International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 09, September-2018

STUDY OF ONE DIMENSIONAL HEAT AND MASS TRANSFER FOR BUILDING FAÇADE IN HOT AND DRY CLIMATE

*Anshu Agrawal *,Dr. Rajesh Sharma ** Dr. Ajay Pal Singh Rathore ***

Assistant professor, Department of Architecture and town planning,
Jai Narayan Vyas University Jodhpur Rajasthan-342001 India

Abstract
The Building envelope is a fence that controls heat exchange between in and outer and plays an important role in providing thermal comfort conditions of residents. No need prove that the present climate changes are directly linked to the human activities and also the concerns regarding exploitation of the fossil fuel have reached a level where the negative effect are having impact on the human life cycle of a common man. In recent years, due to the necessity of saving energy and also preventing environmental pollution, the need of sustainable construction has been doubled. Checking the problems of thermal behavior of the building envelope materials, and what influences in the heating and cooling loads ex-erted and energy consumption of buildings, are the questions that this research seeks to answer.[1] It is concluded that with the application of these techniques the building could be made comfortable with comparatively less use of energy for all.
The trend toward increased building wall insulation to conserve energy enhances the tendency for air moisture to condense within the wall. Efforts to predict the types of building wall construction and climatic variations that could cause such wall condensation have not been generally successful when compared to field measurements. Many predictive models rely on steady-state equations for calculating the diffusion rates for heat and water vapor through the building wall structure, ignoring the transient effects and the storage capacity of the building wall materials. [5] Others include transient effects, but they neglect the distributions of temperature in favor of a lumped parameter approach. Based on conjecture that storage effects may account for the discrepancy between simulation and practice, this paper examines the heat and mass transfer in Building wall materials by utilizing governing equations based on conservation of energy.

Key Words: Building Envelope, Heat Transfer, Thermal Comfort, Composite Wall Assemblies, Heat Flux, Thermal Insulation.

Introduction –

The present scenario as the world is facing increasing demand of energy due to rapid urbanization. Energy requirement for thermal comfort in buildings contributes significantly in global energy demand. Therefore, building professionals are forced to think towards design of energy efficient buildings through passive cooling. The walls of any building are the largest area exposed to environment and responsible for maximum heat load to the building. This heat load can be significantly reduced by increasing thermal resistance of the walls[16].
Objective of the research is to evaluate 1-D Transient Heat Transfer through various composite wall assemblies with different materials. These wall assemblies are categorized in four parts; monolithic, insulated, cavity walls and Aerated blocks. The initial temperature distribution across the wall is assumed to be uniform and equal to the daily mean external air temperature. Orientation and inclination of the assemblies is also kept constant for all the cases. Transient Heat Transfer occurring within the assembly, response of Heat Flux on exterior and interior surfaces with respect to time, Comparison of heat flux at various locations across the thickness of wall assembly and the effect of insulation location are the major concerns of the study. Impact of variables of Time and Temperature becomes an important phenomena to study transient heat transfer. The data generated from simulation runs is then analyzed and compared for various wall assemblies. Final comparison of transient phenomenon between the various cases is made to identify the efficient strategies to be applicable in Jodhpur climatic conditions. Depending on the type, use and working hours of the building one can select the type of assembly appropriate for its use. After studying the heat transfer and performance of assemblies, the study tries to form a matrix in which one can decide best suitable wall assembly for the specific conditions as per the requirement and context[4].
One of the major concerns in hot and dry climate is to negate heat gain from the outside to interior spaces. To create indoor comfort condition immense amount of energy is consumed. This energy is primarily used for cooling in hot & dry region. For instance, the increase in electricity consumption has increased to a tremendous amount in commercial building sector of India for the last decade[5].

Whenever there is a temperature difference across the wall assembly, heat flows naturally from a warmer space to a cooler space. The rate of heat flow through the building envelope is a function of the thermo physical and optical properties of the opaque and transparent component. Therefore, the thermo physical and solar radiation properties of the building envelope are one of the important determinants of the indoor climate and also of the demand for supplementary mechanical energy. To maintain comfort in winter, the heat loss must be replaced by the heating system; and in summer the heat gained must be removed by the cooling system. Various types of facades has been explored, designed and experimented by the architects. However, limited study has been done to explain the facade as a strategy in hot and dry climate. Moreover, the context of hot & dry region of Jodhpur has not been studied. By taking single layer facade, cavity walls, Aerated blocks and insulated composite walls, the study tries to address this gap by understanding the heat transfer in the assembly and its thermal impact[2].

Most homeowners find weatherization of their houses appealing both economically and philosophically. Common weatherization measures include wall insulation to reduce heat conduction and steps such as weather-stripping, caulking, and air/vapor barriers to minimize the exfiltration of heat. Ever since they achieved diffused Eclipse, these methods have been under fire for potentially creating more severe problems than they solve. Because insulation creates a greater temperature gradient through the wall, it was speculated that there would be an increased opportunity for condensation..

ENERGY CONSERVATION

- **WINDOWS**

  Windows provide fresh Air, light, ventilation and in many cases passive solar heating, but are otherwise a source of great heat loss[9].

  In the heat gain and loss calculation, all windows are created equal, no matter which direction they face. This air is necessary for cooling but not for heating of building. In the more northern climates, heat loss occurs equally from all windows regardless of which direction they face.

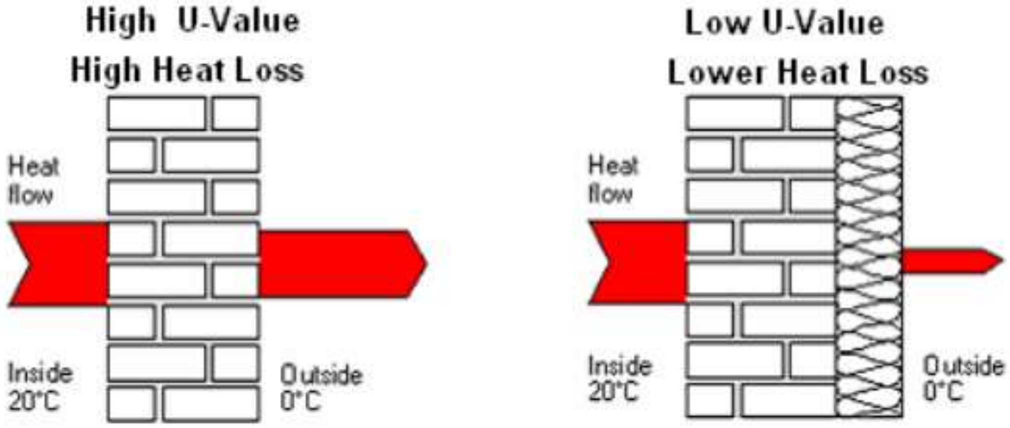
- **INSULATING MATERIALS**

  Insulation is the material added to a structure when the building materials themselves don't provide the desirable amount of resistance to heat transfer. The amount of wall insulation that can be added is limited to the available space between the framing materials, and is typically the most significant factor in determining how well a wall insulates. Since the framing material itself is at best a insulator, framing act as a thermal bridge leaking heat, and reducing the overall "R" value of the wall.

Net Area (A) Measured on the drawing/building

The net area of each building section is determined from either the drawings or from existing field measurements. We will also need to determine the volume of the building to estimate for the rate of infiltration material into the building measured in air changes per hour.

Overall Coefficient of Heat Transfer (U)



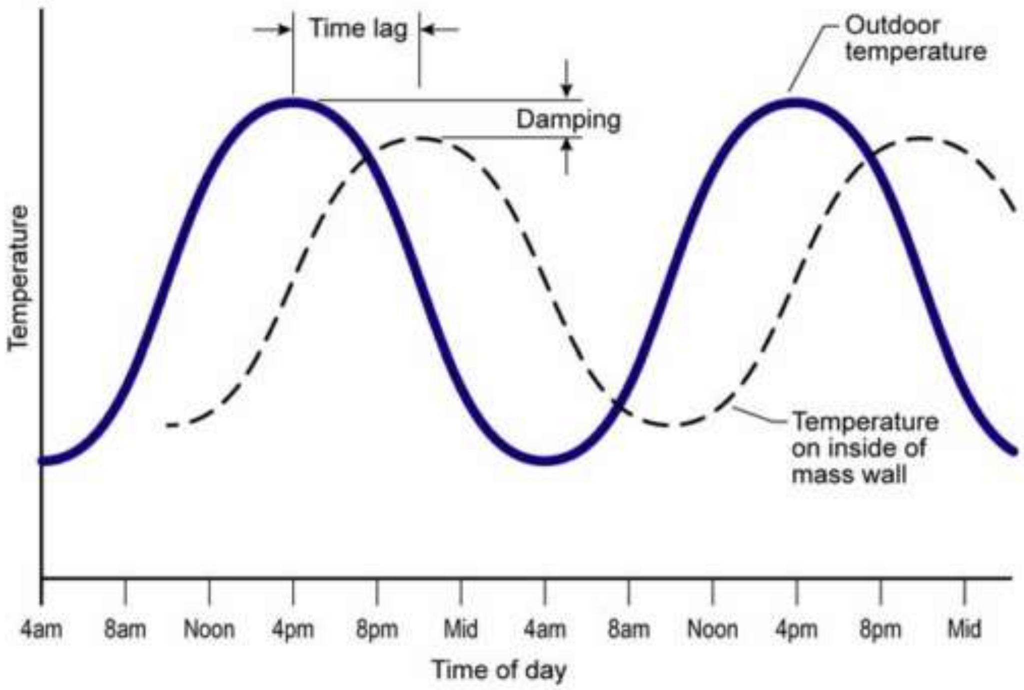
Calculating the U-value is often complicated by the fact that the total resistance to the flow of heat through a building wall made of several layers is the sum of the resistances of the each layer[13].

The Physics of Heat Transmission

Heat and mass transfer is the tendency of heat to move from a warmer space to a cooler space until both spaces are the same temperature. Greater the difference in temperatures, the greater will be the heat flow.

Thermal Mass is another important factor that affects the thermal performance of construction material assemblies. Heavy walls, roofs, and floors have more thermal mass than light ones. Thermal mass both delays and dampens heat transfer (see Figure). The time lag between peak outside temperature and interior heat transfer is between four and 12 hours depending on the heat capacity of the construction and other characteristics. The impact of thermal mass is greater in climates where there is a large temperature difference between night and day (such as mountain and desert climates). Thermal mass has far less impact when outdoor conditions are steadily hot or cold. The benefits of thermal mass in stabilizing indoor temperature are greater when the insulation is placed on the exterior side of the construction assembly.

If the mass is allowed to cool at night, it will absorb heat during the day and reduce the cooling load. If the interior thermal mass is exposed to sunlight, it will warm during the day, release the heat at night, and reduce the heating load[2].



Time lag & Damping Effects oF Thermal Mass

Heat Loss Calculations and Principles

- ✓ The first is to estimate the maximum rate of heat loss to properly size the heating equipment (furnace).
- ✓ The second calculated value that must be determined is the annual heating bill.

Factors Affecting Comfort in summer/winter

- ❖ TEMPERATURE
- ❖ WIND
- ❖ HUMIDITY
- ❖ RADIATION HEATING LOSS ESTIMATION

HEAT LOSS FROM BUILDING ENVELOPE (Wall, Roof, Glass)

Heat loss occurs from a building envelop primarily due to conduction. Because heat moves in all directions, when calculating the heat loss of a building envelop, we much consider all surfaces (building envelop) that divide the inside, heated space from the outside. We refer to that dividing line as the Envelope. Heat loss is determined by equation[11]

$Q = A * U * (T1 – T0)$

Where

Q = Total hourly rate of heat loss through building envelop etc in Btu/hr

U = Overall heat-transfer coefficient of building envelop material in Btu/hr ft2 °F

A = Net area of building envelop in ft2

Ti = Inside room design temperature in °F

To = Sun face design temperature in °F

Let's examine each one of these terms, starting at bottom with the Sun face wall design temperature.

Calculation Methods

Conductance and resistances of homogeneous material of any thickness can be obtained from the following formula:

$Cx=k/ x$, and $Rx=x /k$

Where:

- ➢ x=thickness of material in inches
- ➢ k = thermal conductivity

Materials in which heat flow is identical in all directions are considered thermally homogeneous.

There is an electrical analogy with conduction heat transfer that can be used in solving heat transfer problem. Based on similarity in the mechanism of electrical conductivity and thermal conductivity, an analogy is made between electric current transfer and heat transfer as follows:

For electric system,

$$lectrical\ Current\ Transfer(I) = \frac{Voltage\ Potential\ (\Delta V)}{Electrical\ Resistance\ (R)}$$

For thermal system,

$$Heat\ Transfer(Q) = \frac{Temperature\ Potential\ (\Delta T)}{Thermal\ \ Resistance\ (R)}$$

The analog of Q is current (I) , and the analog of the temperature difference, (ΔT=T1 - T2), is voltage difference (ΔV).

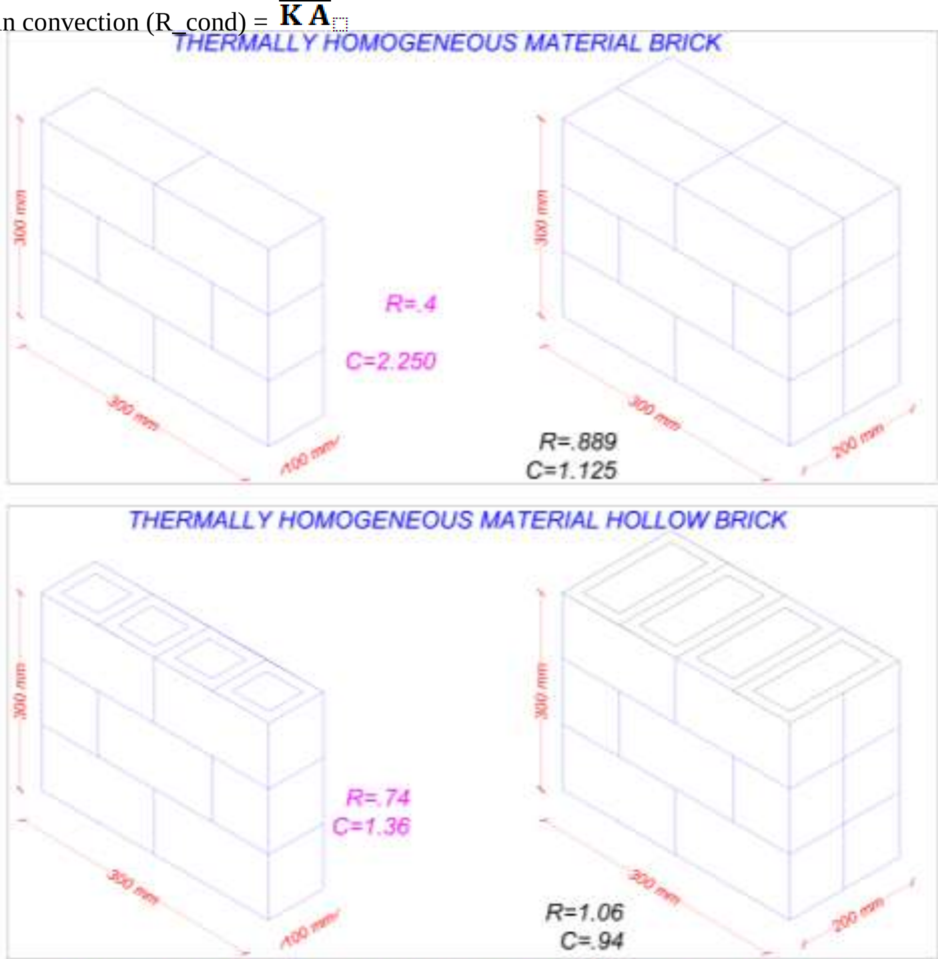
From this perspective the wall/slab is a pure resistance to heat transfer and we can define

$$Q = \frac{(T_1 - T_2)}{R}$$

Where, R is thermal resistance.

Thermal resistance in convection (R_conv) = $\frac{\mathbf{1}}{\mathbf{A\ U_0}}$

Thermal resistance in convection (R_cond) = $\frac{\mathbf{X}}{\mathbf{K\ A}}$



THERMAL TRANSMITTANCE THROUGH MATERIALS

In computing the heat devolution coefficients of layered construction, the aisle of heat flow should first be laid down. If these are in series, the counteraction are additive, but if the paths of heat flow are in similar, then the thermal transmittances are averaged. The word "series" implies that in cross-section, each layer of building wall material is one continuous material. However, that is not always the case. For instance, in a longitudinal wall section, one layer could be composed of multi material, such as studs and insulation, hence having parallel paths of heat flow within that wall layer[19].

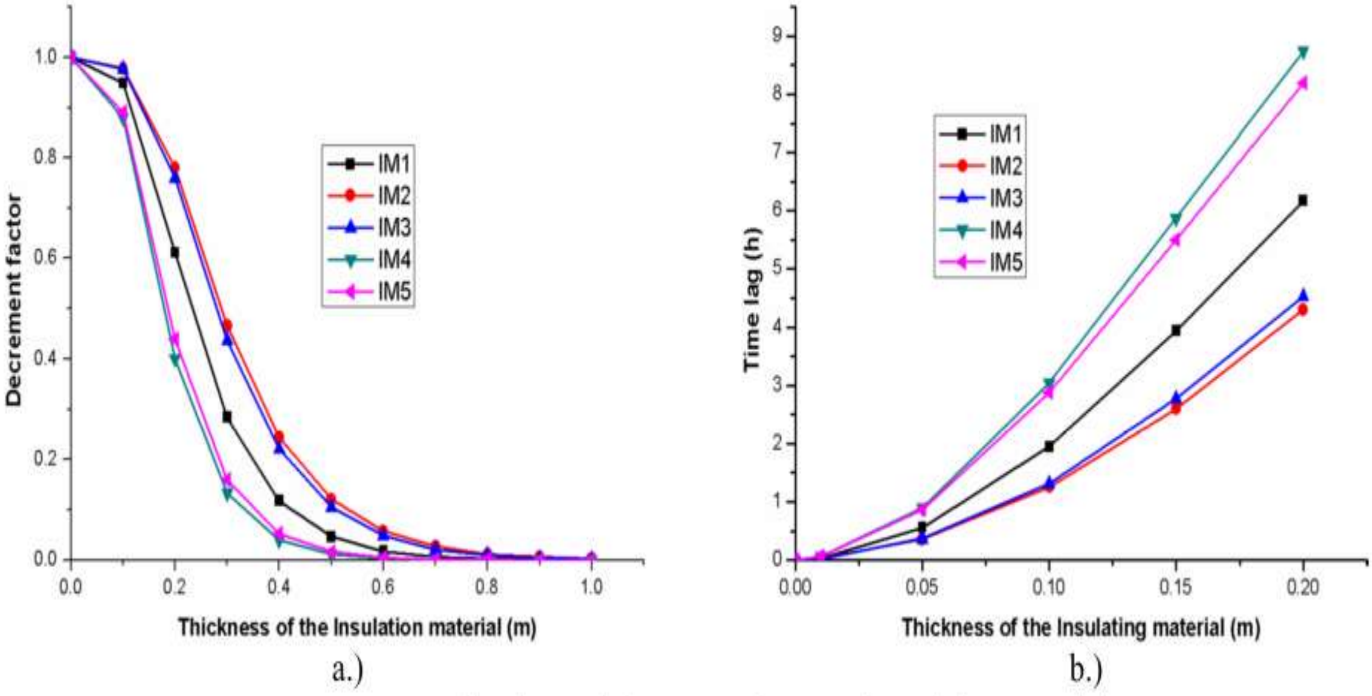
Heat Loss (Q)

Total hourly rate of heat loss through external walls, roof, and floor is given by equation

Q = U * A * ΔT.

Since the building structure is made of different wall materials, for example a wall that contains windows, ventilation and door, just calculate the heat loss through each of the components separately, then add their mass heat losses together to get the total amount[20].

Q (wall) =Q (framed area) +Q (windows) +Q (door)



Time lag and decrement factors of insulating materials

Series heat flow

Calculate the "R Total" value of anything that composed of multiple different wall materials, just add up the "R" values of each of components. For example for composite wall , the overall envelop thermal resistance is[14]:

R Total = R1 + R2 +...

Or

R Total = 1/ho+ x1/ k1 +...........+1/C + x2/k2 + 1/hi

Where:

ho, hi are the out and in film conductance in Btu/hr.ft2.F

k1, k2 are the thermal conductivity of wall materials in Btu/hr.ft2.F

x1,x2 are the wall thickness (in)

C is air space conductance in Btu/hr.ft2.F

And overall coefficient of heat transmission is:

U = 1/R Total

Or

$$U = \frac{1}{Ri+R1+R2+\ldots R0}$$

Where:

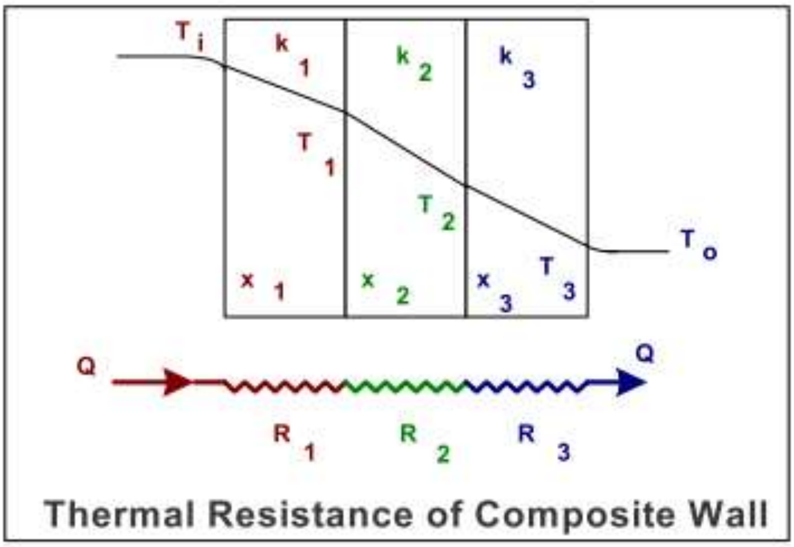
Ri = the resistance of a "boundary layer" of air on the in surface.

R1, R2 …= the resistance of each component of walls for the actual thickness of component used. The counteraction per inch thickness is used, the value should be multiplied by the thickness of component[21].

Ro = the resistance of the "air boundary layer" on the out surface of the building wall.

The formula for calculating U factor is intricate by the fact that the total counteraction to heat flow through a substance of multi layers is the sum of the counteraction of the various layers. The resistance to heat flow is the reciprocal of the

conductivity. Therefore, in order to calculate the overall heat transfer factor, it necessary to first find overall counteraction to heat flow, and then find the reciprocal of the overall resistance to calculate the U factor[18].
The total R-value should be calculated to two decimal places, and the total U-factor to three decimal places.



Heat gain through the exterior building walls and roofs is cyclic in nature. This shaky state heat flow results in unsteady state thermal features. There are two levels of modeling i.e., Transient and Cyclic. Present study focuses on cyclic response admittance method. The out air temperature the admittance model uses hypothetical sol–air temperature, as a single point variable to establish thermal gradient. This represents rate of heat flow into the wall surface by convection from the surrounding air plus shortwave solar radiation and radioactive exchange to surroundings[23].

$$\frac{\partial^2 T(X,t)}{\partial X^2} = \frac{\rho C p}{k}\frac{\partial T(X,t)}{\partial t}$$

Calculation Methodology:
Calculate a design heating load, we should prefabricate the following design about building wall design and weather data at design conditions.
1. Sun face design weather conditions: temperature, wind speed.
2. Decide on the Inside air temperature
3. Split the building into thermal zones
4. Define heat transfer coefficients (U-values) for sun face walls, glass and roof by finding the inverse of sum of individual R-values for each layer of wall material
5. Define the net area of sun face walls, glass and roof. Computing heat transmission losses for each kind of building wall, glasses and roof.
7. Computing Intrusion around sun face doors, windows porous all building materials and other openings in wall .

CONCLUSION

Rate flow of the heat energy, for each degree of deviation about the average environmental temperature value, is known as the thermal penetration. The wall thickness of homogeneous material considered for the study is 0 to 1m. The decrement factor of the building wall material decreases and it’s time lag rise with an enlargement in the wall thickness. The smaller the decrement factor the more effective the wall at suppressing temperature swings the thickness of the homogeneous walls considered for the study is 0 to 1m. The numerical model has been developed to study the effects of the porous absorber on the temperature distribute and airflow in the composite wall. The composite building wall with insulation placed at the mid centre plane of the wall and insulation placed at external surface of the wall are the recommended composite walls for higher time lag and lower decrement values step by step.
Insulation material located at the mid centre plane of the composite 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 is a sustainable tool to reduce building energy. These are light in weight and do not require maintenance or it has very low value. Between 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 efficient and material savings for sustainable construction work.

NOMENCLATURE:-

Cp	Specific heat	(J/kgK)
k	Thermal Conductivity	(W/mK)
P	Time period	(s)
Q	Heat Flux	(W/m^2)
R	Surface Resistance	(m^2K/W)
U	Thermal Transmittance	(W/m^2K)
Y	Thermal Admittance	(W/m^2K)
Greek Letters		
α	Thermal Diffusivity	(m2/s)
ρ	Density	(kg/m3)
ϕ	Decrement Delay	(h)
χ	Thermal Heat Capacity	(J/m^2K)
Subscripts heat		
e	Exterior surface	
I	Interior surface	

References:-

1. Dehra H. Modelling of airflow window with integrated photovoltaics. Doctoral seminar, Department of Building, Civil and Environmental Engineering, Concordia University, Montréal, Québec, Canada; April 2002.
2. Dehra H. Modelling of an airflow window with a photovoltaic solar wall. In: Proceedings 10th international conference on sustainable energy technologies (SET 2011), Istanbul, Turkey, September 4–7; 2011
3. KCK Vijaykumar,"Transient thermal analysis of hollow clay tiled concrete roof for energy conservation & comfort" Dept. of mechanical engineering,Kongu engineering college, Erode, India, 2006.
4. Report for ASHRAE,'Modeling Two & Three Dimensional Heat Transfer through Composite Wall & Roof Assemblies in Transient Energy Simulation', by Enermodel Engineering Ltd & Oak Ridge National Lab, March 2001.
5. Sami A., Al Saena & M.F Zedan,'Effect of Insulation Location on Initial Transient Thermal Response of Building Walls,' Journal of Thermal Envelope & Building Science 2001.
6. K C K Vijaykumar, 'Transient thermal analysis of Aerated clay tiled concrete roof for energy conservation and comfort,' Journal of Scientific & Industrial research, Vol 65, August 2006.
7. G.P. Mitalas,'Calculation of Transient Heat Flow Through Walls & Roofs,' Division of Building Research,
8. C.P. Kothandaraman,"Fundamentals of Heat & Mass Transfer",New Age Pvt Ltd, New Delhi,1997
9. Mani A.,Handbook of solar radiation data for India, Allied Publishers, New Delhi, 1981.
10. Gulten Manioglu,Zerrin Yilmaz,"A Comparative evaluation of the importance of Thermal Mass of Traditional Architecture in Hot & Dry Region in Turkey", Istanbul Technical University, Faculty of Architecture,2000.
11. D.S.Kumar,'Heat & Mass Transfer,'Katson Publishing House,Ludhiana,1988
12. Magyari, E., Keller, B., 1998, "The storage capacity of a harmonically heated slab revisited". Int. J. Heat Mass Transfer, vol. 41, no. 10: p.
13. SP:41 (S&T) 1987, Handbook on functional Requirement of Buildings other than industrial buildings. Bureau of Indian Standards, India,
14. Hartwig M. Kunzel,'Simultaneous Heat & Moisture Transport in Building Components' Fraunhofer Institute of Building Physics, Stuttgart 1995,
15. Weather:http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region =2_asia_wmo_region_2/country=IND/cname=India
16. Incropera, DeWitt,& Bergmann,'Fundamentals of Heat & Mass Transfer,' Sixth Edition John Wiley & Sons. Inc,UK, 2007.
17. Asan, H., 1998, Effects of wall's insulation thickness and position on time lag and decrement factor, Energy and Buildings, vol. 28, no. 3:
18. Asan, H., 2000, Investigation of wall's optimum insulation position from maximum time lag and minimum decrement factor point of view, Energy and Buildings, vol. 32, no. 2:
19. Asan, H., 2006, Numerical computations of time lag and decrement factors for different building materials, Building and Environment, vol. 41, no. 5:
20. CIBSE, 2006, CIBSE Environmental Design Guide-A. Chapter 3, chartered Institution of Building services engineers, London.
21. Davies, M.G., 2004, Building Heat Transfer, Chapter 15, U.K., John-Wiley & sons Ltd. 500 p. Gasparellaa, A., Pernigottob, G., Baratieri, M., Baggioc, P., 2011, Thermal dynamic transfer properties of the opaque envelope: Analytical and numerical tools for the assessment of the response to summer outdoor conditions, Energy and Buildings, vol. 43, no. 9:
22. Magyari, E., Keller, B., 1998, "The storage capacity of a harmonically heated slab revisited". Int. J. Heat Mass Transfer, vol. 41, no. 10:
23. SP:41 (S&T) 1987, Handbook on functional Requirement of Buildings other than industrial buildings. Bureau of Indian Standards, India