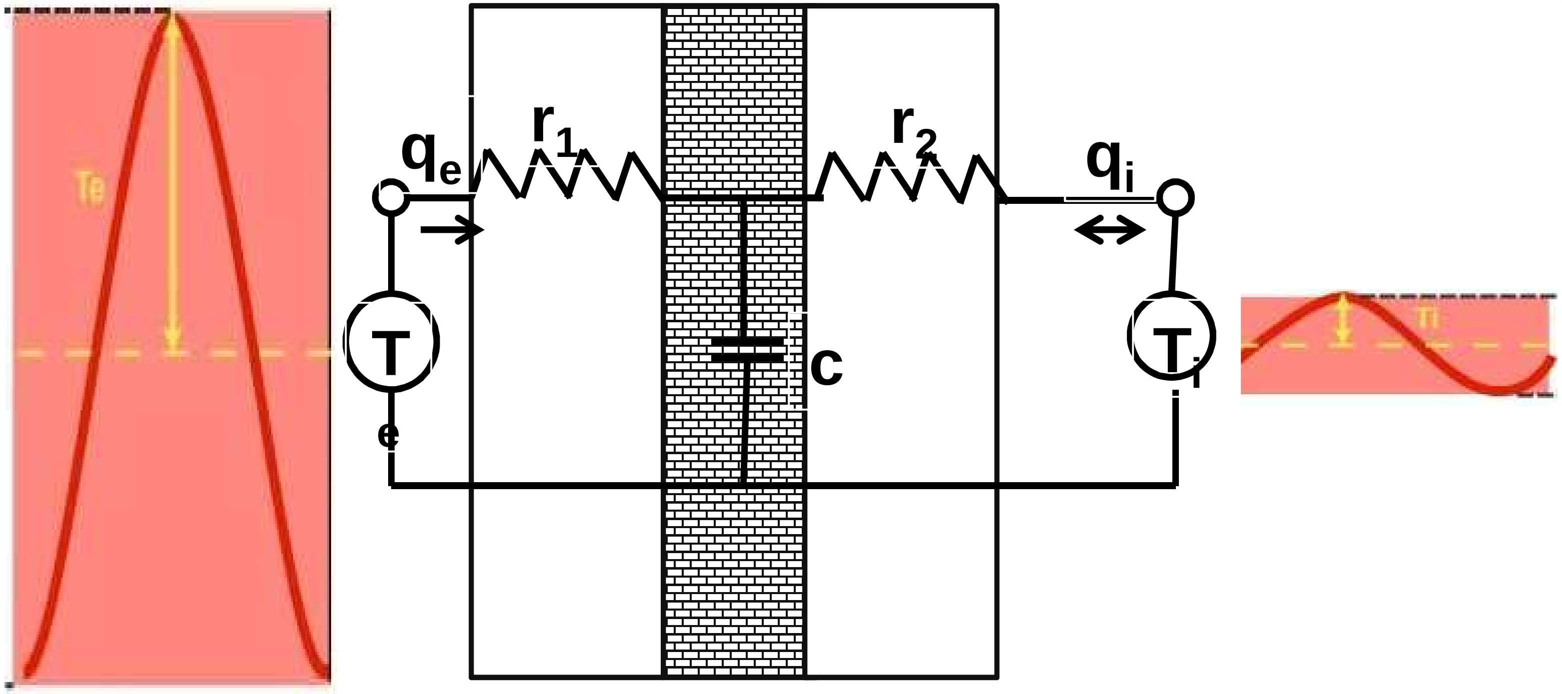

Fig. 3.5 SINGLE CAPACITY CIRCUIT

$$\begin{bmatrix} T_e \\ q_e \end{bmatrix} = \begin{bmatrix} 1 & r_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} m_1 & m_2 \\ m_3 & m_1 \end{bmatrix} \begin{bmatrix} n_1 & n_2 \\ n_3 & n_1 \end{bmatrix} \dots . \begin{bmatrix} 1 & r_2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} T_i \\ q_i \end{bmatrix} \quad (3.17)$$

$$\begin{bmatrix} T_e \\ q_e \end{bmatrix} = \begin{bmatrix} M_1 & M_2 \\ M_3 & M_4 \end{bmatrix} \begin{bmatrix} T_i \\ q_i \end{bmatrix} \quad (3.18)$$

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

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

Thermal Admittance, Y.

$$y_c = \left(\frac{q_i}{\theta i}\right)_{T_{e=0}} = -M1/M2 \quad \rightarrow \quad (3.19)$$

$$Y = |y_c| \quad \rightarrow \quad (3.20)$$

Decrement Factor, f.

$$f_c = -\frac{1}{UM_2} \quad \rightarrow \quad (3.21)$$

$$f = |f_c| \quad \rightarrow \quad (3.22)$$

Decremental time lag, ϕ.

$$\phi = \frac{12}{\pi} arctan\left(\frac{Im(f_c)}{Re(f_c)}\right) \quad \rightarrow \quad (3.23)$$

Areal Thermal heat capacity, χ.

$$\chi = \frac{t}{2\pi}\left|\frac{M_4 - 1}{M_2}\right| \quad \rightarrow \quad (3.24)$$

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
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4. THERMAL PERFORMANCE OF STUFFED BRICKS EXPOSED TO SINUSOIDAL SOLAR THERMAL EXCITATION

Table 4.1 Thermo physical properties of the brick materials

Brick material	Code	k	ρ	Cp
Mud brick	B-1 (MB)	0.75	1731	880
Burnt brick	B-2 (BB)	0.811	1820	880
Concrete block	B-3 (CB)	1.74	2410	880
Fly ash brick	B-4 (FAB)	0.360	1700	857
Foam glass	I-1 (FG)	0.055	160	750
Asbestos fiber	1-2 (AF)	0.06	640	840

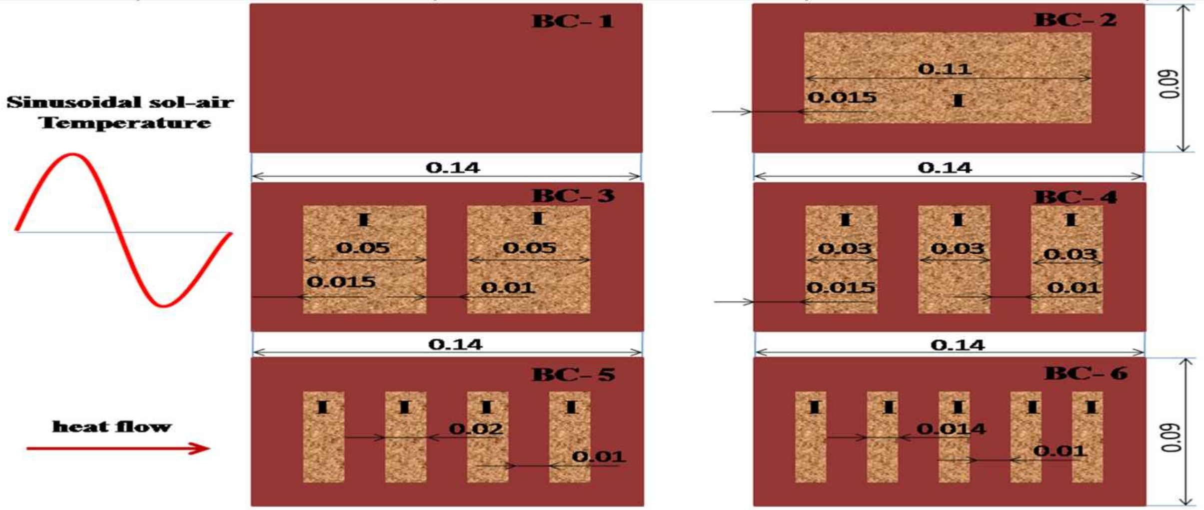


Figure 4.1 Configurations of the bricks (All dimensions are in "m")

Table 4.2 Mud brick with foam glass insulation material

MB with FG Configuration	U (W/m^{2}K)	f	ϕ (h)	Y (W/m^{2}K)	ω (h)	χ (J/m^{2}K)
BC-1	2.8048	0.75336	3.9118	4.2737	1.4119	60797
BC-2	0.4525	0.9386	2.5657	1.8469	4.0568	29867
BC-3	0.4899	0.7764	4.0927	1.9555	3.7253	33034
BC-4	0.5339	0.7019	5.0626	2.1046	3.4474	36459
BC-5	0.5867	0.6519	5.7125	2.2575	3.2165	39883
BC-6	0.6511	0.6184	6.1351	2.4142	3.0153	43478

Table 4.3 Burnt brick with foam glass insulation material

BB with FG Configuration	U (W/m^{2}K)	f	ϕ (h)	Y (W/m^{2}K)	ω (h)	χ (J/m^{2}K)
BC-1	2.9197	0.74693	3.9355	4.4045	1.3641	62491
BC-2	0.4531	0.9362	2.6091	1.9177	4.0603	31051
BC-3	0.4908	0.7644	4.2029	2.0250	3.7233	34235
BC-4	0.5354	0.6865	5.2147	2.1742	3.4395	37688
BC-5	0.5888	0.6349	5.8896	2.3278	3.2043	41151
BC-6	0.6541	0.6006	6.3261	2.4858	2.9999	44809

Table 4.4 Concrete brick with foam glass insulation material

CB with FG Configuration	U (W/m^{2}K)	f	ϕ (h)	Y (W/m^{2}K)	ω (h)	χ (J/m^{2}K)
BC-1	3.9947	0.73609	3.6727	5.3355	0.98347	70521
BC-2	0.4572	0.9196	2.8710	2.3803	4.0335	38878
BC-3	0.4973	0.6877	4.8589	2.4692	3.6794	41928
BC-4	0.5450	0.5921	6.1191	2.6108	3.3733	45397
BC-5	0.6028	0.5342	6.9372	2.7634	3.1219	49033
BC-6	0.6744	0.4987	7.4480	2.9257	2.9038	53053

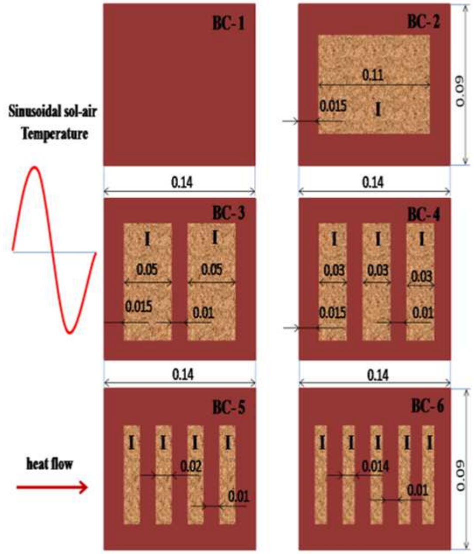


Table 4.5 Fly ash brick with foam glass insulation material

FAB with FG Configuration	U (W/m²K)	f	ϕ (h)	Y (W/m²K)	ω (h)	χ (J/m²K)
BC-1	1.7897	0.6400	5.34	3.6448	1.764	56658
BC-2	0.4438	0.9344	2.6821	1.7703	4.0152	28722
BC-3	0.4764	0.7760	4.1785	1.8725	3.6895	31644
BC-4	0.5141	0.6990	5.1548	2.0099	3.4177	34747
BC-5	0.5583	0.6448	5.8348	2.1480	3.1928	37764
BC-6	0.6109	0.6060	6.3065	2.2865	2.9984	40839

Table 4.6 Mud brick with asbestos fiber insulation material

MB with AF Configuration	U (W/m²K)	f	ϕ (h)	Y (W/m²K)	ω (h)	χ (J/m²K)
BC-1	2.8048	0.7533	3.9118	4.2737	1.4119	60797
BC-2	0.4894	0.6513	6.3317	2.4181	3.3967	41956
BC-3	0.5291	0.5658	6.7176	2.3838	3.2561	41452
BC-4	0.5759	0.5377	7.0252	2.4437	3.0710	43079
BC-5	0.6316	0.5270	7.1740	2.5391	2.9136	45498
BC-6	0.6994	0.5255	7.1997	2.6534	2.7718	48446

Table 4.7 Burnt brick with asbestos fiber insulation material

BB with AF Configuration	U (W/m²K)	f	ϕ (h)	Y (W/m²K)	ω (h)	χ (J/m²K)
BC-1	2.9197	0.7469	3.9355	4.4045	1.3641	62491.44
BC-2	0.4901	0.6504	6.3650	2.4806	3.4052	43053
BC-3	0.5303	0.5584	6.7915	2.4429	3.2632	42468
BC-4	0.5775	0.5275	7.1358	2.5027	3.0729	44115
BC-5	0.6340	0.5150	7.3104	2.5999	2.9103	46599
BC-6	0.7028	0.5123	7.3535	2.7168	2.7639	49643

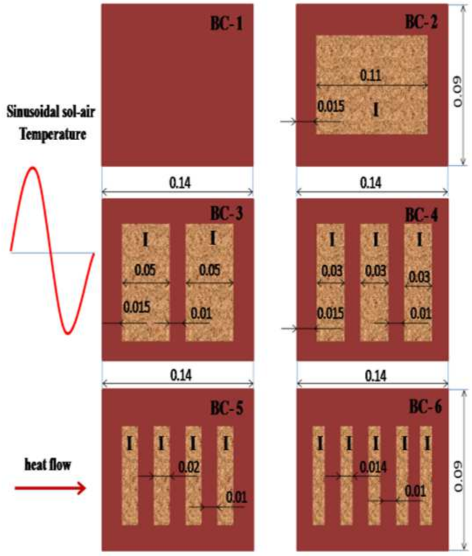


Table 4.8 Concrete brick with asbestos fibre insulation material

CB with AF Configuration	U (W/m^2K)	f	ϕ (h)	Y (W/m^2K)	ω (h)	χ (J/m^2K)
BC-1	3.9947	0.73609	3.6727	5.3355	0.98347	70521
BC-2	0.4949	0.6435	6.5613	2.8919	3.4254	50411
BC-3	0.5378	0.5123	7.2328	2.8303	3.2819	49238
BC-4	0.5887	0.4653	7.8014	2.8848	3.0674	50929
BC-5	0.6503	0.4441	8.1286	2.9887	2.8795	53766
BC-6	0.7263	0.4359	8.2666	3.1181	2.7090	57366

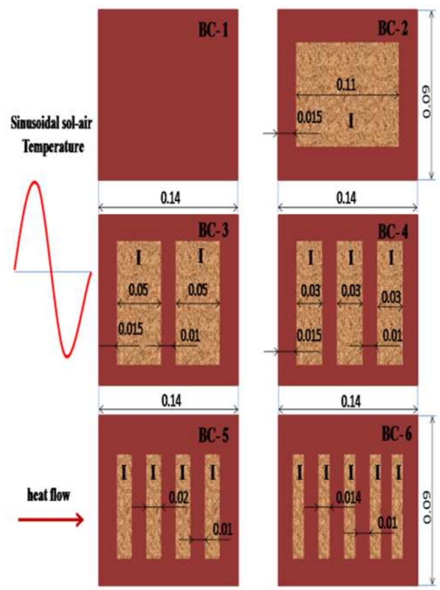
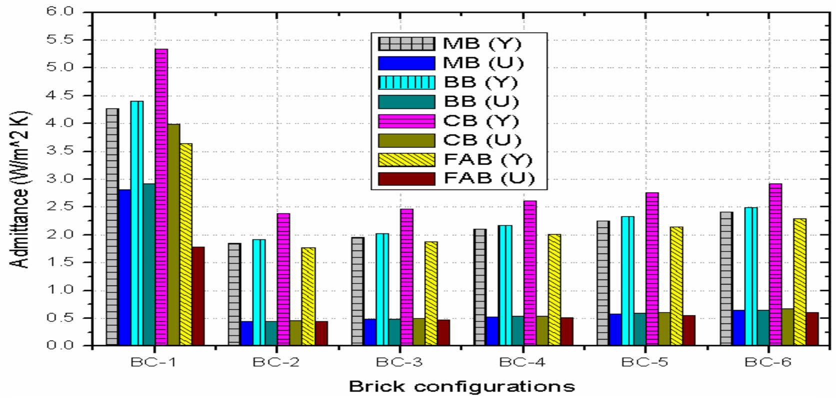
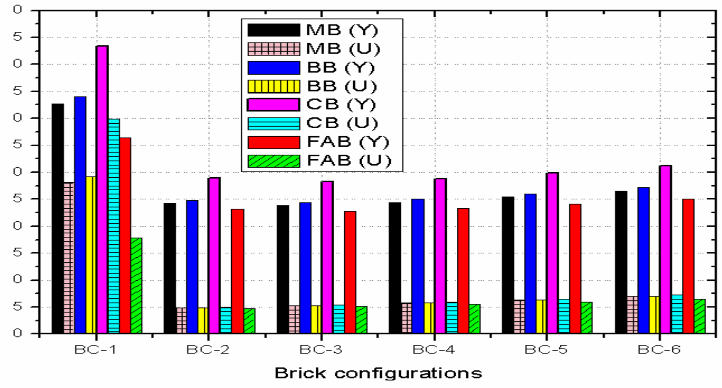
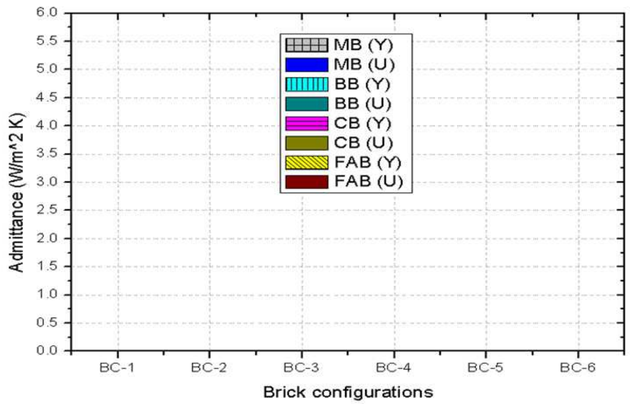


Table 4.9 Fly ash brick with asbestos fibre insulation material

FAB with AF Configuration	U (W/m^2K)	f	ϕ (h)	Y (W/m^2K)	ω (h)	χ (J/m^2K)
BC-1	1.7897	0.6400	5.34	3.6448	1.764	56658
BC-2	0.4793	0.6341	6.5313	2.3147	3.3238	40125
BC-3	0.5134	0.5548	6.9026	2.2827	3.1949	39608
BC-4	0.5529	0.5257	7.2138	2.3331	3.0231	40934
BC-5	0.5988	0.5119	7.3887	2.4137	2.8770	42917
BC-6	0.6532	0.5060	7.4591	2.5093	2.7461	45296







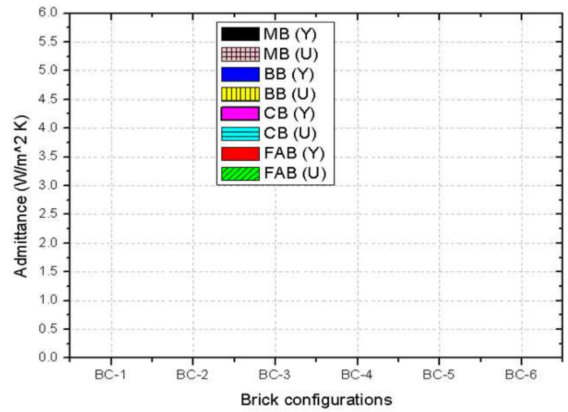


Figure 4.2 Admittance and Transmittance of insulated bricks with foam glass insulation

CB with FG (Y)=2.9257 W/m^{2}K for BC-6

FAB with FG (Y)=2.28 W/m^{2}K for BC-6

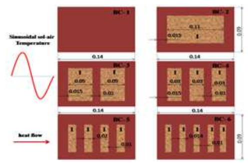
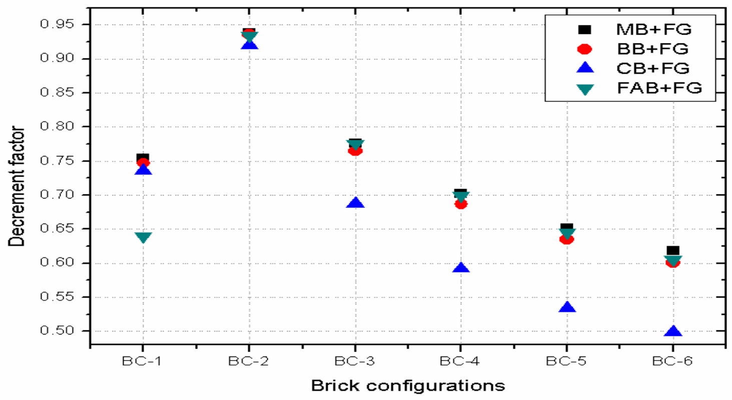
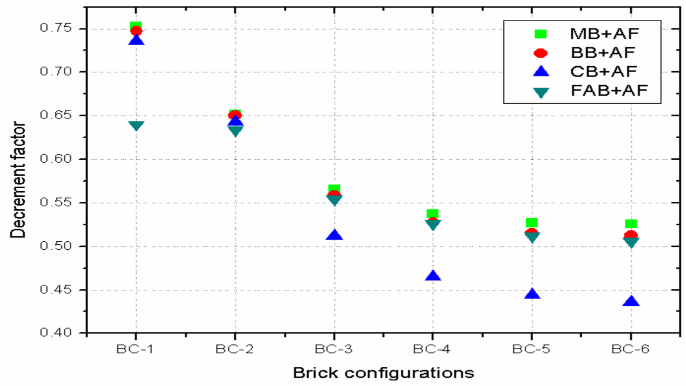


Figure 4.3 Admittance and Transmittance of insulated bricks with asbestos fiber insulation

CB with AF (Y)=3.1181 W/m^{2}K for BC-6

FAB with AF (Y)=2.50 W/m^{2}K for BC-6





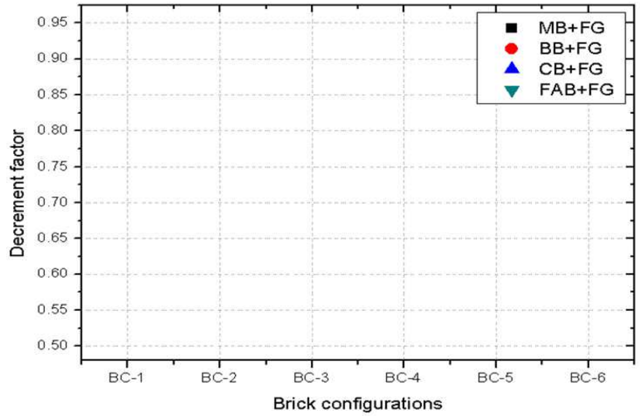
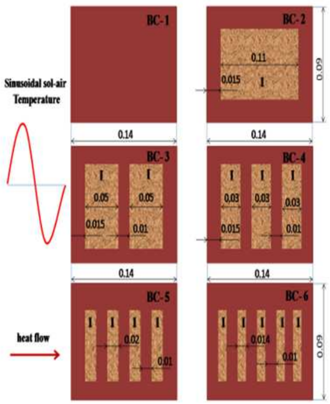


Figure 4.4 Decrement factor of insulated bricks with foam glass insulation

CB with FG (f)= 0.4987 for BC-6

MB with FG (f)=0.6184 for BC-6



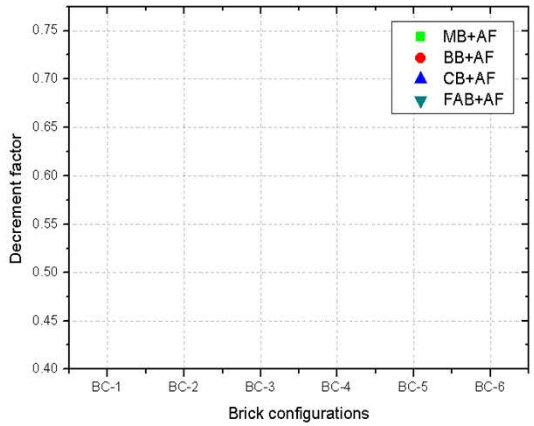
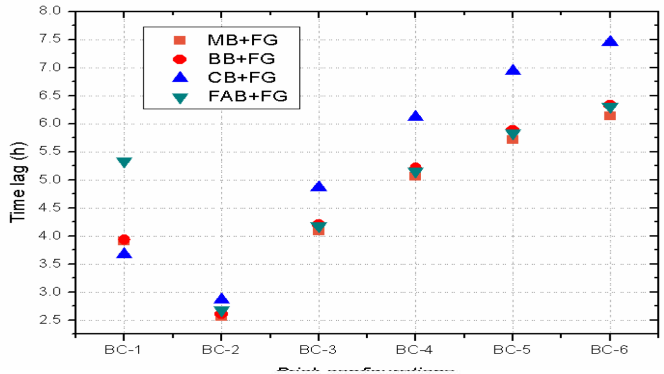
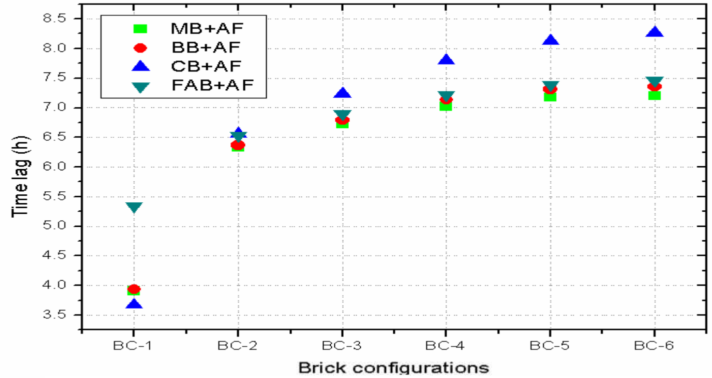


Figure 4.5 Decrement factor of insulated bricks with asbestos fibre insulation

CB with AF (f)= 0.4359 for BC-6

MB with AF (f)=0.525 for BC-6





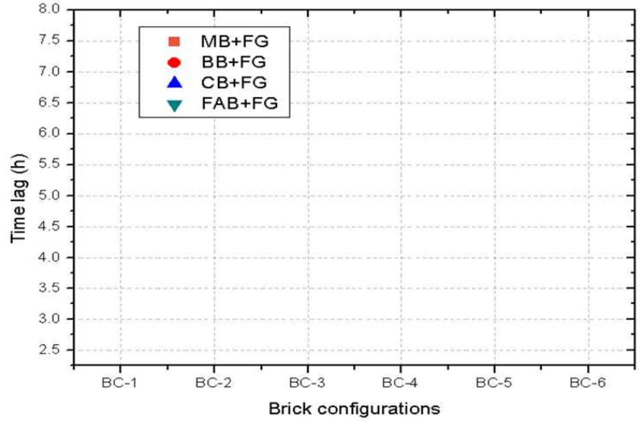
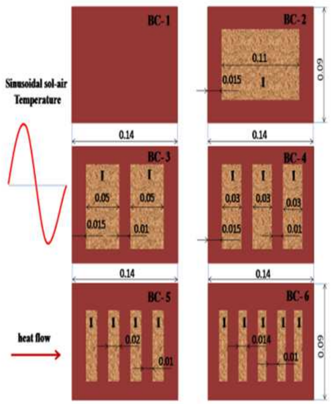


Figure 4.6 Time lag of insulated bricks with foam glass insulation

CB with FG (ϕ)= 7.44 h for BC-6

MB with FG (ϕ)=6.13 h for BC-6



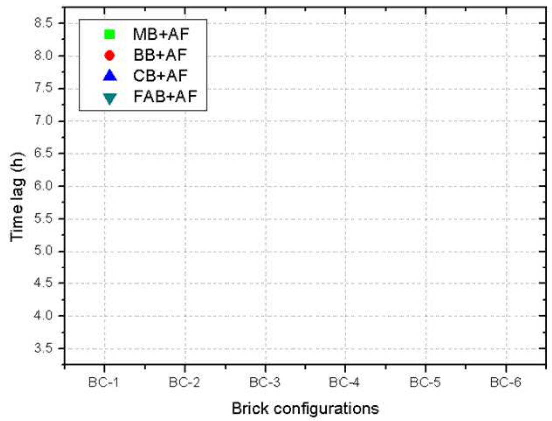


Figure 4.7 Time lag of insulated bricks with asbestos fiber insulation

CB with AF (ϕ)= 8.26 h for BC-6

MB with AF (ϕ)=7.19 h for BC-6

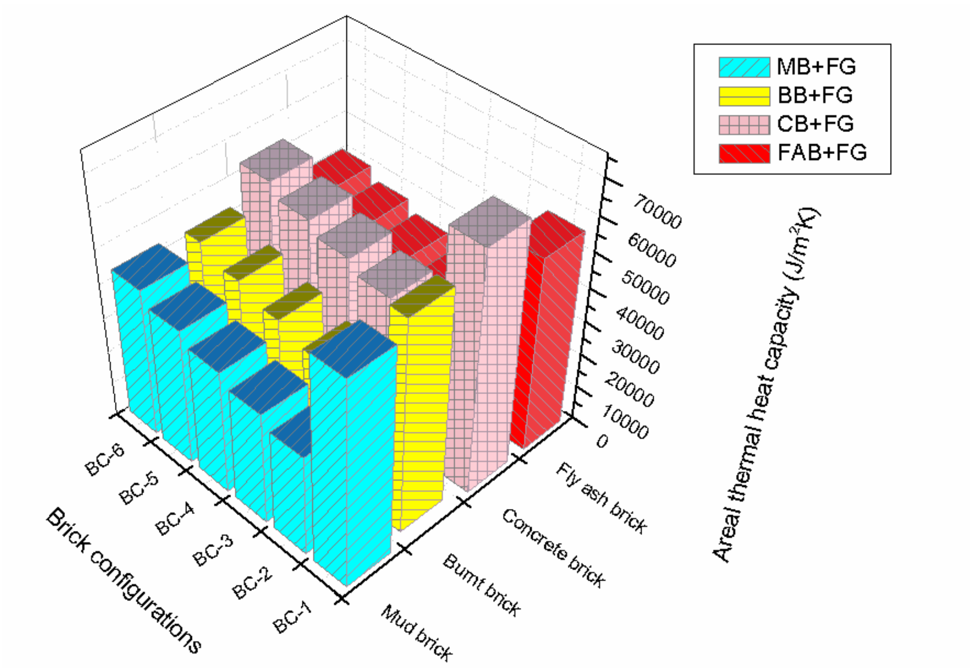


Figure 4.8 Areal thermal capacity of insulated bricks with foam glass insulation

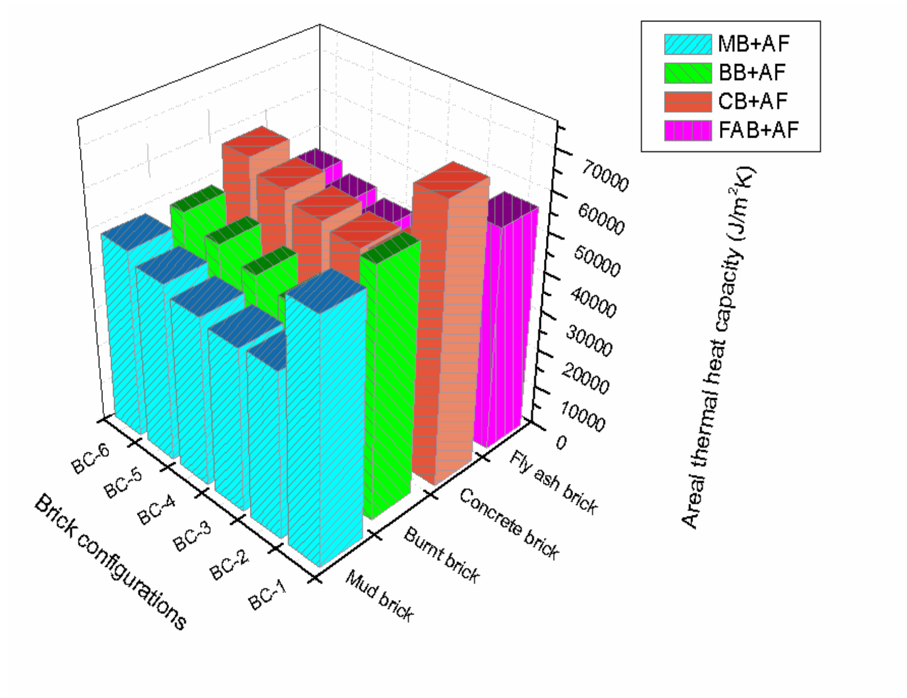
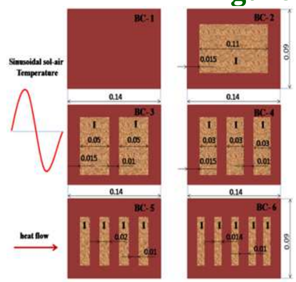


Figure 4.9 Areal thermal capacity of insulated bricks With asbestos fiber insulation



CB with FG (χ)= 53053 J/m^{2}K for BC-6

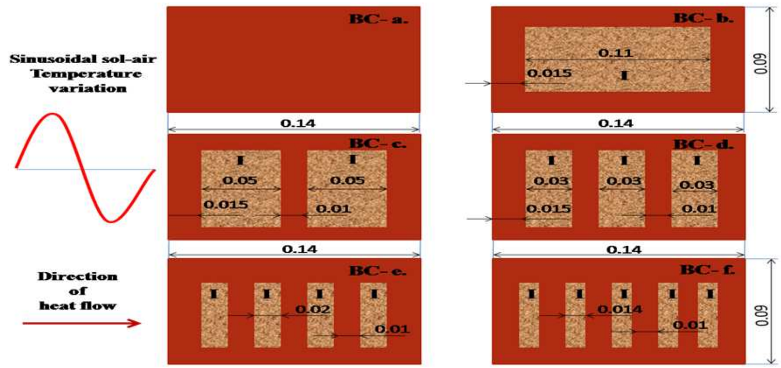
FAB with FG (χ)=40839 J/m^{2}K for BC-6

CB with AF (χ)= 57366 J/m^{2}K for BC-6

FAB with AF (χ)=45296 J/m^{2}K for BC-6

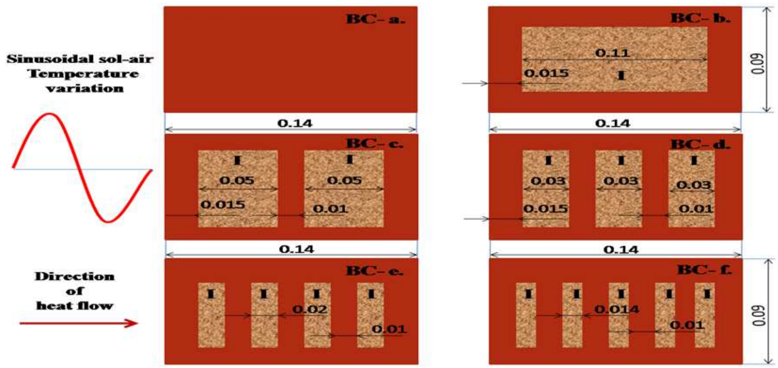
5. CONCLUSION

The thermal admittance, decrement time lag and areal thermal heat capacity of the insulation filled bricks increase with the increase in the number of insulation layers in the bricks due to improved thermal mass. These enhanced dynamic parameters make the stuffed bricks more energy efficient than the ordinary solid bricks.



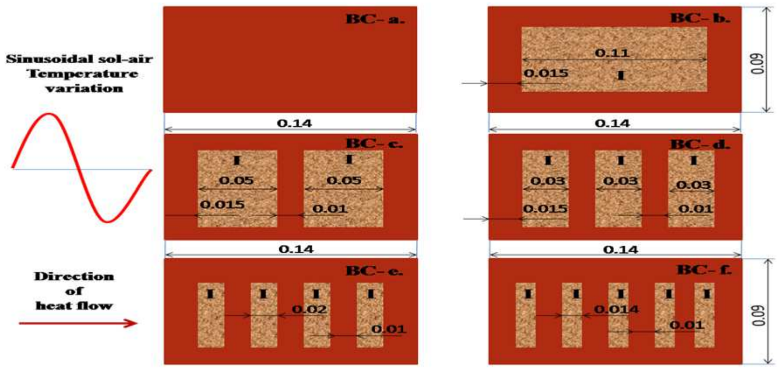
The decrement factor of the insulation filled bricks decreases with the increase in the number of insulation layers in the bricks. The lower decrement factor values are essential to reduce the effect of outdoor climatic changes on indoor conditions.

The concrete blocks with the shell of the bricks filled with five layers of asbestos fiber insulation offer the highest admittance (3.11W/m^{2}K), the lowest decrement factor (0.435), the highest time lag values (8.26 h) and the highest areal thermal heat capacity (57366 J/m^{2}K) among all insulation filled bricks studied.



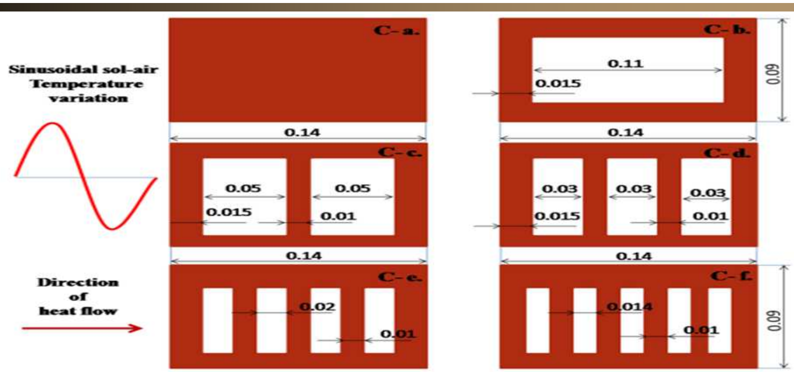
Stuffed bricks with five foam glass insulation layers (BC-6) decrease the decrement factor of mud bricks, burnt bricks, dense concrete bricks and fly ash bricks by 17.91%, 35.84%, 45.76% and 35.14%, respectively as compared to the stuffed bricks with single foam glass insulation layer (BC-2).

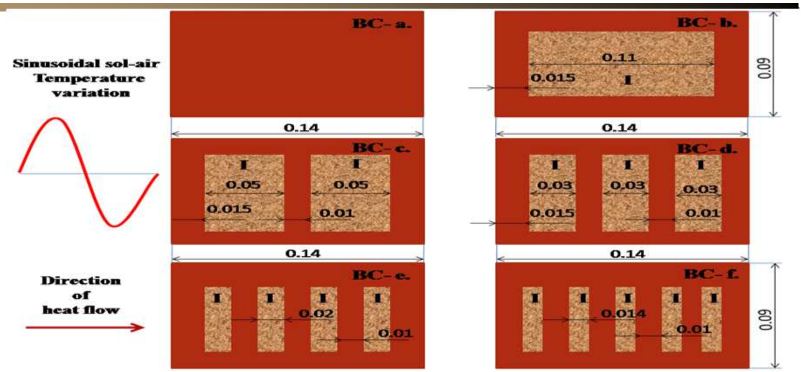
Stuffed bricks with five foam glass insulation layers (BC-6) increase the time lag of mud bricks, burnt bricks, dense concrete bricks and fly ash bricks by 36.23%, 58.75%, 61.45% and 57.47%, respectively as compared to the stuffed bricks with single foam glass insulation layer (BC-2).



In hot regions, the wall thermal transmittance should be as low as possible and the wall admittance should be as high as possible whereas, In cold regions, the wall thermal transmittance should be as high as possible and the wall admittance should be as low as possible. For reducing cooling loads, the stuffed bricks are recommended and for reducing heating loads, the hollow bricks are recommended.

HOLLOW BRICKS Vs STUFFED BRICKS





CB with FG Configuration	U (W/m²K)	f	ϕ (h)	Y (W/m²K)	χ (J/m²K)
BC-1	3.9947	0.73609	3.6727	5.3355	70521
BC-2	**0.4572**	**0.9196**	**2.8710**	**2.3803**	**38878**
BC-3	**0.4973**	**0.6877**	**4.8589**	**2.4692**	**41928**
BC-4	**0.5450**	**0.5921**	**6.1191**	**2.6108**	**45397**
BC-5	**0.6028**	**0.5342**	**6.9372**	**2.7634**	**49033**
BC-6	**0.6744**	**0.4987**	**7.4480**	**2.9257**	**53053**

HOLLOW BRICKS (For reducing heating loads)

CB Configuration	U (W/m²K)	f	ϕ (h)	Y (W/m²K)	χ (J/m²K)
C-a	3.994	0.736	3.672	5.335	70521
C-b	**2.630**	**0.976**	**1.100**	**2.986**	**38711**
C-c	**1.802**	**0.938**	**2.005**	**2.692**	**47231**
C-d	**1.376**	**0.868**	**3.143**	**2.813**	**53999**
C-e	**1.110**	**0.764**	**4.452**	**2.973**	**57862**
C-f	**0.930**	**0.641**	**5.842**	**3.605**	**58885**

STUFFED BRICKS (For reducing cooling loads)

CB with AF Configuration	U (W/m²K)	f	ϕ (h)	Y (W/m²K)	χ (J/m²K)
BC-1	3.9947	0.73609	3.6727	5.3355	70521
BC-2	**0.4949**	**0.6435**	**6.5613**	**2.8919**	**50411**
BC-3	**0.5378**	**0.5123**	**7.2328**	**2.8303**	**49238**
BC-4	**0.5887**	**0.4653**	**7.8014**	**2.8848**	**50929**
BC-5	**0.6503**	**0.4441**	**8.1286**	**2.9887**	**53766**
BC-6	**0.7263**	**0.4359**	**8.2666**	**3.1181**	**57366**

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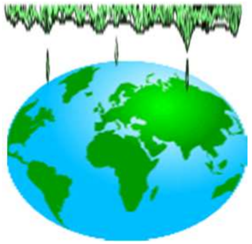

Go Green……………………

THANK YOU