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TRANSPARENT INSULATION MATERIALS DEVICES FOR SUSTAINABLE DEVELOPMENT AND ENERGY AUDIT IN BUILDINGS

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Abstract: Sustainable Development in a building is related to focus on low cost and low energy architecture.The site of work is the key point for investigation. In hilly stations, the buildings are constructed by various types of soil and rock formations.Varying slope characteristics in development on improper selection of sites often causes landslides, loss of life and damages of properties. Hill slope less than 30^0 is stable gradient corresponds to safe angle of repose of slope forming materials. Computational results for honeycomb cell depth in the range of 2 to 16 cm show that the cell width range of 7 mm to 19 mm is sufficient to suppress the convection for the angle of inclination of 10^0 ,40^0 & 70^0 and ΔT in the range of 20^0C to 120^0C which is the range of interest in solar thermal applications. Simultaneously experimental results in fabrication of noryl air heater are capable of providing hot air of temperature difference [15^0 C-30^0 C] on a moderate sunny day. Therefore it is a suitable air heater for producing hot air of space heating and agricultural drying applications. Innovative applications of TIM Devics for sustainability and heat tranfer analysis corresponding to New Delhi and Leh in India and Boulder in USA for TIM device of depth 5 cm to 10 cm and aspect ratio of 10-20 considerably enhances the heat flux entering the living space and increases the indoor temperature to comfortable conditions in cold climates.Therefore an appropriate engineering design of building with TIM insulation would involve tradeoff between several of above-mentioned factors.

Key Words: Sustainable Development in Buildings, Site of work, Modelling of Noryl Air Heater, Transparent Insulation Material Technology and Simulation.

Introduction: Sustainable Development in buildings is related with durability, aesthetically pleasant and economic environment. With special emphasis on passive solar heating and cooling, we can achieve contemporary materials and devices for the control of air, water and vapor flow, rain penetration, control of light, solar radiation, noise and fire to provide strength and rigidity. In old days, Greek philosopher Aristotle (384-322 B.C.) advised that house should have large window on walls facing south and as small as possible window on the north side, with horizontal shading device above the south facing window to allow the winter sun to shine indoors and cut the direct radiation entering the room in summer season. Socrates (Circa 400 B.C.) describe techniques for passive heating of building by providing large fenestration with an horizontal louvre on the south side wall and little fenestration on the north side wall. During Mohenjo-Daro civilizations in India the same principles for heating and cooling the buildings by the natural energy sources were used. Ancient Iranian architecture used the concepts like clustering of buildings, use of thick walls, tree and shrub plantations, rooms basement, wind tower, evaporative cooling etc. for providing cooling of buildings in summer. Passive solar techniques are used in the construction of dwellings in Chacko Canyon and Mesa Verde by American Indian as long as AD 1100. The old Indian forts, domes and historical buildings are good examples of ancient Indian architecture where several concepts like flow of water near the buildings, water fountain, use of thick walls made of stone, mud, limestone, etc, high ceiling, overhangs, low fenestration area on south and west side, planting trees, tower in the center of the building, clustering of houses, etc. are used for keeping the building warm in winter and cool in summer. The early work on sustainable development of buildings was not based on scientific experiments but on common sense and experience; their thermal performances were far from satisfactory. Simultaneously natural disasters strikes countries, both developed and developing causes enormous destruction and creating human sufferings and producing negative impacts on natural economies. To maintain socio-economic sustainable development, it is necessary to rescue reliable supply of electricity and energy to the different sectors of economy. As a means of solar energy audit the computational results shows that daily solar energy collected over 340 square meters of area is equivalent to one barel of the oil, whereas One barel of the oil is equivalent of 6×10^9 MJ of Energy. The Global average solar energy estimated is about 200 W/m^2 or 17 MJ/day. Development agencies and foundations can accelerate universal energy access by directing funds toward sustainable market building that directly engages the energy impoverished in creating their own energy. Developed countries have the facilities to reach the above target; while developing countries like India faces many difficulties in meeting their energy demand. The expected economic development will considerably boost energy consumption and more particularly demand for electricity requiring new generating capacity and infrastructures. The installed capacity of India at the end of march 2004 was about 1,11,400 MW.The ministry of Power envisages “Power for all” by 2019, which includes electrification of all villages up to the end of april 2018 and PM Modi’s Ujjwala helps LPG coverage expand to 90% households up to the beginning of 2019 which aims to more than double existing power generation by a considerable100,000 MW by 2013. Under the Jawaharlal Nehru National Solar Mission, a target of 1100 MW grid connected solar power was envisaged. A capacity of 500 MW has been enmarked after march 2013 for solar thermal power plants and 10 such plants were selected under different schemes with different completion schedules for which a better governance regime is required to ensure cooperation and compliance. Hence a large area solar collector are essentially needed for solar energy utilization. The conventional solar energy collector are metal like galvanized iron copper etc. These materials are energy intensive. It takes about 5 years for them to collect solar energy equal to that used in their production. The plastics are therefore being investigated as an alternative for metallic collectors for example (Blaga, 1980). Computational investigation shows that some of the plastic have very suitable property for glazing in collectors as compared to glass.

Honeycomb Design for convection suppression in inclined Plane: Hollands first presented the theoretical performance characteristics for a honeycomb device. Subsequently it was the subject of several theoretical and experimental investigations related to their convective, radiative and solar transmittance characteristics. Hollands (1979) considered the base flow and recommended the engineering design of honeycomb with Nusselt number of 1.2. The minimum aspect ratio A that is required just to suppress the convection is given by

$$A = F(\beta)\left(\frac{Ra}{2420}\right)^{1/4} \quad (1)$$

where $F(\beta) = \left(4.45\cos\ (\beta - 60)\right)^{1/(11.52 - 6.56\sin\beta)}, 30^0 \le \beta \le 90^0$ (2)

And the value of Ra used here is defined by equation

$$Ra = 2737(1 + 2\beta_1)^2\, \beta_1{}^4 \Delta T (100L)^3\, p^2 \quad (3)$$

Where $\beta_1 = 100/Tm, Tm(inK) = (Th + Tc)/2, \Delta T = Th - Tc$, and p is the atmospheric pressure for mean temperature, 280K $\le$ Tm $\le$ 500K.

By analytical observations, we see that the above expression is also valid for β = 0, if F (β) is taken as 1.072 and the linear interpolation of values for the range 0^0 to 30^0 is also permitted. For air, at atmospheric pressure and moderate temperature (280 K ≤ Tm ≤ 370 K) the minimum cell width that is required to just suppress the convection is

$$d = \frac{(100L)^{1/4}}{100c(\beta)(1+2\beta_1)^{1/2}\beta_1(\Delta T)^{1/4}} mts = \frac{(100L)^{1/4}}{c(\beta)(1+2\beta_1)^{1/2}\beta_1(\Delta T)^{1/4}} cm \quad (4))$$

Where L is in m, $\beta_1 = \dfrac{100}{Tm}$ is in K^{-1}, ΔT is in K. The function c (β) is given by

$$c(\beta) = 1.03F(\beta)\ for\ 30^0 \le \beta \le 90^0 = 1.1 + 0.25\sin\beta,\ for\ 0^0 \le \beta \le 30^0 \quad (5)$$

The computational results for the minimum cell width required to suppress the convection for the angle of inclination of 10^0 ,40^0 & 70^0 based on the above correlations for honeycomb cell depth in the range of 2 to 16 cm and ΔT in the range of 20^0C to 120^0C which is the range of interest in solar thermal applications are shown in Fig. 1a, 1b &1c. It is found that cell width range of 7 mm to 19 mm is sufficient to suppress the convection.

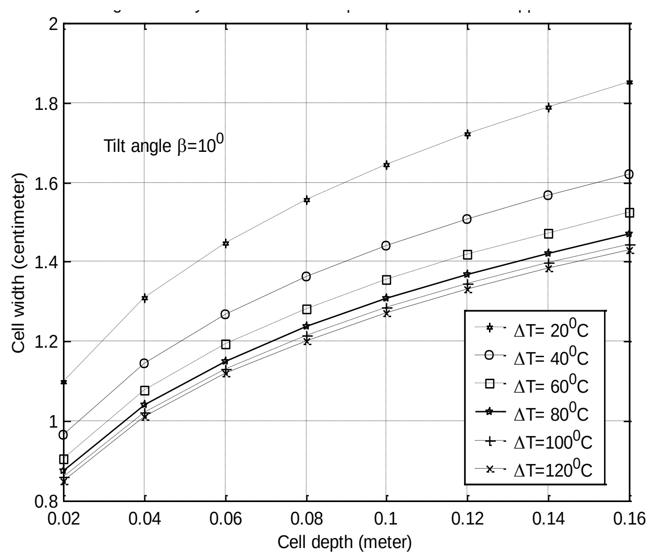


Fig1a:Honeycomb cell width for convection suppression at 10^0 tilt angle

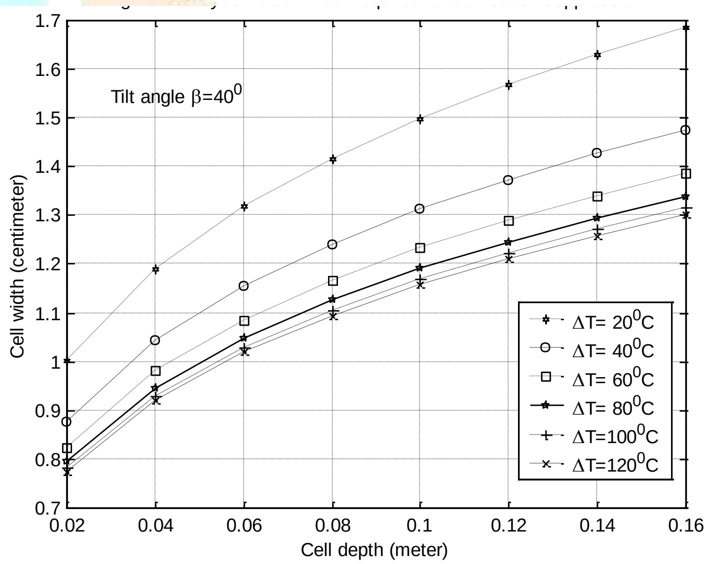


Fig1b:Honeycomb cell width for convection suppression at 40^0 tilt angle

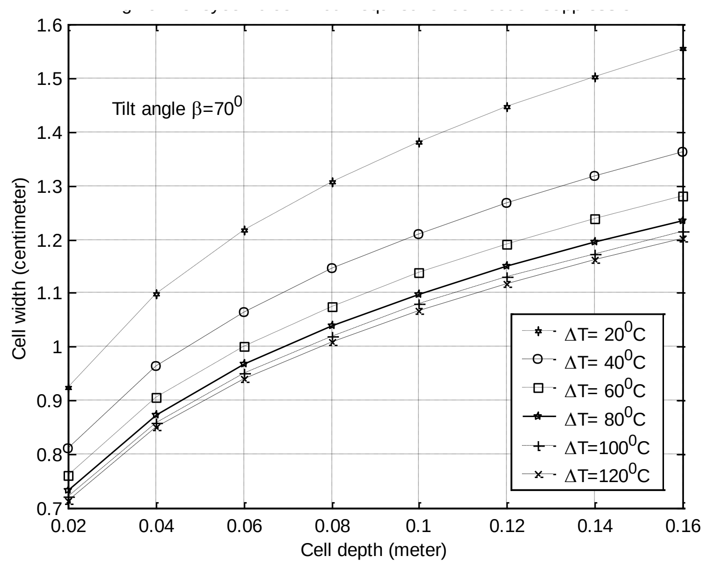


Fig1c:Honeycomb cell width for convection suppression at 70^{0} tilt angle

Kaushika (1997) investigated the application of sheets as solar collector absorber plates at the instance of GE plastic through a consultancy project and reported that these sheets have all properties required for the absorber plates of a collector. However the joining of the headers of the plastics suffered a set back of leakage resulting from the heavy pressure exerted by the flowing water. Although Kaushika suggested that the noryl plastics could be quite suitable solar absorber when air is used as a heat removal fluid. Thus the business on Structured Products viz (GE Plastics) have been considered as one of the fastest growing business for TIMs in India.

Design of Lexan multiwall sheet structures: The structured Products consists of a range of Lexan polycarbonate sheets, profile, films and formed products for a variety of application in buildings and construction signage and other industrial areas. Lexan polycarbonate is an amorphous thermoplastic resin which offers a unique combination of mechanical optical, thermal and electrical properties offered by metals, glass and other plastics. Lexan sheet are 250 times stronger than glass. Thus they are virtually unbreakable. These sheets can be transparent, tinted, or in bright opaque colors, textured, multiwall sheets and in corrugated sheets(sinusoidal/trapzoidal configurations).Lexan Multiwall sheet structures can be represented by twin wall rectangular structure, Triple wall structure, Twin wall 'N' structure, Four wall rectangular structure and five wall rectangular structure as follows :

Fig 2.1:Twin Wall Rectangular Structure

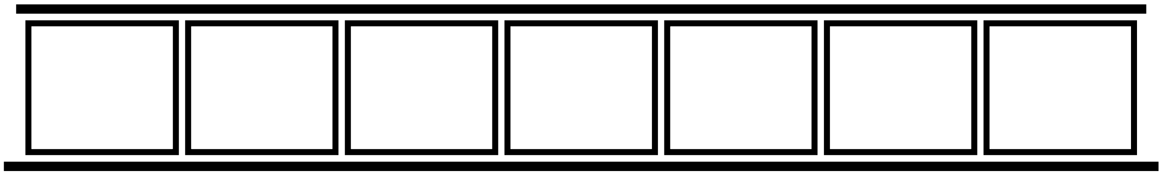


Fig 2.2:Triple Wall Structure

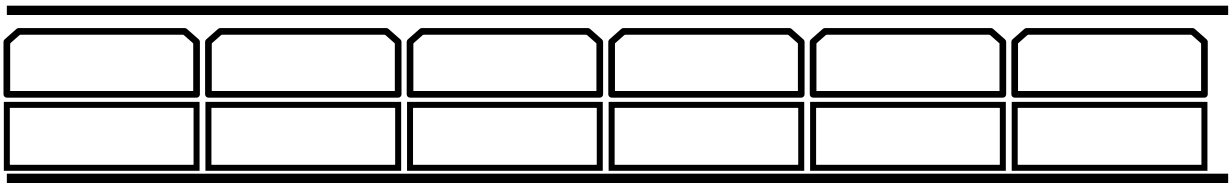


Fig 2.3: Twin Wall 'N' Structure

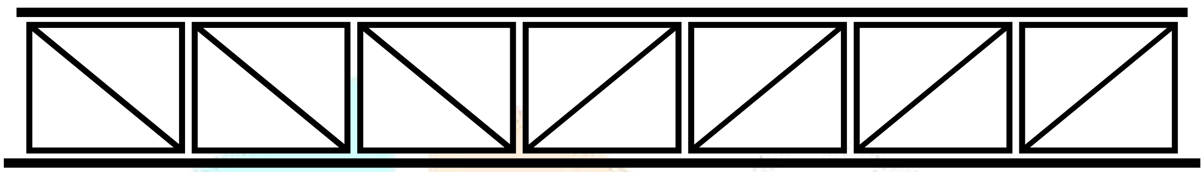


Fig2.4:Four Wall Rectangular Structure

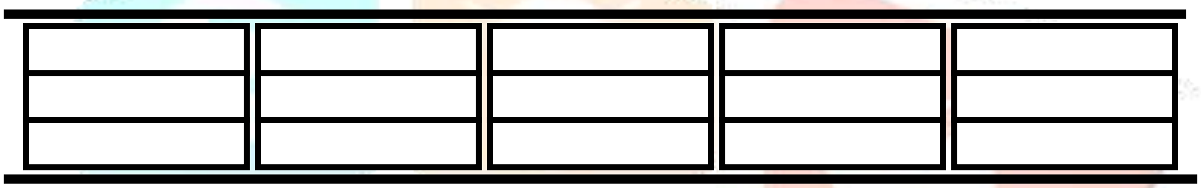
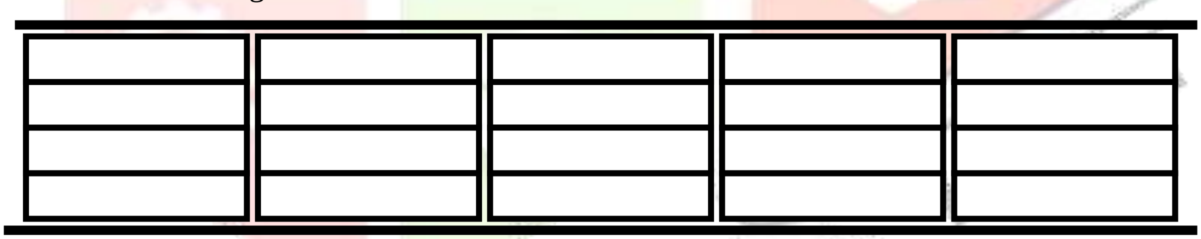


Fig2.5: Five Wall Rectangular Structure



Lexaon sheets have an excellent energy saving insulation property. These sheets help us to save 50% of the energy costs in comparison to glass.

On the other hand Lexan compact sheets are best suited for high impact architectural and safety applications. These are available in transparent colored oriented forms. Typical applications include glow signs, skylights exterior canopies and roof glazing. Simultaneously Lexan thermoclear is an impact resistant, energy saving, multi-wall polycarbonate glazing sheet. It features a proprietary surface on the treatment which provides almost total resistance against degradation caused by UV radiation in sun light. The entire lexonthermoclear sheet range carries a ten year limited waranty against discolouration, loss of light transmission and/or loss of stregthdue to weathering . Typical applications for the use of LexonThermoclear sheet include industrial roofs and side walls, Commercial Green houses, Sunroom, Swimming Pool and conservatory roofing, Shopping Centre roofing, Railway/ Metro Station and Football Stadium roofing . One of the ideal roof glazing material in any application where water drops are unacceptable is lexanthermoclear drip sheet. The Lexan thermoclear drip sheet is useful for instance greenhouses, varanda's, sunrooms, swimming pool enclousers, industrial roof glazing etc. one more example is lexan Profiled sheets. This sheet does not features latter's proprietary surface protection against UV radiation. It is used in partitioning, shower stalls and false ceilings. In view of impact strength, The Lexan Thermoclear sheet has outstanding impact performance over a wide range-40^0 C to $+120^0$ C and also after prolonged exposure.Annual fuel savings are strongly dependent upon building type, location and regional environment conditions. Multiwall Structure of Lexan Thermoclear sheet offers significant advantages where thermal insulation is a major consideration. The hollow form provides excellent insulation characteristics with heat losses significantly lower than mono-wall glazing materials. Experimental results shows that both thermo plastics and thermo setting plastics may be highly transparent, opaque or have any degree of clarity and light transmission in between. The total solar energy transmission may run as high as 90% with 91-93 in the visible region (400 & 750 mm).The investigations of Raghu Raman V in 2000 shows that the industry sector in India consumes more than 51% of the commercial energy. The advisory board on energy in 1986 has estimated that there will have to be an investment of Rs 450000 crores for achieving a production of 450 million tons of coal for 654 billion units of power capacity. 50 million tonnes of oil was the requirement of indiatill 2004-2005,which was reported 5156 Barrel/Day in Dec 2018 . The country is thus faced with the challenge of meeting the serious energy short falls and economic stagnation. One of our project attempt in this direction is to design and fabricate theNoryl Air Heater. Above said air heater consists of a plane black absorber sheet (1250 mm $\times$ 1000 mm) made of noryl plastic material. The riser tubes are channel with a square cross section and are embodied in the absorber plate. The header tubes are PVC pipes of diameter 65 mm. The glazing is made of polycarbonate structured materials of thickness 10 mm. The air gap between the absorber and the glazing is 10mm. The bottom insulation is provided by the thermocole sheet of 10 mm thickness. An air gap of 10mm is provided between the black absorber and the bottom thermo cole insulation.No way for the collector box frame is provided instead the channel are covered with wooden frame which provides the strength. The detailed engineering drawing are given in Fig 3.1and fig 3.2.

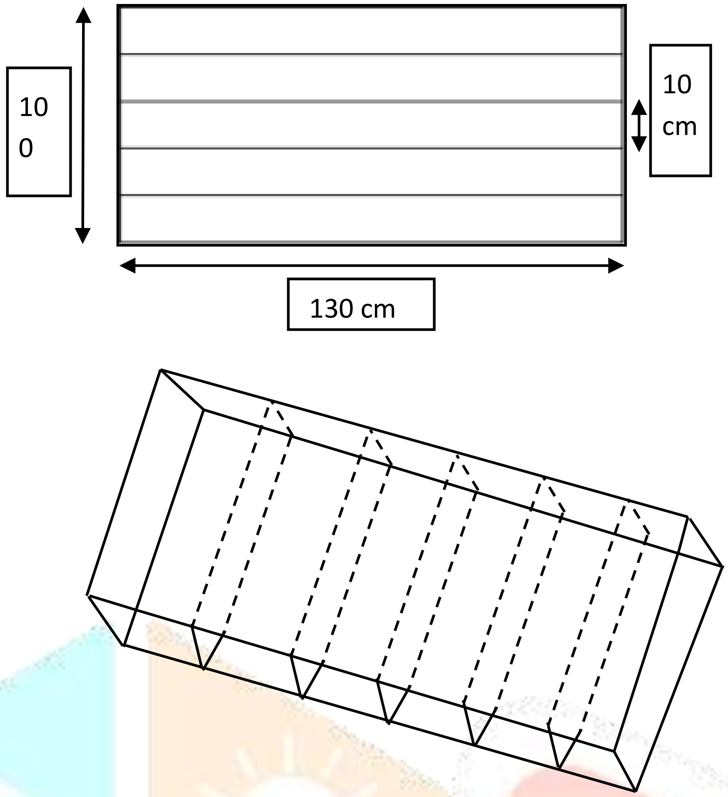


Fig 3.1

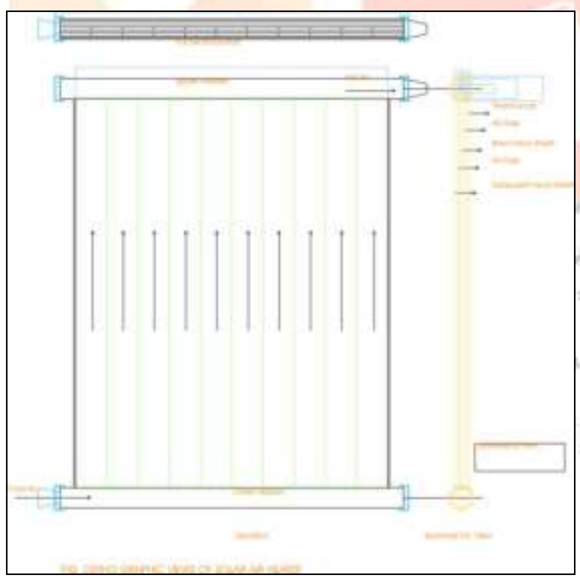


Fig 3.2

The assembly of air collector is given in photo represented by Fig 3.3.

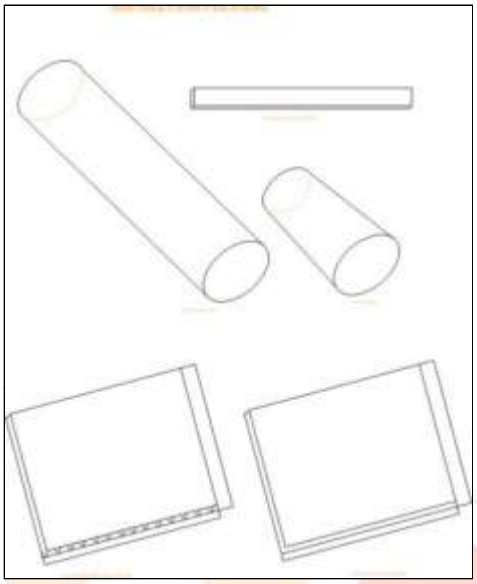


Fig 3.3

In this experiment the diameter of inlet nozzle was 65 mm and that of outlet nozzle was 30 mm. Air velocity observed at the inlet was 0.2 m/s while atmospheric pressure was 750 mm of Hg.

The collector was placed facing southward at an angle of 15^0 inclined to horizontal. The inlet and the outlet temperature have been measured with the help of nickel and chromium thermocouples. Intensity of solar radiation on horizontal surface has been measured using the pyranometer.The computed value ofCross sectional area of inlet = $\frac{\pi}{4} D_i^2 = 3.318 \times 10^{-3} m^2$ which gives volume flow rate represented by $\dot{V} = area \times velocityOf\ air = 6.636 \times 10^{-4} m^3/s$;Atmospheric pressure= $13.6 \times 10^3 \times 0.75 \times 9.81 = 1\ bar$. ThereforeMass flow rate will be $\dot{m} = \frac{P\dot{V}}{RT} = \frac{1 \times 10^5 \times 6.636 \times 10^{-4}}{287 \times 313} = 7.387 \times 10^{-4}\ Kg/s = 0.738 gm/s = 0.66\ L/s$. Experimental results shows that noryl air heater is capable of providing hot air of temperature difference[15^0 C-30^0 C] on a moderate sunny day. Therefore it is a suitable air heater for producing hot air of space heating and agricultural drying applications.Similarlythe radiation exchange between a human body and surfaces of a room isan important part of study in energy transfer mechanism for providingcomfort and sustainable development in a building as shown in fig 4. Practically building collect some amount of solar radiation for heating to some degree in winter and reject the heat to some extent in summer, but when the building structure is designed in such a way that maximum amount of solar radiation is collected in winters and is used as a significant proportion of heating load of the building and similarly if a building structure is designed in such a way that the heat is rejected in summer to an extent that the cooling produced is a significant proportion of cooling load .Efforts have been made especially by developing countries, to work towards synergizing experiences and raising shared regional concerns as a strong united front in international forums.For monitoring the compliance of countries to their obligations under various environmental agreements; there is a multiplicity of institutions with fragmented responsibilities.Mechanisms must be put in place to facilitate such international exchange of domestic and global experiences in sustainable development.

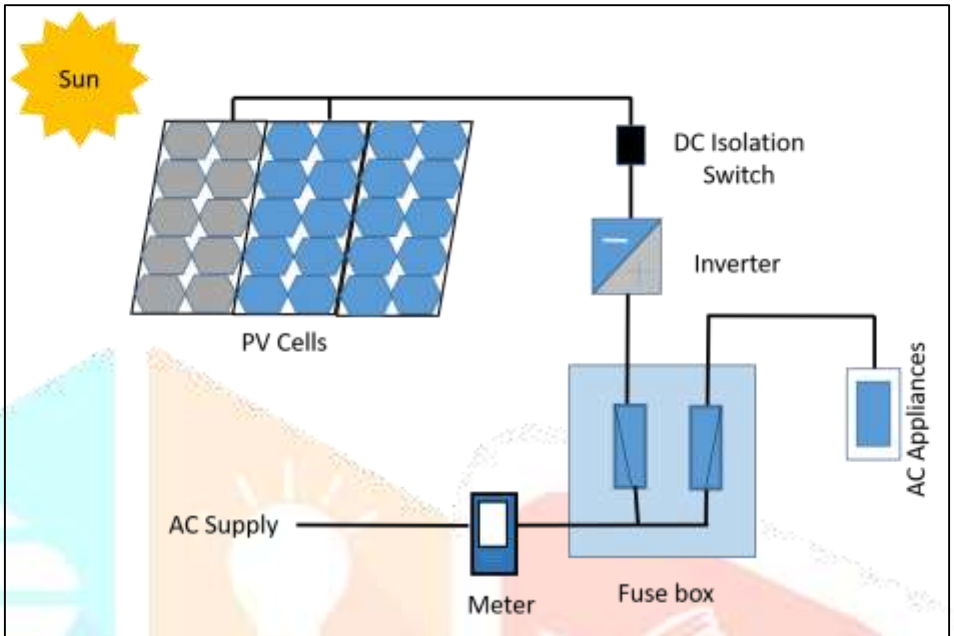


Fig 4 : Building integrated photo voltaic system

The key point for modelling a building is energy conservation and sustainability for which the study of temperature distribution through walls /roof slab play an important role. The temperature distribution through walls/roof slab in a building is governed by one-dimensional Fourier heat conduction equation given by

$$\kappa^k \frac{\partial^2 T^k(x,t)}{\partial x^2} = \frac{\partial T^k(x,t)}{\partial t} \tag{6}$$

where $\kappa^k = \frac{K^k}{\rho^k C^k}$ is the thermal diffusivity of the k th wall/roof material.The boundary conditions of k th wall/roof for both outer and inner surfaces are as follows:

Outer Surface:

$$-K^k \left.\frac{\partial T(x,t)}{\partial x}\right|_{x=0} = h_0^k \{T_{SA}^k(t) - T^k(x=0,t)\} \tag{7}$$

*Inner Surface:*An appropriate engineering design of building with TIM insulation would therefore involve trade off between several of above-mentioned factors.

$$-K^k \frac{\partial T(x,t)}{\partial x}\bigg|_{x=l} = h_i^k (T^k(x=l^k,t) - T_R(t)) \qquad (8)$$

where $T_{SA}^k(t)$ is thesolair temperature of k th wall/roof defined as follows:

For bare walls/roof

$$T_{SA}^k(t) = \frac{\alpha I_t^k(t) - \varepsilon \Delta R}{h_0} + T_A(t) \qquad (9)$$

and for TIM insulated walls/roof

$$T_{SA}^k(t) = \frac{(\alpha\tau)_{eff}\; I_t^k(t) - \varepsilon \Delta R}{U_L} + T_A(t) \qquad (10)$$

Since solar intensity and ambient air temperature are assumed to be periodic in nature, the solair temperature and room air temperature will also be periodic and may be represented by Fourier series as follows:

$$T_{SA}^k(t) = T_{s0}^k + \sum_{m=1}^{N} T_{sm}^k e^{im\omega t} \qquad (11)$$

$$T_R(t) = T_{r0} + \sum_{m=1}^{N} T_{rm} e^{im\omega t} \qquad (12)$$

Where $\omega = (2\pi/24)h^{-1}$ and $T_{sm}^k = T_{SM}^k e^{-i\phi_m}$ (13)

$$T_{SM}^k = \sqrt{(A_{km}^2 + B_{km}^2)} \qquad (14)$$

$$\phi_{km} = \tan^{-1}(\frac{B_{km}}{A_{km}}) \qquad (15)$$

A_{km} and B_{km} are Fourier coefficients of $T_{SA}^k(t)$ and

$$T_{rm} = T_{Rm} e^{-i\phi_m} \qquad (16)$$

$$T_{Rm} = \sqrt{(A_{rm}^2 + B_{rm}^2)} \qquad (17)$$

$$\phi_{rm} = \tan^{-1}(\frac{B_{rm}}{A_{rm}}) \qquad (18)$$

A_{rm} and B_{rm} are Fourier coefficient of $T_R(t)$. Computational results for six harmonics of the Fourier series give the fairly good representation for the above periodic function on synthesizing. So six harmonics are considered to be sufficient for further computations. The validity of this consideration for solair temperature of south wall for Leh is illustrated in Fig. 5.

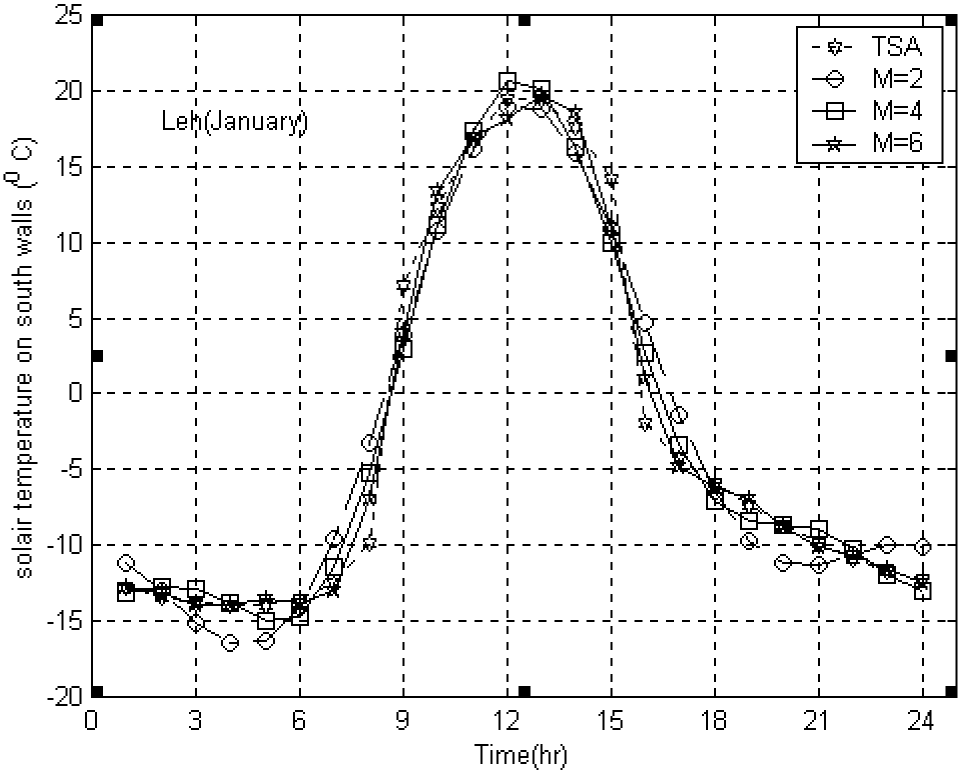


Fig 5: Effect of Harmonics on solairteperature on south wall at Leh

Since solair temperature and room air temperature are assumed to be periodic in nature. So T(x, t) must also be periodic in nature. The periodic solution of equation (1) may, therefore, be assumed as Fourier series given by

$$T^k(x,t) = [(A_0^k x + B_0^k) + \sum_{m=1}^{6}(A_m^k e^{x\delta_m^k} + B_m^k e^{-x\delta_m^k})e^{im\omega t}]; \quad (19)$$

$$\delta_m^k = (im\omega/\kappa^k)^{\frac{1}{2}} = (\frac{m\omega}{2\kappa})^{\frac{1}{2}}(1+i) \text{ where } \omega = (2\pi/24\times 60\times 60) \text{ per second} \quad (20)$$

Now by using outer and inner surface boundary conditions in equation(19) and on separating time dependent and time independent parts we get the system of equations given by

$$\begin{bmatrix} -K^k & h_0^k \\ lh_i^k & h_i^k \end{bmatrix}\begin{bmatrix} A_0^k \\ B_0^k \end{bmatrix} = \begin{bmatrix} h_0^k T_{s0}^k \\ h_i^k T_{r0} \end{bmatrix} \quad (21)$$

$$\begin{bmatrix} (-K^k\delta_m^k + h_0^k) & (K^k\delta_m^k + h_0^k) \\ (K^k\delta_m^k + h_i^k)e^{l\delta_m^k} & (-K^k\delta_m^k + h_i^k)e^{-l\delta_m^k} \end{bmatrix}\begin{bmatrix} A_m^k \\ B_m^k \end{bmatrix} = \begin{bmatrix} h_0^k T_{sm}^k \\ 0 \end{bmatrix} \quad (22)$$

The heat flux entering the room through k th wall/roof is given by

$$\dot{Q}^{k}(t) = -K^{k} \left.\frac{\partial T}{\partial x}\right|_{x=l} = h_i^k [(l^k A_0^k + B_0^k - T_{r0}) + \mathrm{Re} \sum_{m=1}^{6} (A_m^k e^{l^k \delta_m^k} + B_m^k e^{-l^k \delta_m^k}) e^{im\omega t} \quad (23)$$

on solving matrix equations (21) and (22)we get $A_0^k, B_0^k, A_m^k \,\&\, B_m^k$; which on substitution in equation (23) give the heat flux entering the room through k th wall/roof.

To compute $A_{i0}^k, B_{i0}^k, A_{im}^k \,\&\, B_{im}^k$ for TIM insulated walls we have applied outer surface boundary condition (7), replacing h_0 by U_L and inner surface boundary condition (8) in equation (19) and on separating time dependent and time independent parts we get the system of equations given by

$$\begin{bmatrix} -K^k & U_L \\ Dh_i^k & h_i^k \end{bmatrix} \begin{bmatrix} A_{i0}^k \\ B_{i0}^k \end{bmatrix} = \begin{bmatrix} U_L T_{is0}^k \\ h_i^k T_{r0} \end{bmatrix} \quad (24)$$

$$\begin{bmatrix} (-K^k \delta_m^k + U_L) & (K^k \delta_m^k + U_L) \\ (K^k \delta_m^k + h_i^k) e^{D\delta_m^k} & (-K^k \delta_m^k + h_i^k) e^{-D\delta_m^k} \end{bmatrix} \begin{bmatrix} A_m^k \\ B_m^k \end{bmatrix} = \begin{bmatrix} U_L T_{ism}^k \\ 0 \end{bmatrix} \quad (25)$$

where D=l^k+L, l^k is the thickness of k th wall and L is depth of Honeycomb.

Now substituting the value of $A_{i0}^k, B_{i0}^k, A_{im}^k \,\&\, B_{im}^k$ in equation (7) we get the heat flux entering the room through k th insulated wall/roof, and is given by

$$\dot{Q}^{k}(t) = -K^{k} \left.\frac{\partial T}{\partial x}\right|_{x=l} = h_i^k [(D A_{i0}^k + B_{i0}^k - T_{r0}) + \mathrm{Re} \sum_{m=1}^{6} (A_{im}^k e^{D\delta_m^k} + B_{im}^k e^{-D\delta_m^k}) e^{im\omega t} \quad (26)$$

Heat transfer between the ground and room air can be obtained by solving the Fourier heat conduction equation with appropriate boundary conditions. Fourier heat conduction equation for the ground is

$$K_g \frac{\partial^2 T_g(y,t)}{\partial y^2} = \rho_g C_g \frac{\partial T_g(y,t)}{\partial t} \quad (27)$$

Heat transfer between the ground and room air temperature can be written as

$$-K_g A_g \left.\frac{\partial T_g(y,t)}{\partial y}\right|_{y=0} = A_g h_g \{T_R(t) - T_g(y=0,t)\} \quad (28)$$

The periodic solution for the ground temperature may be taken as

$$T_g(y,t) = [(A_{g0}\, y + B_{g0}) + \sum_{m=1}^{6} A_{gm}\, e^{y\,\delta_{gm}} + B_{gm} e^{-y\delta_{gm}})e^{im\omega t}] \quad (29)$$

where $\delta_{g\,m} = (im\omega\,\rho_g\, C_g\,/\,K_g)^{\frac{1}{2}} = (\frac{m\omega}{2\kappa_g})^{\frac{1}{2}}(1+i)$ (30)

Since the ground is semi-infinite medium, so as $y \to \infty, A_{g0} \to 0 \,\&\, A_{gm} \to 0$. Therefore

$$T_g(y,t) = B_{g0} + \sum_{m=1}^{6} B_{gm} e^{-y\delta_{gm}}\, e^{im\omega t} \quad (31)$$

Solving equations (31), (28)& (14) and separating time dependent and time independent parts we get

$$B_{g0} = T_{r0} \quad (32)$$

and $$B_{gm} = \frac{T_{rm}}{1 + K_g h_g \delta_{gm}} \quad (33)$$

For an air condition building $T_{rm} = 0$, hence $B_{gm} = 0$

Therefore $T_g(y,t) = B_{g0} = T_{r0}$. (34)

Further the thermal load leveling factor is evaluated using formulation given by

$$LLF = \frac{\dot{Q}_{\max} - \dot{Q}_{\min}}{\dot{Q}_{\max} + \dot{Q}_{\min}} \quad (35)$$

ASSUMPTIONS:

The wall/roof are considered to be made of concrete material. Corresponding heat transfer coefficient and other thermo physical parameters used in these computations are listed below:

α=0.9, K^k = 0.72 W/m K, h_0=22.78 W/m^2 K, h_i=6.82 W/m^2 K, T_R=293 K. (36)

Following Kaushika [14] the heat flux across the bare wall/roof slab may be expressed as follows

$$Q(t) = U(T_{SA}^{k}(t) - T_R(t)) \quad (37)$$

The over all heat transfer coefficient for kth bare wall/roof is given by

$$\frac{1}{U} = \frac{1}{h_0} + \frac{l^k}{K^k} + \frac{1}{h_i} \quad (38)$$

For transparently insulating a wall/roof, a TIM slab of thickness L is placed on concrete wall/roof. Air gap of 10 mm is assumed to be maintained between the two slabs. The total heat loss coefficient (U_t) across the wall/roof clad with TIM is given by

$$\frac{1}{U_t} = \frac{1}{U_L} + \frac{L}{K} + \frac{1}{h_i} \tag{39}$$

and the heat flux across the insulated wall/roof slab is given by

$$Q(t) = U_t (T_{SA}^k(t) - T_R(t)) \tag{40}$$

$$\varepsilon \Delta R = \begin{cases} 61.1 W/m^2 K \ \ for\ bare\ roof \\ 0 \ \ for\ TIM\ insulated\ roof/wall \\ 0\ for\ bare\ wall \end{cases} \tag{41}$$

COMPUTATION AND DISCUSSION:

In above analysis, solar irradianceon the walls and roof have been evaluated using the formulations for the tilted surface outlined in Duffie and Beckman [5] and Kaushika [14] given by

$$I_t(t) = I_{hb}(t) R_b(t) + I_{hd}(t) R_d(t) + I_{hg}(t) R_r \tag{42}$$

Where $R_b(t) = \frac{\cos\theta_i}{\cos\theta_z}$, $R_d(t) = \frac{1+\cos\beta}{2}$, $R_r = \frac{\rho_g (1-\cos\beta)}{2}$,

$\cos\theta_z = \cos\phi\cos\delta\cos\omega_s + \sin\delta\sin\phi$, ω_s (in degree) $= 15(t-12)$,

δ(in degree) = $23.45\sin(360\frac{284+n}{365})$,

FollowingPawan Kumar [19], the angle of incidence θ_i $(0 \le \theta_i \le 90)$ vary with hour angle ω_s as :

For $\cos\omega_s > \frac{\tan\delta}{\tan\phi}$;

$$\cos\theta_i = \cos\delta\cos\omega_s\sin\phi\cos\gamma\sin\beta - \sin\delta\cos\phi\cos\gamma\sin\beta + \cos\delta\sin\omega_s\sin\gamma\sin\beta + \cos\beta\cos\phi\cos\delta\cos\omega_s + \cos\beta\sin\phi\sin\delta \tag{43}$$

and for $\cos\omega_s < \frac{\tan\delta}{\tan\phi}$;

$$\cos\theta_i = -\cos\delta\cos\omega_s\sin\phi\cos\gamma\sin\beta + \sin\delta\cos\phi\cos\gamma\sin\beta + \cos\delta\sin\omega_s\sin\gamma\sin\beta + \cos\beta\cos\phi\cos\delta\cos\omega_s + \cos\beta\sin\phi\sin\delta \tag{44}$$

The hourly values of solar radiation intensity on horizontal surface and ambient temperature for Leh have been obtained from Mani [2] and Bansal et. al. [18]. Monthly mean average values of solar intensity and ambient temperature for the hour ending at the indicated time have been used. The solar radiation intensity on horizontal surface and ambient temperature for Boulder, USA has been derived from (Duffie and Beckman [5]) by taking mean of weekly value of solar intensity and ambient temperature for the hour ending at the indicated time. The computation of solar intensity and solair temperature on the surface of walls /roof involves θ_i ; which before the time of sunrise or after the time of sunset is either very small (less than 15^0) or greater than 90^0 . In view of the step size of one hour (15^0) taken in computations we have neglected these values by taking $R_b(t)=0$ at these hours. Simultaneously we have taken negative tilt factor to be zero.

RESULTS

First of all we evaluate solar intensity and solair temperature on the surface of wall/roof of the suggested building at the given site and express the solair temperature on the surface of walls/roof slab in terms of six harmonics of Finite Fourier Series. We assume underground earth as a semi -infinite medium and then compute the heat flux entering the living space through various walls/roof slabs. As a final result we compute the load leveling factor for different walls/roof thickness and for different depth of TIM cover.The computations have been carried out using the MATLAB software.

The computational results for solar radiation intensity on walls/roof of the building for these regions show that the solar radiation intensity are very small on North wall and it increases on west wall from morning to 3 P.M. and then gradually decreases. Simultaneously the solar radiation intensity first increases and then decreases on east wall from morning to evening. The maximum intensity is obtained on south wall and the roof. It, therefore, makes sense to insulate south wall and roof by TIM device for heating purpose of the building. The computational results for hourly heat flux entering the building through all walls and roof in different insulation conditions of walls/roof in Leh, Boulder and Delhi regions for 0.10m, 0.15m and 0.20m walls/roof thickness are shown in Fig. 6(a-c), Fig. 7(a-c) and Fig. 8(a-c) respectively. It is seen that placement of TIM insulation device on south wall enhances the heat flux and hence reduces the air conditioning heating load. A panel of depth 0.10m-0.15m seems suitable for significant energy conservation in buildings of cold climates. However the total heat flux entering the indoor space exhibits diurnal variation. The capacity and the capital cost of an air-conditioning plant is determined by the range of thermal load. We have, therefore examined the load levelling of heat flux entering the indoor space in Fig. 5(a-c). The simulation results indicate significant reduction of load levelling factor with thickness of TIM cover as well as concrete walls/roof thickness. Larger thickness of TIM cover and the walls/roof would obviously involve higher costs. The lower values of load leveling factor corresponds to savings in air-conditioned heating load as well as cost. The reduction in load leveling factor would also correspond to reduction of control strategies to prevent overheating and discomfort in the living space.

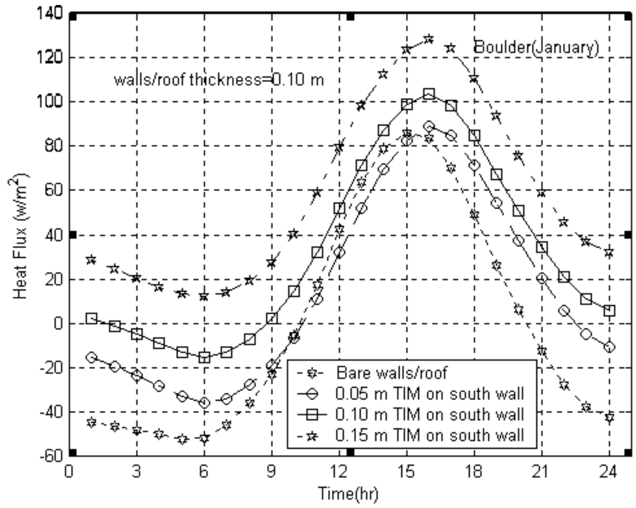
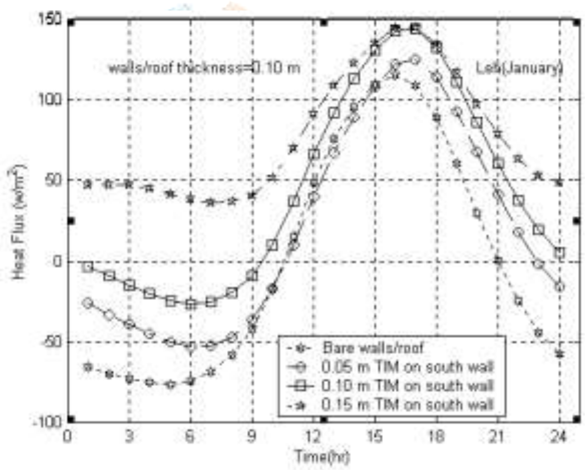


Fig 6a : Boulder



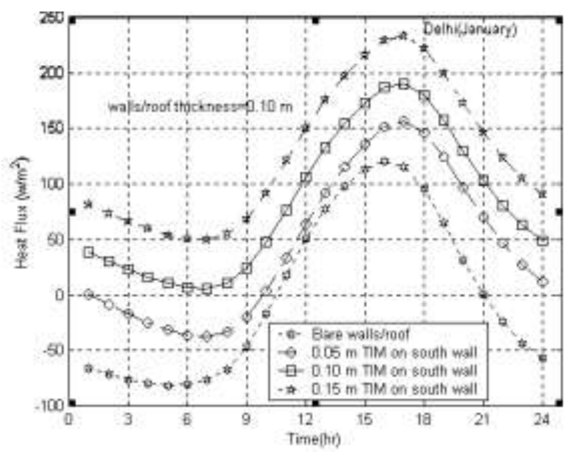


Fig 6b : Leh

Fig 6c : Delhi

Fig 6 : Total heat flux entering the room for 10cm wall thickness

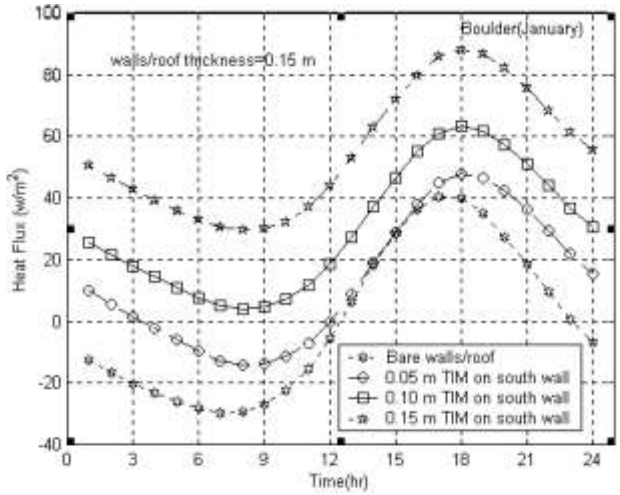
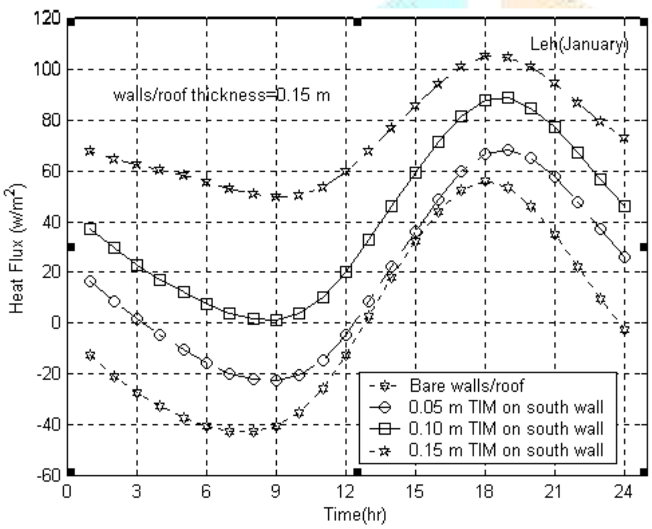


Fig 7a : Boulder



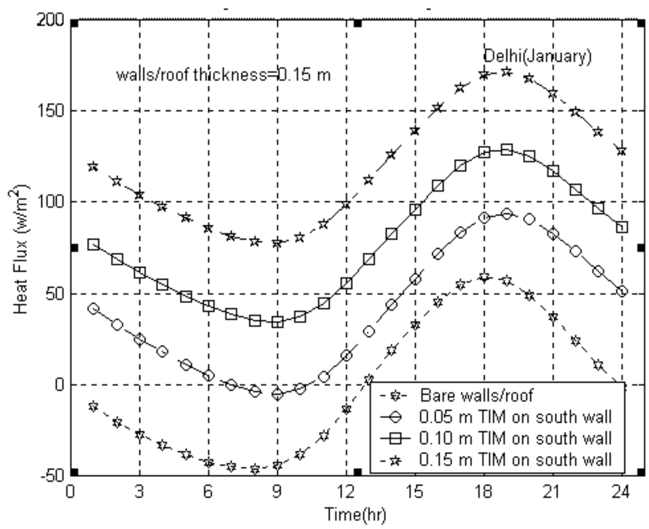


Fig 7b : Leh

Fig 7c : Delhi

Fig 7 : Total heat flux in the room for 15 cm wall thickness

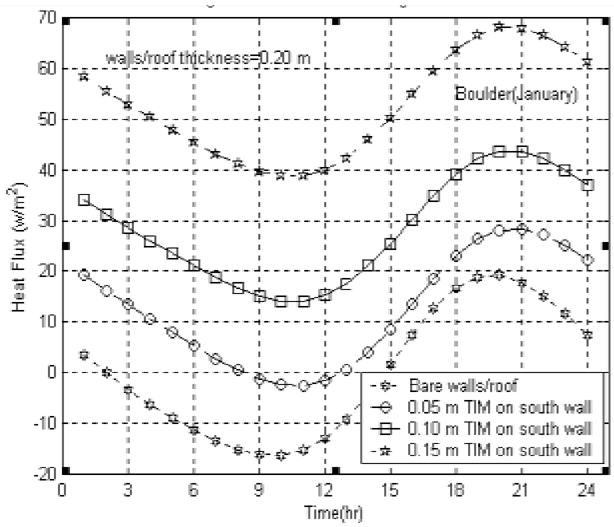


Fig 8a : Boulder

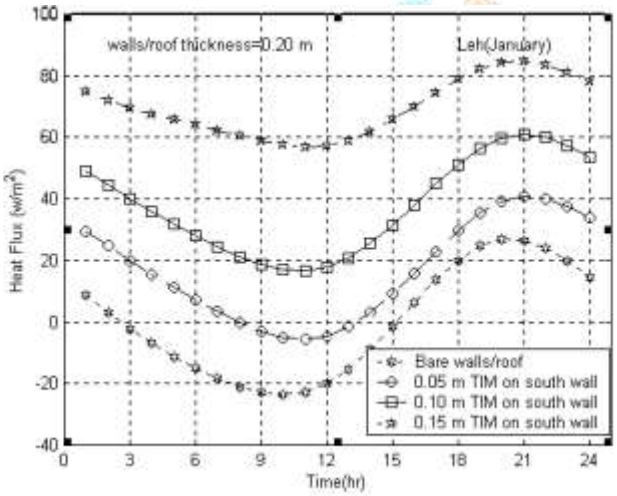


Fig 8b : Leh

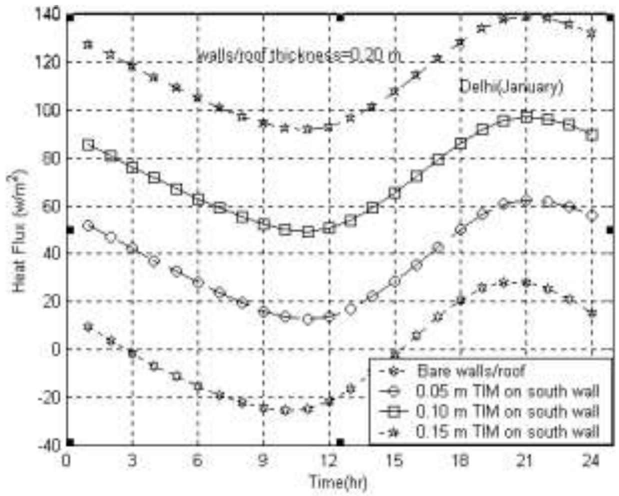


Fig 8c : Delhi

Fig: Total Heat flux entering the room for 20 cm wall thickness

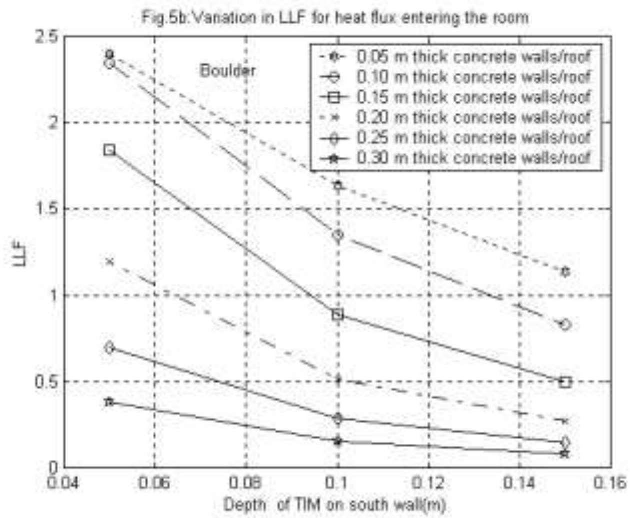


Fig 8a : Boulder

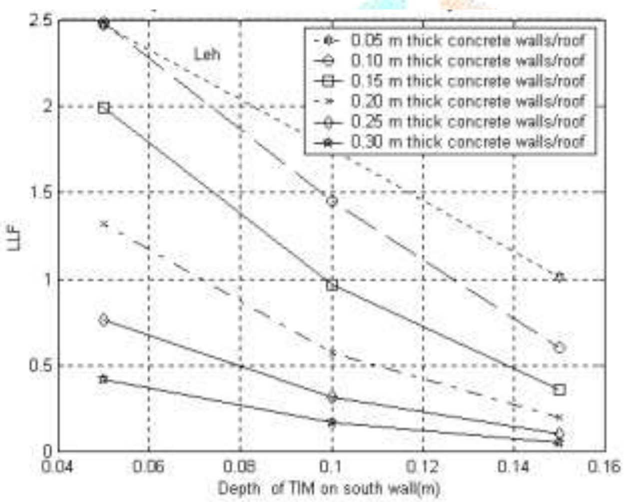


Fig 8b :Leh

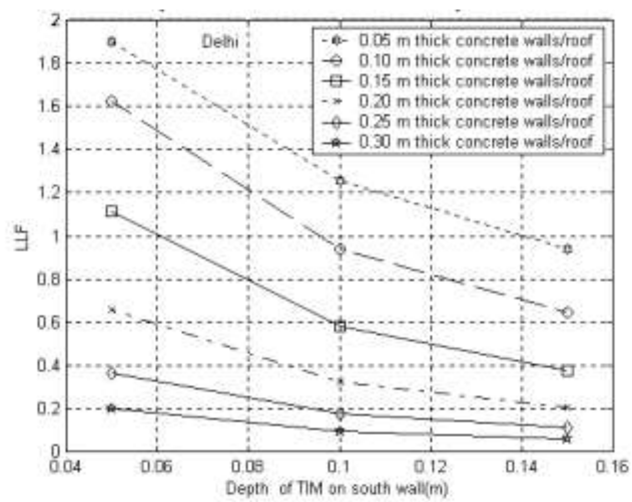


Fig 8b : Delhi

Fig 8 : Variation of LLF for heat flux entering the room

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