Building and Environment, Vol. 26, No. 4, pp. 371–380, 1991.
Printed in Great Britain.

0360–1323/91 $3.00+0.00

Design of a Non-airconditioned Passive Solar House for the Cold Climate of Srinagar

G. N. TIWARI*

The design of a passive solar house for the harsh cold climate of Srinagar in Jammu and Kashmir, India is presented. The concept of a water drum wall and transwall for heating the house has been incorporated in the design. A transient analysis based on the energy balance of different components of the proposed design has been developed by incorporating the effect of an isothermal mass within the house. Numerical computations have been carried out for a typical day in Srinagar for consecutive days to evaluate the performance of the proposed design in terms of inside room temperature. The following conclusions are drawn:

(i) the cyclic steady state condition is reached after 3 days and
(ii) the required load levelling for thermal comfort is achieved for a higher isothermal mass in the case of the transwall.

NOMENCLATURE

- A area, m^2
- A_I surface area of isothermal mass, m^2
- A_{RF} roof area, m^2
- b breadth of roof, m
- C_a specific heat of air, J/kg °C
- C_I specific heat of isothermal mass, J/kg °C
- C_w specific heat of water, J/kg °C
- h heat transfer coefficient from absorber to ambient through glass cover, W/m^2 °C
- h' heat transfer coefficient from roof sheet to ambient, W/m^2 °C
- h_I convective heat transfer coefficient from room air to isothermal mass, W/m^2 °C
- h_i convective heat transfer coefficient from inside room to room air, W/m^2 °C
- h_0 convective heat transfer coefficient from absorber to water, W/m^2 °C
- h'_0 convective heat transfer coefficient from roof sheet to moving air below sheet, W/m^2 °C
- h_t heat transfer from one water column to other through trap material, W/m^2 °C
- H heat transfer coefficient from water to ambient or room air through glass cover of transwall, W/m^2 °C
- $I(t)$ solar radiation intensity (normal to wall), W/m^2
- K_f thermal conductivity of insulation (timber), W/m °C
- K_g thermal conductivity of glass cover, W/m °C
- K_i thermal conductivity of insulation, W/m °C
- K_t thermal conductivity of trap material (Perspex), W/m °C
- L length of roof, m
- L_f floor thickness, m
- L_g thickness of glass cover (toughened), m
- L_i thickness of wooden roof/wall/floor/insulation, m
- $\dot{m}_a$ mass flow rate of air below roof, kg/sec
- M_a mass of air in room, kg
- M_I isothermal mass, kg
- M_w mass of water per m^2 of water wall/transwall, kg
- $\dot{Q}_G$ heat flux into the living room, W/m^2
- $\dot{Q}_L$ heat flux lost to ambient air, W/m^2
- T_a ambient air temperature, °C
- T_I isothermal temperature, °C
- t time, sec.
- T_R room air temperature, °C
- T_w water temperature, °C
- T_{w1} water temperature of column 1 for transwall, °C
- T_{w2} water temperature of column 2 for transwall, °C
- U overall heat transfer coefficient from living room to ambient air through glass/water wall/transwall, W/m^2 °C

Greek letters

- α absorptivity of absorber
- τ transmittivity of glass cover
- δL_w thickness of elementary layer of water column, m
- δL_{w1} thickness of elementary layer of water column 1, m
- δL_{w2} thickness of elementary layer of water column 2, m
- δL_t thickness of ditto trap material, m
- ε long wave emissivity of the surface
- $\frac{\Delta E_{bj}}{E_b}$ emissive power
- n_j extinction coefficient for water, m^{-1}
- μ_j extinction coefficient for trap material, m^{-1}
- δ_j fraction of solar radiation having extinction coefficient, n_j
- ΔR difference between the long-wave radiation, incident on the surface from sky and surroundings, and the radiation emitted by a black body at atmospheric temperature, W/m^2

Subscripts

- a ambient
- g glass cover
- G gain
- i insulation
- j harmonics
- R room
- t trap material (Perspex)
- w water.

*Centre for Energy Studies, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi 110 016, India.

1. INTRODUCTION

THE DESIGN of a house from the thermal comfort point of view depends on the climatic conditions of the location. The climatic conditions in India are mainly classified into three categories, namely harsh cold climate, harsh warm conditions and mixed conditions of cold and warm. For each category, thermal comfort for human life is set at around 20°C living temperature with maximum thermal load levelling. The living temperature around 20°C with maximum thermal load levelling or zero fluctuation in living temperature over a fixed period is referred to as the airconditioned house. This condition is achieved by active methods. If the living room temperature cannot be maintained at around 20°C with fluctuation in living room temperature, the condition is referred to as the non-airconditioned situation. In the proposed design, the discussion has been concentrated on the non-airconditioned house and the heating of the house will be by passive methods using the thermal energy available from the sun's radiation.

Reviews of non-airconditioned and airconditioned houses using different concepts for their heating and cooling have been carried out in detail by Sodha *et al.* [1] and Kaushik *et al.* [2], respectively. If the house is heated by using solar thermal energy through the design of the house, the system is referred as a "passive solar house for heating".

Basically, there are three components in the house, viz walls, roof and the isothermal mass within the house. Before designing a house, each component should be studied rigorously to achieve thermal comfort along with the level of solar insolation and ambient air temperature, particularly in the case of heating the living room. It is observed that for harsh cold climatic conditions, where the ambient air temperature generally goes much below zero degrees Centigrade, housing is mostly constructed from the following materials:

(i) timber,
(ii) galvanized iron sheet,
(iii) glass.

The roof of such a house is constructed by using the base of wooden material as a support and on the top of this support there is sheet metal which is easily available at location. The capacity of the isothermal mass within the house can be adjusted by the well-known method of water tanks inside the house as is done in greenhouses. The use of an isothermal mass can only effect a fluctuation in living room temperature, which is very important from a thermal comfort point of view.

The external walls are the only component of house through which passive heat gains can be made by the following methods:

(i) direct gain,
(ii) indirect gain.

In the direct method, this can be achieved by using the glass cover which is responsible for a "greenhouse effect", while in the case of the indirect method the thermal energy is absorbed and stored in one medium and released later on towards living space, e.g. trombe wall—Sodha *et al.* [1], water wall—Maloney and Habib [3], transwall—Fuchs and McClelland [4] and Sodha *et al.* [5].

Nayak *et al.* [6] have presented a cyclic steady state analysis of an enclosure for using different heating concepts based on their earlier thermal model of a solarium [7]. Their analysis was general in terms of considering all components of enclosed air (building) [8]. Their analysis was limited to cyclic steady state conditions and cannot be applied to transient modes of operation of a passive solar house under similar conditions.

In this communication, the proposed design of a solar house (Fig. 1) has been studied for climatic conditions of Srinagar by using a transient thermal model which can also be extended to a cyclic steady state condition. The proposed model also includes the concept of a water wall and transwall [9] with removable insulation during off sunshine hours to reduce the heat losses from the system to the outside environment. An expression for the inside room temperature has been evaluated in terms of system as well as climatic parameters. The details of the water wall and transwall are discussed in a later section. Numerical calculations have been carried out for a typical day in Srinagar by using the present thermal model of the proposed design.

2. DESIGN OF PROPOSED HOUSE

The floor plan/layout of the proposed house under study is shown in Fig. 1a. It is a two room apartment with other facilities—kitchen, bathroom and toilet. The two living rooms have been divided by a wooden wall of lower height than the ceiling so that both room temperatures can be considered the same. Since the level of insolation is a maximum for a south facing wall, most of the solar radiation will be trapped inside the living room from the south wall by using different heating concepts such as a glass cover (Fig. 1b), a water drum wall (Fig. 1c) and a transwall (Fig. 1d) respectively. There is also provision of a window in the east and west walls (Fig. 1a) respectively. The size of the window can be optimized as required before construction of the house to raise the living room temperature. For further heating the space provided between the wooden base and metallic sheet can be used to circulate room air for heating. This can be done either in thermosiphon mode or forced circulation mode. In thermosiphon mode, the flow of air below the metal sheet should be in the opposite direction, i.e. from the lower end to the upper end with a large inclination of the roof. In this case, room air will enter through the lower end, is heated and moves up and will be distributed uniformly throughout the room with the help of a fan inside the room. In the forced circulation mode, an electric fan will be made available either at the inlet (as shown in Fig. 1) or at the outlet for a uniform flow of air in a space provided between the metallic roof and wooden base. In this way, the air will have more time to be heated more effectively than in thermosiphon mode due to the flow opposite to gravity. The height of all partition walls is less than the ceiling so that the assumption of uniform temperature throughout the living room can be made. Further, the additional heat generated during cooking can be added to the enclosed room for thermal comfort in the kitchen if required. It may also be mentioned that

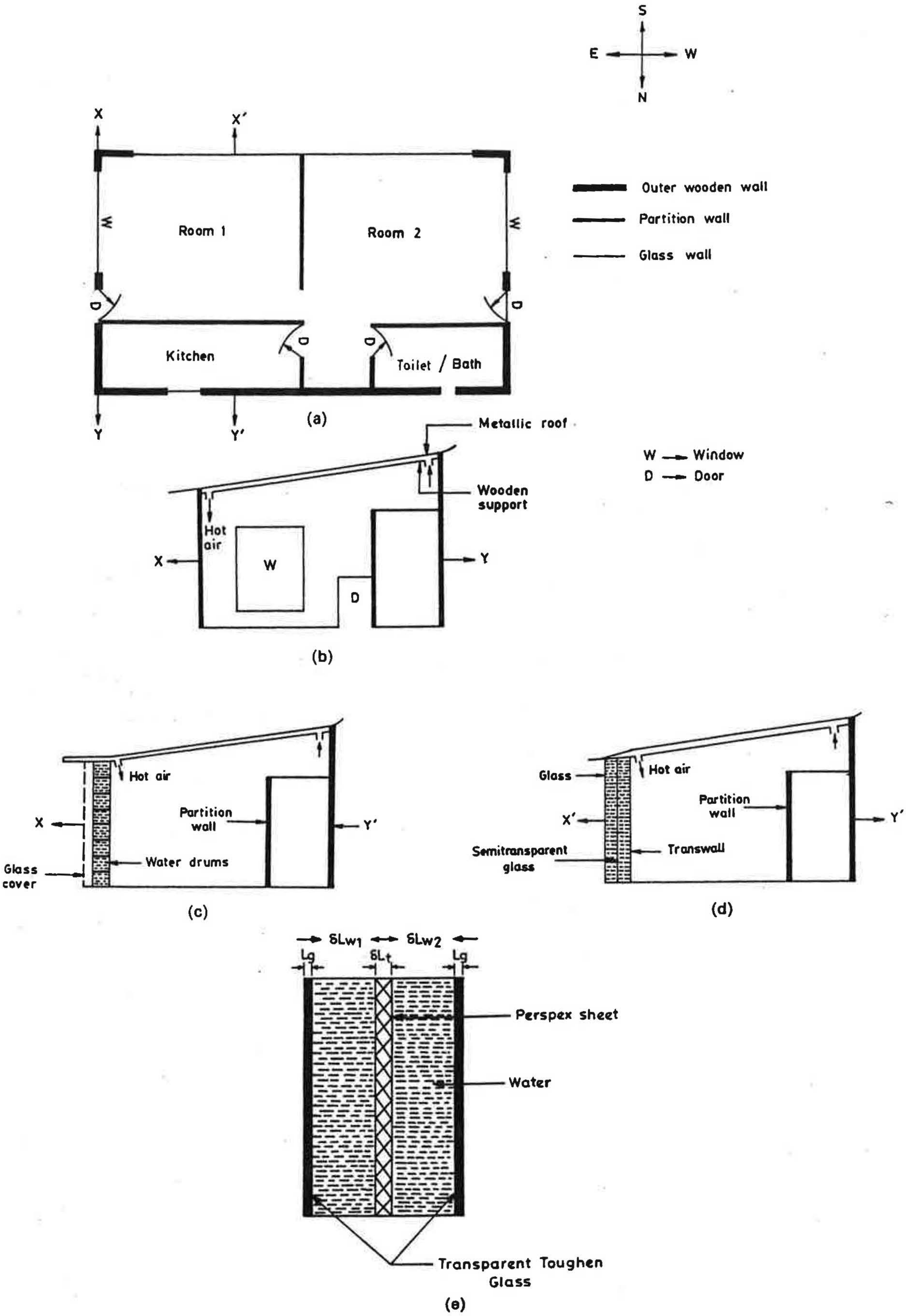

Fig. 1. (a) The floor plan of the proposed winter house. (b) Cross-sectional view at X–Y of the proposed plan. (c) Cross-sectional view at X′–Y′ of the proposed plan with water wall in south. (d) Cross-sectional view at X′–Y′ of the proposed plan with transwall in south. (e) Cross-sectional view of transwall in detail.

the heat gain through the wooden wall is negligible due to the highly insulating properties of wood.

It has been observed by earlier workers as well as in the present calculation that to reduce the fluctuation in living room temperature, the heat capacity of the isothermal mass should be increased. To achieve this condition, water drums of large size are provided in the living room which occupies living floor area. In order to avoid this problem, the use of two new concepts has been studied in detail. These are the following.

(a) *Water drum wall*

The concept of a water drum wall is depicted in Fig. (1c). It consists of two parallel metallic sheets. The space between two metallic sheets is fixed by providing different joints as shown in Fig. 1c. The space is filled with water containers so that there will not be any leakage in the system. The south facing surface is blackened and glazed for trapping maximum solar radiation. Once the solar radiation is absorbed by the blackened surface, it is transferred to the water which is heated storing the thermal energy. This stored energy is released slowly to the inside environment of the living space. During off-sunshine hours, the front portion is covered with an adequate amount of insulation to reduce heat loss. In such a way, the living room is heated with less fluctuation in temperature. The disadvantages of this concept are:

(i) corrosion of the metallic sheet, and
(ii) light coming into the living space is blocked.

The above problems can be solved by using a transwall.

(b) *Transwall*

The cross-sectional view of a transwall is depicted in Fig. 1e. In this case, the metallic parallel sheets of the drum wall are replaced by glass sheet (preferably toughened glass of larger thickness to avoid bulging due to water) and between the two glass covers, semitransparent material of an appropriate thickness which (i) partially absorbs solar radiation with that remaining transmitted through the cover and (ii) reduces the pressure on the glass cover. This is done by keeping the total water column constant for comparison purposes. This system solves the corrosion problem and also allows light inside the living space which is not possible in the case of the water drum. The semi-transparent partition cover also acts as insulation during night hours. Due to these advantages, the transwall gives better performance in terms of thermal load levelling than two other cases which will be explained in the next section. A south wall as a transwall, as an integral part of the proposed design, is shown in Fig. 1d. Basically, a complete south wall consists of a number of transwalls having dimensions of 1 m × 1 m (preferably) to cover the entire exposed wall for efficient working. In the case of water leakage in the transwall, it can be taken out from the wall and replaced by another before repairing. The transwall is fitted in a metal frame to give strong support to the system.

3. ASSUMPTIONS FOR THERMAL ANALYSIS

In order to evaluate the transient as well as periodic behaviour (cyclic steady state consideration) of the proposed system, the following assumptions have been made:

(i) there is no stratification in living enclosures,
(ii) temperatures in all rooms are same due to lower height of the partition wall,
(iii) heat capacity of enclosed air is negligible in comparison to the isothermal mass (for present case, water),
(iv) all glazed exposed surfaces are covered with appropriate insulating material to reduce night heat losses,
(v) the heat generated during cooking is uniformly distributed over a certain period if required.

4. ENERGY BALANCE

The energy gain from the different components, namely glass wall/window, water wall and transwall, in terms of Joules per sec per m^2 into the living room are as follows [10]:

Glass walls/windows:

$$\dot{Q}_G = \tau I(t) - U(T_R - T_a)$$

(Net heat available) = (Rate of heat transmitted) − (Rate of heat loss from room to ambient through wall). (1)

Water wall:

$$\dot{Q}_G = h_i(T_w - T_R) - U(T_R - T_a)$$

(Net heat available) = (Rate of heat transferred from water to room) − (Rate of heat loss from room to ambient through wall)

$$= \frac{h(\alpha\tau)}{h_0 + h} I(t) - \frac{h_0 h}{h_0 + h}(T_w - T_a) - M_w C_w \frac{dT_w}{dt} - U(T_R - T_a). \quad (2)$$

Transwall:

$$\dot{Q}_G = I(t) \sum_{j=1}^{5} \delta_j \exp(-n_j \delta L_{w1}) \sum_{j=1}^{5} \frac{\Delta E_{bj}}{E_b} \times \exp(-\mu_j \delta L_t)\left\{1 - \sum_{j=1}^{5} \delta_j \exp(-n_j \delta L_{w2})\right\} - U(T_R - T_a) \quad (3)$$

(Net heat available) = (Rate of heat transmitted through wall to room) − (Rate of heat loss from room to ambient)

where the values of U are given by (i) during sunshine hours:

$$U = \left[\frac{1}{h_0} + \frac{L_g}{K_g} + \frac{1}{h_i}\right]^{-1}, \quad \text{for glass cover}$$

$$= \left(\frac{1}{h_0} + \frac{1}{h} + \frac{1}{h_i}\right)^{-1}, \quad \text{for water wall}$$

$$= \left(\sum \frac{1}{h_i} + \frac{L_t}{K_t}\right)^{-1} \cong \frac{K_t}{\delta L_t} \quad \text{for transwall,}$$

and (ii) during off-sunshine hours:

$U \cong \frac{K_i}{L_i}$ for all cases when the system is covered with insulation, effect of other heat transfer coefficient will be negligible,

and the values of δ_j, n_j, μ_j and $\Delta E_{bj}/E_b$ are given in Tables 1 and 2 respectively. Table 3 gives the net attenuation factor due to water and trap material.

Roof:

$$\dot{Q}_G = \frac{\dot{m}_a C_a}{A_{RF}}(1-e^{-aL})\left\{\frac{\overline{f(t)}}{a} - T_R\right\} - U(T_R - T_a) \quad (4)$$

(Net heat available) = (Rate of heat transferred to room) − (Rate of heat lost from room to ambient)

where,

$$a = \frac{1}{\dot{m}_a C_a}\frac{bh'h'_0}{h'+h'_0}$$

$$\overline{f(t)} = \frac{1}{\dot{m}_a C_a}\left[\left(\frac{bh'_0}{h'_0+h'}\right)\{\alpha\overline{I(t)} - \varepsilon\Delta R\} + \frac{bh'h'_0}{h'+h'_0}\overline{T}_a\right]$$

During off-sunshine hours, $\dot{m}_a = 0$.

Isothermal mass:

$$h_I(T_R - T_I)A_I = M_I C_I \frac{dT_I}{dt} \quad (5)$$

(Amount of heat transferred from room air to isothermal mass) = (amount of heat stored by isothermal mass).

Wooden wall:

$$\dot{Q}_L = -U(T_R - T_a) \quad (6)$$

= rate of heat lost to surrounding through walls

where,

$$U = \left(\frac{1}{h_0} + \frac{1}{h_i} + (L_i/K_i)\right)^{-1} \cong (K_i)/(L_i).$$

Wooden floor:

$$\dot{Q}_L = -U(T_R - T_a) \quad (7)$$

= amount of heat lost to surroundings through wooden floor

Table 1. Extinction coefficient of polymethylmethacrylate (i.e. Perspex) plastic for five wavelength regions (for semi-transparent material) [11]

j	Wavelength λ (μm)	Emissive power $\Delta E_{bj}/E_b$	Extinction coefficient μ_j (m^{-1})
1	$0 \leq \lambda < 0.36$	0.0667	∞
2	$0.36 \leq \lambda < 1.06$	0.6615	2.3786
3	$1.06 \leq \lambda < 1.3$	0.0923	12.5328
4	$1.3 \leq \lambda < 1.6$	0.0664	31.0039
5	$1.6 \leq \lambda < \infty$	0.1132	∞

Table 2. The values of δ_j and n_j for different j for water-mass [11]

j	Wavelength λ (μm)	δ_j	Extinction coefficient n_j (m^{-1})
1	$0 \leq \lambda < 0.36$	0.237	0.032
2	$0.36 \leq \lambda < 1.06$	0.193	0.45
3	$1.06 \leq \lambda < 1.3$	0.167	3.00
4	$1.3 \leq \lambda < 1.6$	0.179	35.0
5	$1.6 \leq \lambda < \infty$	0.224	255.0

where,

$$U = \left(\frac{1}{h_0} + \frac{1}{h_i} + \frac{L_f}{K_f}\right)^{-1} \cong \frac{K_f}{L_f}.$$

Room air:
[Net heat gain from walls/window and roof] − [heat lost to surrounding due to wooden walls/floor-heat transferred to isothermal mass]

$$= M_a C_a \frac{dT_R}{dt}. \quad (8)$$

Water column of transwall:

Column 1:

$$I(t)\left\{1 - \sum_{j=1}^{5} \delta_j \exp(-n_j \delta L_{w1})\right\} = M_{w1} C_{w1} \frac{dT_{w1}}{dt} + H(T_{w1} - T_a) + h_t(T_{w1} - T_{w2}) \quad (9)$$

Column 2:

$$I(t)\left\{1 - \sum_{j=1}^{5} \delta_j \exp(-n_j \delta L_{w2})\right\} \times \sum_{j=1}^{5} \delta_j \exp(-n_j \delta L_{w1}) \sum_{j=1}^{5} \exp(-\mu_j \delta L_t)\frac{\Delta E_{bj}}{E_b}$$
$$= M_{w2} C_w \frac{dT_{w2}}{dt} - h_t(T_{w1} - T_{w2}) + H(T_{w2} - T_R). \quad (10)$$

Equation (8) has been solved for living room air temperature for the following cases under transient as well as cyclic steady state conditions.

Table 3. The variation of attenuation factor with water and semitransparent depth respectively (calculated by using Tables 1 and 2 respectively)

δL (m)	$\Sigma \delta j \exp(-n_j \delta L_w)$	$\Sigma(\Delta E_{bj})/(E_b) \times \exp(-n_j \delta L_t)$
0.20	0.51	0.4187
0.10	0.5492	0.5508
0.08	0.5648	0.5863
0.06	0.5858	0.6274
0.04	0.6185	0.6766
0.02	0.6756	0.7229
0.01	0.7344	0.7761
0.008	0.7565	0.7843
0.004	0.831	0.8016
0.0	1.0	0.8202

(i) The south wall has a glass cover without isothermal mass [equations (1) and (3) respectively].
(ii) The south wall has a glass cover with isothermal mass [equations (1), (5) and (8) respectively].
(iii) The south wall has a glass cover with isothermal mass and roof as an air heater (equations (1), (4), (5) and (8) respectively].
(iv) The south wall has a water wall without isothermal and with roof as an air collector [equations (2), (4) and (8) respectively].
(v) The south wall has a transwall without isothermal mass and with roof as an air collector [equations (3), (4) and (8) respectively].

In the case of (iv) and (v) only the heat capacity of room air has been neglected because of small heat capacity of air. This has been observed by the numerical calculations.

Equation (8) can be written as

$$\frac{dT_R}{dt} + a_0 T_R = g(t) \tag{11}$$

where a_0 is a constant depending on various heat transfer coefficients and design parameters while $g(t)$ is a function of solar intensity and ambient air temperature in addition to other design parameters. The expression for a_0 and $g(t)$ can be obtained after algebraic simplification after substituting an appropriate values in equation (8).

The solution of above equation is

$$T_R = \frac{g(\bar{t})}{a_0} 1 - \exp(-a_0 t) + T_{R0} \exp(-gt) \tag{12}$$

where $g(\bar{t})$ is the average of $g(t)$ over a period of 0–t which depends on system as well as climatic parameters and a_0 is a constant only depends on system parameters.

5. RESULTS AND DISCUSSION

In order to evaluate the performance of the proposed design in terms of room air temperature, the following parameters and Table 4 have been used:

$\alpha = 0.9$
$\tau = 0.9$
$C_w = 4190$ J/kg °C
$\delta L_{w1} = \delta L_{w2} = 0.05$ m
$\delta L_w = \delta L_{w1} + \delta L_{w2} = 0.10$ m
$\rho_w = 1000$ kg/m^3
$K_t = 0.20$ W/m °C
$K_g = 0.78$ W/m °C
$K_i = 0.060$ W/m °C
$\delta L_t = 0.01$ m
$L_g = 0.004$ m
$L_i = 0.04$ m
$L = 11$ m
$\varepsilon \Delta R = 200$ W/m^2
$\dot{m}_f = \dot{m}_a = db\rho_a u$
$d = 0.05$ m
$b = 10$ m
$\rho_a = 1.2$ kg/m^3
$u = 1$–5/sec
$h_i = 20$ W/m^2 °C
$h_0 = 75$ W/m^2 °C
$h = 8$ W/m^2 °C
$h' = 20$ W/m^2 °C
$h'_0 = 75$ W/m^2 °C
$h_1 = 20$ W/m^2 °C
$M_w = M_{w1} + M_{w2} = 100$ kg/m^2
$M_{w1} = M_{w2}$
$M_a = 316$ kg
$C_a = 1000$ J/kg °C
$M_I = 1000$ kg
$C_I = C_w$ (assumed)

Figure 2 represents the variation of room air temperature with and without roof as an air collector. It is clear that there is an increase of about 5°C due to additional heat supplied to the living room by blowing air through the space provided in the roof. In this case, the effect of the isothermal mass has not been considered, hence there is a significant fluctuation in room temperature without a phase shift of maxima of room temperature with respect to solar intensity. The effect of the isothermal mass is shown in Fig. 3. From this one can also conclude that the condition of thermal load levelling along with phase shift was observed as expected. The same calculations used for Fig. 3 were extended for a further few days for the same sets of parameters to see the effect of the steady state condition and has been plotted in Fig. 4. It can be observed that steady state conditions were achieved after 3 days (Fig. 4b) which is due to considering the isothermal mass.

A comparison of different concepts of direct and indirect heating (water as well as transwall) are shown in Fig. 5 under cyclic steady state condition. Figure 5 indicates that the performance of the transwall is better than both isothermal mass and water wall. In the case of the transwall, the best load levelling along with appropriate thermal control (about 20°C) is achieved for given sets of parameters by a thickness of 0.10 m. Table 5 gives the maximum and minimum room air temperature under

Table 4. Area of different components of the proposed house plan

Components	Area (m^2)	Components	Area (m^2)
South wall (glass)	9 × 3 = 27	Floor (wood)	10 × 6 = 60
South wall (wood)	13	Roof (wood + sheet)	10 × 6.1 = 61
East wall (wood)	23	Isothermal	6
West wall (wood)	23	Water wall	27
North wall (wood)	50		
Door (wood)	1.9 × 0.9 = 1.71	Transwall	27
Window (glass)	2 × 2 = 4		

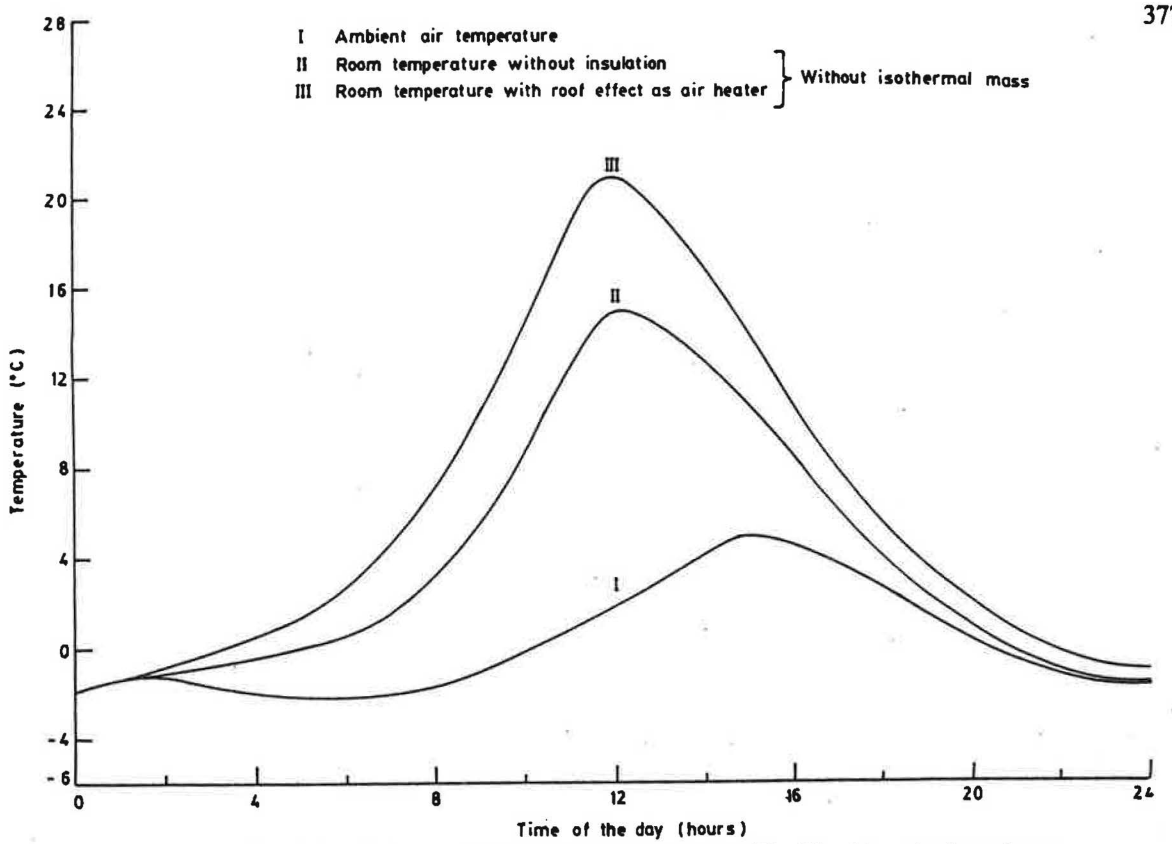

Fig. 2. Effect of roof air collector on enclosed room air temperature (Fig. 1b) without isothermal mass ($M_I \approx 0$).

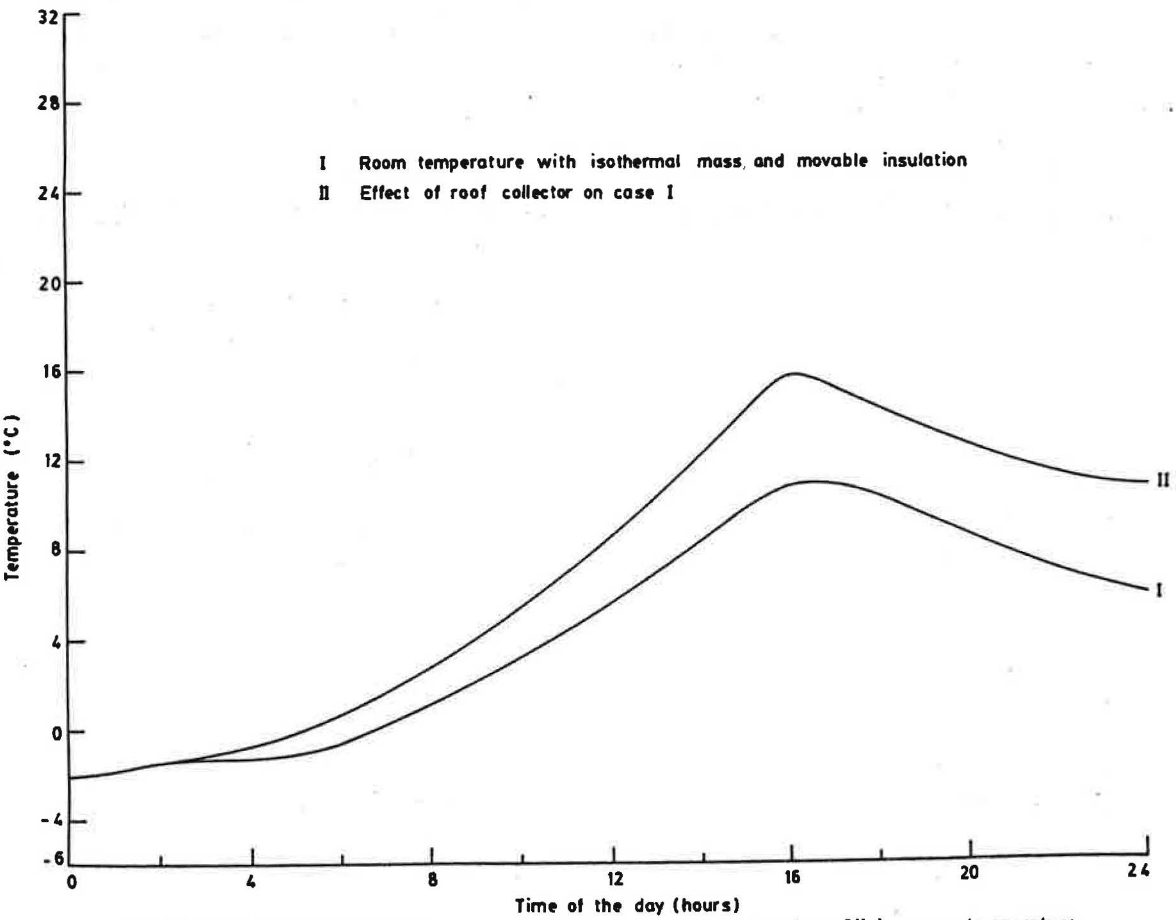

Fig. 3. Effect of isothermal mass and movable insulation on hourly variation of living room temperature.

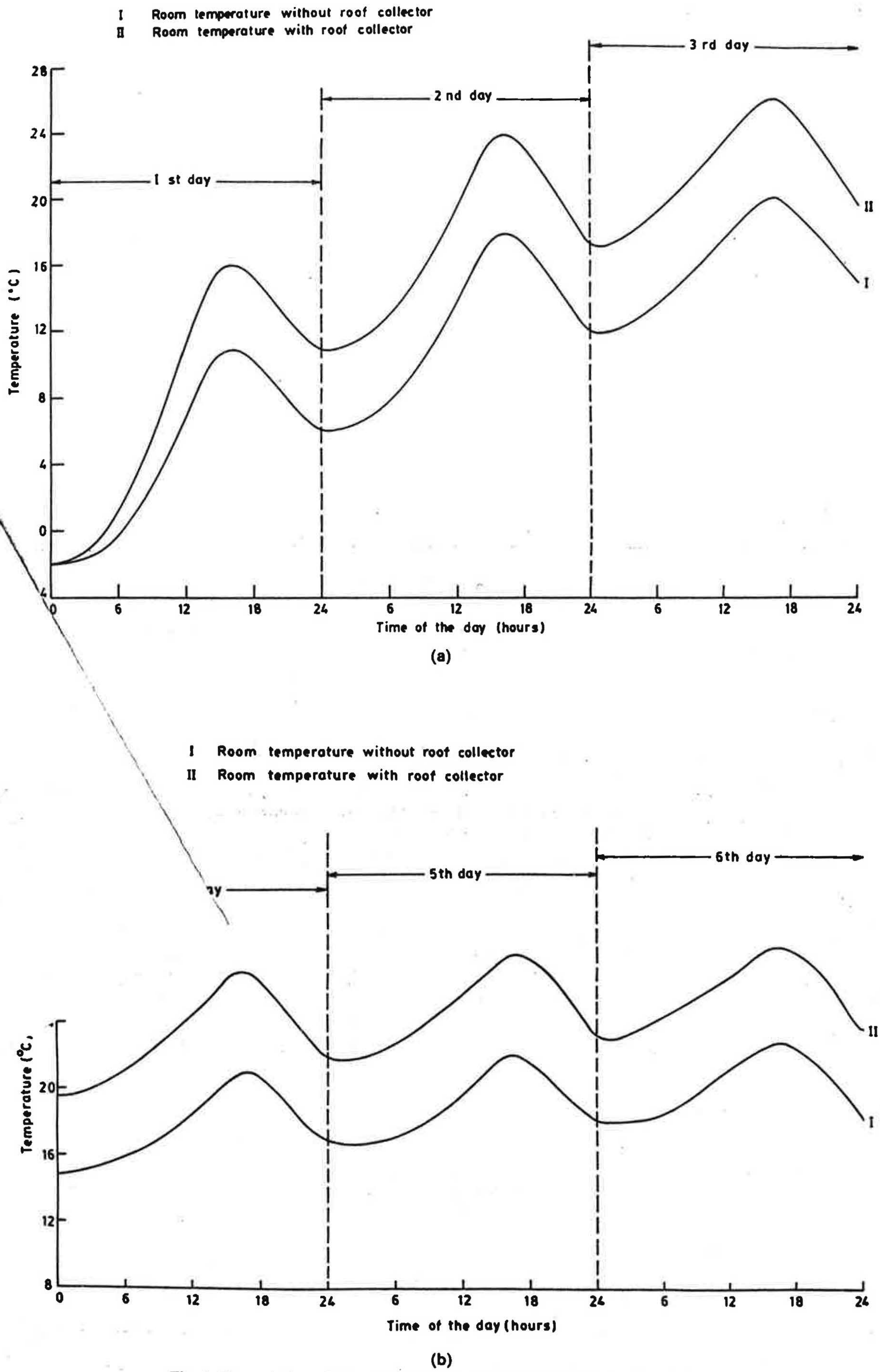

Fig. 4. The variation of living room temperature with time for a number of days.

Table 5. The maximum and minimum room air temperature for different south wall conditions

	Water wall		Isothermal mass		Transwall	
Days	T_R (max) °C	T_R (min) °C	T_R (max) °C	T_R (min) °C	T_R (max) °C	T_R (min) °C
1	13.1	−2	18.2	−2	13.8	−2
2	15.9	6.3	20.9	7.8	17.2	10.2
3	18.6	8.9	23.8	10.5	20	13.0
4	20.1	13.1	25.4	14.9	21.1	17.3
5	20.8	14.3	26.1	16.1	22.3	18.2
6	21.2	15.1	26.7	17.3	22.8	19.1

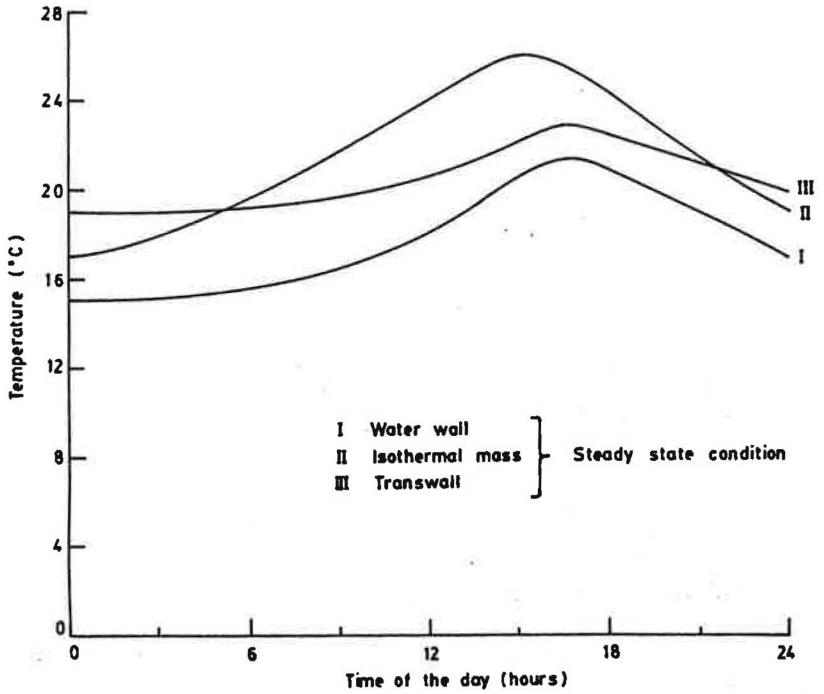

Fig. 5. A comparison of performance of room air temperature under steady cyclic conditions.

different south wall conditions, namely direct gain (isothermal mass) and indirect gain (water and transwall). From this table, it is inferred that conclusion drawn from Fig. 5 is same for all days from the 1st to 6th day under similar climatic conditions.

The water temperature for the transwall can be obtained by using equations (9) and (10) respectively.

6. CONCLUSIONS

On the basis of numerical calculations, the following conclusions have been drawn:

(1) the condition of cyclic steady state with required thermal load levelling is achieved after 3–4 days by considering the effect of either isothermal mass or water and transwall (Fig. 5).
(2) the transwall gives better performance than other cases (isothermal and water wall) (Fig. 4b).
(3) there is a significant effect in living room temperature due to additional heat provided to living room from roof air collector (Fig. 2).
(4) the fluctuation in living room temperature increases with decrease of isothermal mass as expected.

REFERENCES

1. M. S. Sodha, N. K. Bansal, P. K. Bansal, A. Kumar and M. A. S. Malik, *Solar Passive Building: Science and Design*, Vol. 2. Pergamon Press International Series on Building Engineering. Oxford (1986).
2. S. C. Kaushik, G. N. Tiwari and J. K. Nayak, Thermal control in passive solar building. Geo-Environ. Academia, Jodhpur, India (1988).
3. T. J. Maloney and V. Habib, Design fabrication and testing of marketable waterwall components. DOE report DES-5171-2 (1979).

4. R. Fuchs and J. F. McClelland, Passive solar heating using a transwall structure. *Solar Energy* **23**, 123–128 (1971).
5. M. S. Sodha, N. K. Bansal and Sant Ram, Periodic analysis of a transwall: a passive heating concept. *Appl. Energy* **14**, 33 (1983).
6. J. K. Nayak, M. S. Sodha and N. K. Bansal, Analysis of passive heating concepts. *Solar Energy* **30**, 51–69 (1983).
7. M. S. Sodha, J. K. Nayak, N. K. Bansal and I. C. Goyal, Thermal performance of a solarium with a removable insulation. *Bldg Envir.* **17**, 23–32 (1982).
8. J. D. Balcomb and R. D. McFarland, A simple empirical method for estimating the performance of a passive solar heated buildings of a thermal storage wall. *Proc. 2nd National Passive Solar Conference*, **2**, 377 (1978).
9. Rashmi Rakshit, Evaluation of passive techniques in non-conditioned buildings. Ph.D. Thesis, I.I.T., Delhi (1986).
10. G. N. Tiwari, Optimisation of various passive heating concept for airconditioned room. *Energy Conversion and Management* (Communicated, 1990).
11. G. N. Tiwari, Usha Singh and J. K. Nayak, Applied Solar Thermal Energy Devices, Kamala Kuteer Publication (AP, India (1985)).