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Solar Thermal Modeling Of A Non –Air Conditioned Room With A Southern Thermal Storage Walls

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Abstract

In this paper a drum water wall consists of metallic containers filled with water. Outer surface of this wall is blackened and glazed, while the inner surface is directly contact with a massive wall. With the help of appropriate energy balance conditions, the Fourier equation of heat conduction has been solved to drive the explicit expression for the indoor temperature and heat-flux entering the living space as a function of time. Since the ambient temperature and solar radiation vary periodically, the periodic solution for equation of heat conduction has been considered in the analysis. This lead to closed form solutions.

The effect of drum water depth, massive wall and thickness are studied in this paper. Numerical calculations have been carried out for a typical cold day in Baghdad on 21- January-2000.

It is found that the average indoor temperature and heat flux into the living space is maximum for water-concrete configuration.

التمثيل الحراري لبناية غير مكيفة ذات جدران جنوبية خازنة للحرارة

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الخلاصة

في هذه الدراسة تم استحداث جدار خازن للحرارة يتكون من جدار مائي مبني من حاويات معدنية صغيرة مملوءة بالماء. السطح الخارجي لهذا الجدار ذو لون اسود و مغطى بطبقة من الزجاج، في حين أن السطح الداخلي في حالة تماس مباشر مع جدار الغرفة الجنوبي.

تم حل معادلة فورير لانتقال الحرارة باتجاه واحد خلال جدار مستوي باستخدام ظروف موازنة حرارية مناسبة. و من خلال الحل تم الحصول على صيغة حل رياضي محدد لتغير الحرارة الداخلية والحرارة المنتقلة إلى الغرفة. وبما إن درجة الحرارة الخارجية والإشعاع الشمسي يتغيران زمنيا. لذلك تم اعتبار إن الحرارة المنتقلة إلى البناية خلال تركيبها تتغير زمنيا أيضا.

تم دراسة تأثير سمك الجدار المائي و مواد بناء الجدار الجنوبي و سمكه على الأداء الحراري للغرفة،كذلك تم إجراء حسابات رقمية ليوم ٢١ من شهر كانون الثاني لعام ٢٠٠٠. ومن خلال الحسابات تم التوصل إلى إن معدل درجة الحرارة الداخلية و معدل الحرارة المنتقلة إلى الغرفة خلال الجدار الجنوبي في حدهما الأعلى لجدار على هيئة ماء + كونكريت.

1. Introduction

Energy conservation in buildings is usually perceived as reducing energy consumption, whether the conserved energy is renewable or nonrenewable. A Trombe wall represents a simple way of collecting solar energy and stored it release the energy to the living space at later time. Then simply Trombe wall can be regarded as conservation system.

A Trombe wall is a thick wall built up either by concrete or stone. The outer surface of the wall is painted dark to absorbed solar energy and stored as a sensible heat within the wall and transferred it by conduction through the wall and by convection and radiation to the living space.

A water wall is considered as a liquid thermal storage medium, which is based on the same considerations as massive Trombe wall. In water wall, drums of water are arranged up one above the other behind the collector glazing. The solar energy is absorbed by water drums and converted into heat, stored heat in the water and transferred by convective and radiation to the living space.

In this communication a drum water wall consist of metallic containers with water. One surface of the wall is blackened and glazed, while the another surface is directly contact with a massive wall.

The water concrete configuration is assumed as a southern wall of a room, and the effect of water depth, massive wall materials and the thickness on the room thermal performance are studied.

2. Analysis

A building room of rectangular shape, with dimensions of 6m long,5m wide and 4m height, based on the ground is considered. The following reasonable a assumptions are made.

i. All walls except southern walls are of identical materials and the same thickness as in reference (1).
ii. The southern wall is consist of outer glass sheet of 6mm thickness, cavity, water column and massive wall.
iii. The roof of identical materials as in reference (2).
iv. Heat flow in the walls and roof is always transverse to their surface area.
v. The inside air temperature is uniform in space through the room.
vi. Steady state heat transfer through the window.
vii. The outer surfacer of walls and roof are exposed to solar radiation and ambient air which are assumed as a periodic function of time.
viii The outside are temperature for all walls/roof is assumed in fairly true for a building of moderate height.

2.1 Periodic Heat Flux Through Walls and Roof

The temperature distribution in the walls and roof is characterized by one-dimensional heat conduction equation.

$$\frac{\partial 2T_{j,t,x}}{\partial X^2} = \frac{1}{\alpha_j} \cdot \frac{\partial T_{j,t,x}}{\partial t} \qquad (1)$$

Where α_j is the thermal diffusivity of the jth wall/roof material and can be expressed as :

$$\alpha_j = \frac{K_j}{\rho_j \cdot C_j}$$

Equation (1) can be solved by separation of variables techniques as[3] :

$$T_{j,t,x} = A_{oj} \cdot x_j + B_{oj} + \sum_{m=1}^{6} \left(A_{j,m} \cdot e^{\gamma_{j,m} \cdot X_j} + B_{j,m} \cdot e^{-\gamma_{j,m} \cdot X_j} \right) e^{imw} \qquad (2)$$

Where:

$$\gamma_{j,m} = \sqrt{\frac{i.m.w}{\alpha_j}}$$

Where:

$$w = \frac{2\pi}{24} \left(h^{-1} \right)$$

2.1.1 Periodic Heat Flux Through Southern Wall

A schematic sketch for the southern wall is shown figure (1). The heat conduction equation (1) is supplemented with following boundary conditions:

at X = 0

$$-K3.\frac{dT_{3,t,x}}{dx} = hw\left(TW_t - T_{3,t,x}\right) \qquad (3)$$

Where TW_t is the water column temperature and can be expressed by fourier series as [7]:

$$TW_t = Two + \sum_{m=1}^{6} TWM_m.e^{imwt} \qquad (4)$$

at $X=X_3$

$$-K_3 \frac{dT_{3,t,x}}{dx} = h_2 \left[T_{3,t,x} - TRoom_t \right] \qquad (5)$$

Where $Troom_t$ is the indoor temperature and can be expressed by Fourier series as[7]:

$$TRoom_t = TO1 + \sum_{m=1}^{6} TO2_m.e^{imwt} \qquad (6)$$

The heat balance of water column is:

$$Mw\ Cw \frac{dTW_t}{dt} = h_1 \left(SOAT_{3,t} - Tw_t \right) - hw\left(Tw_t - T_{3,t,x} \right) \qquad (7)$$

Where $SOAT_{j,t}$ is solar temperature of jth wall/roof and can be calculated by equation [4]:

$$SOAT_{j,t} = TAM_t + \frac{\alpha_j.SRA_{j,t}}{h_1} - \frac{\epsilon_j.\Delta R_j}{h_1} \qquad (8)$$

Where TAM_t and $SRA_{j,t}$ are the ambient air temperature and solar radiation incident on jth wall and roof. They can be expressed by Fourier series as:

$$TAM_t = TAo + \sum_{m=1}^{6} TT_m.e^{imwt} \qquad (9)$$

$$SRA_{j,t} = So_j + \sum_{m=1}^{6} S_{j,m}.e^{imwt} \qquad (10)$$

equation (8) can be expressed by Fourier series as:

$$SOAT_{J,T} = TSo_j + \sum_{m=1}^{6} TSM_{j,m} . e^{imwt} \quad (11)$$

Substituting equation 2, 4, 6, 9, 10, and 11 in equation 3, 5 and 7 the constants TWo and TWMm can be found as:

$$Two = UT_3 \left[\left[\frac{1}{h_1} + \frac{X_3}{K_3} + \frac{1}{h_w} \right] TSO_3 + \left[\frac{1}{h_w} - \frac{1}{h_2} \right] TO_1 \right] \quad (12)$$

$$TWM_m = \frac{h_1 . TSM_{3,:} + HC5_m TO2_m}{HC4_m} \quad (13)$$

Where:

$$\frac{1}{UT_3} = \frac{1}{h_1} + \frac{1}{h_w} + \frac{X_3}{K_3} + \frac{1}{h_2} \quad (14)$$

The heat flux through the southern wall to the living space is given by the equation:

$$Q_{3,t} = h_2 \left(T_{3,t,x} - TRoom_t \right) \quad (15)$$

Equation (15) can be written as:

$$Q_{3,t} = UT_3 (TSO_3 - TO_1) + \sum_{m=1}^{6} (HC8_m TO2_m + HC9_m TSM_{3,m}) e^{imwt} \quad (16)$$

The constants HCO_m to $HC9_m$ are listed in the appendix (1).

2.1.2 Heat Flux Though Another Walls And Roof

$$Q_{3,j} = h_2 \left(T_{j,t,x} - TRoom_t \right) \quad (17)$$

2.2 Heat Conduction into the Ground [4]

$$Qg_t = K_g . A_g \left. \frac{\partial T(y,t)}{\partial y} \right|_{y=0} \quad (18)$$

where $T_{(y,t)}$ is the ground temperature distribution which can be obtained by solving equation (1) after replacing (y) instead of (x).

2.3 Heat Transfer through Window [4]

$$Qw_t = \alpha_w . \tau_w . A_w SRA_{j,t} - h_3 [TRoom_t - TAM_t] A_w \quad (19)$$

Where the first term of equation 19 represent the direct absorption of solar radiation transmitted through the east-facing window and the second term is the net convection-radiation heat transfer loss through the window.

2.4 Total Heat Loss Due to Air Infiltration [5]

$$Q_{vt} = Ma \cdot Wo [TRoom_t - TAM_t] + Wo \cdot \Delta H \cdot M_a \quad (20)$$

Where the first term of equation (20) represent the sensible heat due to temperature difference between indoor and outdoor, while the second term is the latent heat due the difference in enthalpy between indoor and outdoor air.

2.5 Heat Balance for the Room Air

The net heat balance for the internal air of the room is:

$$MaCa\frac{dTRoom_t}{dt}=\left[\sum_{j=1}^{4}Q_{j,t}\right]+Q_{3,t}+Qwt-Qgt-Qvt \qquad (21)$$

Substituting equation 16, 17, 18, 19, and 20 into equation 21, the constants TO_1 and $TO2_m$ can be found as:

$$Tol=\frac{\sum_{j=2}^{5}\left(U_j\cdot TSo_j\cdot A_j\right)+\left(UT_3-U_3\right)TSo_3\cdot A_j+U_j\cdot TSo_j\cdot A_j}{\left(\sum_{j=2}^{5}U_j\cdot A_j\right)+\left(UT_3-U_3\right)A_3+U_j\cdot A_j}$$

$$To2m=\frac{\left(\sum_{j=2}^{5}H12_{j,m}\cdot TSM_{j,m}\cdot A_j\right)+\left(Hc9_m-H12_{j,m}\right)TSM_{3,m}\cdot A_3+BS18_{j,m}\cdot A_j}{imwt\cdot MaCa-\sum_{j=2}^{5}\left(H11_{3,m}A_j\right)+\left(H11_{3,m}-HC8_{j,m}\right)A_3\cdot BS17_{j,m}\cdot A_j}$$

The constant $H11_{j,m}$,$H12_{j,m}$, $BS17_{j,m}$,$BS18_{j,m}$ are listed in appendix(2).

3. Results and Discussion

The hourly variation of solar intensity [6] on different walls, roof and ambient temperature have been shown in figure (2).

Figure (3) shows the effect of water column depth on the indoor temperature. It is seen from the figure that the water depth has a weak effect on the indoor temperature. Therefor a depth of 0.1m seemed to be suitable.

Figure (4) shows the effect of concrete thickness in water-concrete wall on the indoor temperature. It is seen from the figure that as the concrete thickness decreases the maximum and mean daily indoor temperature increases, therefor, when the water column thickness is 0.1m and the concrete thickness is 0.1m also, the maximum indoor temperature is equal to 13.5 °C, while it is equal to 13.2 °C when the concrete thickness is equal to 0.15m.

Figure (5) shows the variation of heat flux to the room from the southern wall for different valued of concrete thickness. It is seen from the figure that the maximum heat flux to the room from southern wall is equal to 1880 KJ/hr , when the concrete thickness is equal to 0.1m , while it is equal to 1650 KJ/hr when the concrete thickness to 0.3m, therefor the heat flux to the room from southern wall can be increased by 2.5, 6, 9 and 15% as a result of reducing the concrete thickness from 0.3m to 0.25, 0.2, 0.15 and 0.1m respectively.

Figure (6) and (7) show the effect of constructional materials and thickness on the indoor temperature and inside surface temperature of southern wall respectively. It is seen from the figures that concrete gives always higher indoor temperature and higher inside surface temperature compared with that for brick and concrete. While light concrete gives lower indoor and inside surface temperature of southern wall. From these figure it is that then wall gives better thermal performance to the room.

Figure (8) shows the variation of heat flux to the room from southern wall to the living space for different constructional material of the wall. It is seen from the figure that concrete wall gives maximum heat flux of 1880 KJ/hr. while brick wall gives 1650 KJ/hr and light concrete gives 1450 KJ/hr all of then 0.1m thickness for water depth.

4. Conclusions

The calculations have been corresponding to a typical winter day at January 21 at Baghdad. Although to general conclusions for all ranges of meteorological parameters can be drawn the predictions for a single day, it is instructive to summarize to qualitative features of results as follows:

1- The average indoor temperature and heat flux into the living space is maximum for water wall of 0.1m water depth and 0.1m concrete thickness.
2- Water concrete configurations is most suited among other than constructional materials.
3- The fluctuation of indoor temperature of the sun is significantly reduced as compared to the observed by Khalifa et al [2].
4- It is obvious that the establishment of this technology will change the appearance of future buildings and is a real challenge for architects.

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Nomenclature

hw	Heat transfer coefficient between the plates and water KJ/hr. m^2. °C.
Tw_t	Water temperature °C.
h_2	Heat transfer coefficient between mass wall and air of living space KJ/hr. m^2. °C.
$Troom_t$	Room temperature °C.
M_w	Mass of water wall Kg.
C_w	Specific heat of water KJ/Kg. °C.
h_1	Heat transfer coefficient between absorbing and air in sun space of water wall KJ/hr. m^2. °C.
$SOAT_{j,t}$	Solar temperature of the walls and roof °C.
TAM_t	Readable data of ambient air temperature °C.
α_j	Absorptivity of the walls and roof
$SRA_{j,t}$	Solar intensity on walls and roof KJ/hr. m^2.
ϵ_j	Emissivity of the walls and roof.
ΔR_j	Different between long wave radiation incident on surface from sky and the radiation KJ/hr. m^2.
TAO	Average value of ambient air temperature °C.
TTm	Amplitude of mth harmonic of water temperature °C.
Soj	Average value of solar intensity KJ/hr. m^2.
$S_{j,m}$	Amplitude of mth harmonic of Soj KJ/hr. m^2.
Tsoj	Average value of solar temperature °C.
$TSM_{j,m}$	Amplitude of mth harmonic of Tsoj °C.
TW_o	Average value of water temperature °C.
X_j	Total thickness of walls and roof m
K_j	Thermal conductivity of walls and roof KJ/hr. m. °C.
K_g	Thermal conductivity of ground KJ/hr. m. °C.
A_g	Area of ground m^2.
Y	Coordinate normal to the ground m.
α	Absorptivity of the glass.
τ_w	Transmittance of the glass.
A_w	Area of window m^2.
h_3	Heat transfer coefficient between the inside air and ambient air through window glass KJ/hr. m^2. °C.
M_a	Mass of inside air Kg.
C_a	Specific heat of air KJ/Kg. °C.
W_o	Hourly air change due to the door and window openings air change per hour.
ΔH	Latent heat due to the different in humidity of the outdoor and indoor air KJ/m^2
t	Time coordinate hr.
j	1, 2, 3, 4, 5, correspond to roof, east, south, west, north wall respectively.

Appendix (1)

$$HC0_m = \frac{1 - \dfrac{h_2}{K\gamma_{j,m}}}{1 + \dfrac{h_2}{K\gamma_{j,m}}} e^{-2\gamma_m \ell}$$

$$F0_m = \frac{1 - \dfrac{h_2}{K\gamma_{j,m}}}{1 + \dfrac{h_2}{K\gamma_{j,m}}} e^{-2\gamma_m l}$$

$$HC1_m = \frac{1 + \dfrac{hw_2}{K\gamma_m}}{1 - \dfrac{hw_2}{K\gamma_m}}$$

$$F1_m = \frac{\dfrac{hw_2}{K\gamma_{j,m}}}{1 - \dfrac{hw_2}{K\gamma_{j,m}}}$$

$$HC2_m = \frac{F0_m}{HC1_m - HC0_m}$$

$$F2_m = \frac{F1_m}{HC1_m - HC0_m}$$

$$HC3_m = HC1_m \cdot HC2_m$$

$$F3_m = hc0_m \cdot F2_m$$

$$HC4_m = Mw \cdot Cw \cdot i \cdot m \cdot \omega + h_{eff} + hw2 - F3_m - F2_m$$

$$HC5_m = hw2(HC3_m + HC2_m)$$

$$F4_m = \frac{h_{eff} \cdot F3_m}{HC4_m}$$

$$HC6_m = \frac{HC3_m \cdot HC4_m + F3_m \cdot HC5_m}{HC4_m}$$

$$F5_m = \frac{h_{eff} \cdot F2_m}{HC4_m}$$

$$HC7_m = \frac{HC2_m \cdot HC4_m + F2_m \cdot HC5_m}{HC4_m}$$

$$\frac{1}{h_{eff}} = \frac{1}{hw1} + \frac{1}{h1}$$

$$U_T = \frac{1}{\dfrac{1}{h_1} + \dfrac{1}{hw_1} + \dfrac{1}{hw_2} + \dfrac{\ell}{K} + \dfrac{1}{h_2}}$$

$$HC8_m = HC6_m e^{\gamma_m \cdot \ell} + HC7_m e^{\gamma_m \cdot \ell} - 1$$

$$HC9_m = F4_m e^{\gamma_m \cdot \ell} + F5_m e^{-\gamma_m \cdot \ell}$$

Appendix (2)
CONSTANTS OF FOUR-LAYERED ROOF

The roof is consist from cement tile of 30mm thickness, dry sand 10cm thickness, concrete of 15cm thickness and gypsum 20mm thickness.

$$\beta_{j,m} = \sqrt{\frac{i.m.\omega.\rho 1_j.C1_j}{K1_j}} \qquad \alpha_{j,m} = \sqrt{\frac{i.m.\omega.\rho 2_j.C2_j}{K2_j}}$$

$$\phi_{j,m} = \sqrt{\frac{i.m.\omega.\rho 3_j.C3_j}{K3_j}} \qquad \gamma_{j,m} = \sqrt{\frac{i.m.\omega.\rho 3_j.C3_j}{K3_j}}$$

$$BS0_{j,m} = \frac{1 - \dfrac{h2}{K4_j \cdot \gamma_{j,m}}}{1 + \dfrac{h2}{K4_j \cdot \gamma_{j,m}}} \cdot e^{-2\gamma_{j,m} \cdot x4_j}$$

$$BS1_{j,m} = B0_{j,m}.e^{\gamma_{j,m}.x3_j} + e^{-\gamma 4_{j,m}.x3_j}$$

$$BS2_{j,m} = \frac{K4_j \cdot \gamma 4_{j,m}}{K3_j \cdot \phi_{j,m}} \cdot \left[B0_{j,m}.e^{\gamma_{j,m}.x3_j} - e^{-\gamma 4_{j,m}.x3_j}\right]$$

$$BS3_{j,m} = \frac{1}{2} \cdot \left(B1_{j,m} + B2_{j,m}\right) \cdot e^{-\phi_{j,m} \cdot x3_j}$$

$$BS4_{j,m} = \frac{1}{2} \cdot \left(B1_{j,m} - B2_{j,m}\right) \cdot e^{\phi_{j,m} \cdot x3_j}$$

$$BS5_{j,m} = \left(B3_{j,m}.e^{\phi_{j,m}.x2_j} - B4_{j,m} \cdot e^{-\phi_{j,m}.x2_j}\right)$$

$$BS6_{j,m} = \frac{K3_j \cdot \phi_{j,m}}{K2_j \cdot \alpha 2_{j,m}} \cdot \left[B3_{j,m}.e^{\phi_{j,m}.x2_j} - B4_{j,m} \cdot e^{-\phi_{j,m}.x2_j}\right]$$

$$BS7_{j,m} = \frac{1}{2} \cdot \left(B5_{j,m} + B6_{j,m}\right) \cdot e^{-\alpha_{j,m} \cdot x2_j}$$

$$BS8_{j,m} = \frac{1}{2} \cdot \left(B5_{j,m} - B6_{j,m}\right) \cdot e^{\alpha_{j,m} \cdot x2_j}$$

$$BS9_{j,m} = \left(B7_{j,m} . e^{\alpha_{j,m} \cdot x2_j} + B8_{j,m} \cdot e^{\alpha_{j,m} \cdot x2_j}\right)$$

$$BS10_{j,m} = \frac{K2_j \cdot \alpha_{j,m}}{K1_j \cdot \beta1_{j,m}} \cdot \left[B7_{j,m} . e^{\alpha_{j,m} \cdot x1_j} - B8_{j,m} \cdot e^{-\alpha_{j,m} \cdot x1_j}\right]$$

$$BS11_{j,m} = \frac{1}{2} \cdot \left(B9_{j,m} + B10_{j,m}\right) \cdot e^{-\beta_{j,m} \cdot x1_j}$$

$$BS12_{j,m} = \frac{1}{2} \cdot \left(B9_{j,m} - B10_{j,m}\right) \cdot e^{\beta_{j,m} \cdot x_j}$$

$$BS13_{j,m} = \left(1 - \frac{h1_j}{K1_j \cdot \beta_{j,m}}\right) \cdot C11_{j,m} - \left(1 + \frac{h1_j}{K1_j \cdot \beta_{j,m}}\right) \cdot C12_{j,m}$$

$$BS14_{j,m} = \left(1 + \frac{h1_j}{K1_j \cdot \beta_{j,m}}\right) \cdot B12_{j,m} - \left(1 - \frac{h1_j}{K1_j \cdot \beta_{j,m}}\right) \cdot B11_{j,m}$$

$$BS15_{j,m} = \left[\begin{array}{l} \left(1 - \frac{h1_j}{K1_j \cdot \beta_{j,m}}\right) \cdot \left(B0_{j,m} \cdot C11_{j,m} - B11_{j,m} \cdot C0_{j,m}\right) \\ - \left(1 + \frac{h1_j}{K1_j \cdot \beta_{j,m}}\right) \cdot \left(B0_{j,m} \cdot C12_{j,m} - B12_{j,m} \cdot C0_{j,m}\right) \end{array}\right]$$

$$BS16_{j,m} = \frac{B13_{j,m}}{B14_{j,m}}$$

$$BS17_{j,m} = h2 \cdot \left(\frac{B16_{j,m} \cdot e^{\gamma_{j,m} \cdot x4_j} + B13_{j,m} \cdot e^{-\gamma_{j,m} \cdot x4_j}}{B14_{j,m}} - 1\right)$$

$$BS18_{j,m} = \frac{h1_j \cdot h2}{K1_j \cdot \beta_j} \cdot \left(\frac{B0_{j,m} \cdot e^{\gamma_{j,m} \cdot x4_j} + e^{-\gamma_{j,m} \cdot x4_j}}{B14_{j,m}} - 1\right)$$

$$H0_{j,m} = \frac{\dfrac{h2}{K4_j \cdot \gamma 4_{j,m}}}{1+\dfrac{h2}{K4_j \cdot \gamma_{j,m}}} \cdot e^{-\gamma_{j,m} \cdot x4_j}$$

$$H1_{j,m} = \left(C0_{j,m} \cdot e^{\gamma_{j,m} \cdot x3_j}\right)$$

$$H2_{j,m} = \frac{K4_j \cdot \gamma_{j,m}}{K3_j \cdot \phi 3_{j,m}} \cdot \left[C0_{j,m} . e^{\gamma_{j,m} \cdot x_j}\right]$$

$$H3_{j,m} = \frac{1}{2} \cdot \left(C1_{j,m} + C2_{j,m}\right) \cdot e^{-\phi_{j,m} \cdot x3_j}$$

$$H4_{j,m} = \frac{1}{2} \cdot \left(C1_{j,m} - C2_{j,m}\right) \cdot e^{\phi_{j,m} \cdot x3_j}$$

$$H5_{j,m} = \left(C3_{j,m} . e^{\phi_{j,m} . x2_j} - C4_{j,m} \cdot e^{-\phi_{j,m} . x2_j}\right)$$

$$H6_{j,m} = \frac{K3_j \cdot \phi_{j,m}}{K2_j \cdot \alpha_{j,m}} \cdot \left[C3_{j,m} . e^{\phi_{j,m} \cdot x2_j} - C4_{j,m} \cdot e^{-\phi 4_{j,m} \cdot x2_j}\right]$$

$$H7_{j,m} = \frac{1}{2} \cdot \left(C5_{j,m} + C6_{j,m}\right) \cdot e^{-\alpha_{j,m} \cdot x2_j}$$

$$H8_{j,m} = \frac{1}{2} \cdot \left(C5_{j,m} - C6_{j,m}\right) \cdot e^{\alpha_{j,m} \cdot x2_j}$$

$$H9_{j,m} = \left(C7_{j,m} . e^{\alpha_{j,m} . x2_j} + C8_{j,m} \cdot e^{\alpha_{j,m} . x2_j}\right)$$

$$H10_{j,m} = \frac{K2_j \cdot \alpha_{j,m}}{K1_j \cdot \beta 1_{j,m}} \cdot \left[C7_{j,m} . e^{\alpha_{j,m} \cdot x1_j} - C8_{j,m} \cdot e^{-\alpha_{j,m} \cdot x1_j}\right]$$

$$H11_{j,m} = \frac{1}{2} \cdot \left(C9_{j,m} + C10_{j,m}\right) \cdot e^{-\beta_{j,m} \cdot x1_j}$$

$$H12_{j,m} = \frac{1}{2} \cdot \left(C9_{j,m} - C10_{j,m}\right) \cdot e^{\beta_{j,m} \cdot x1_j}$$

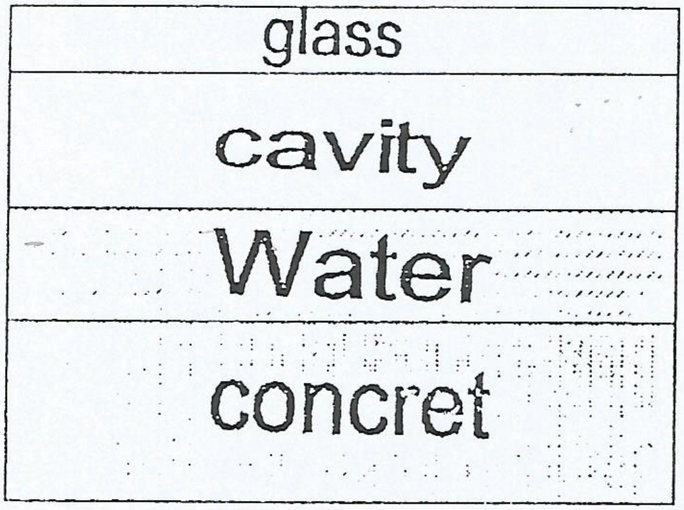

Figure (1): WatermWall

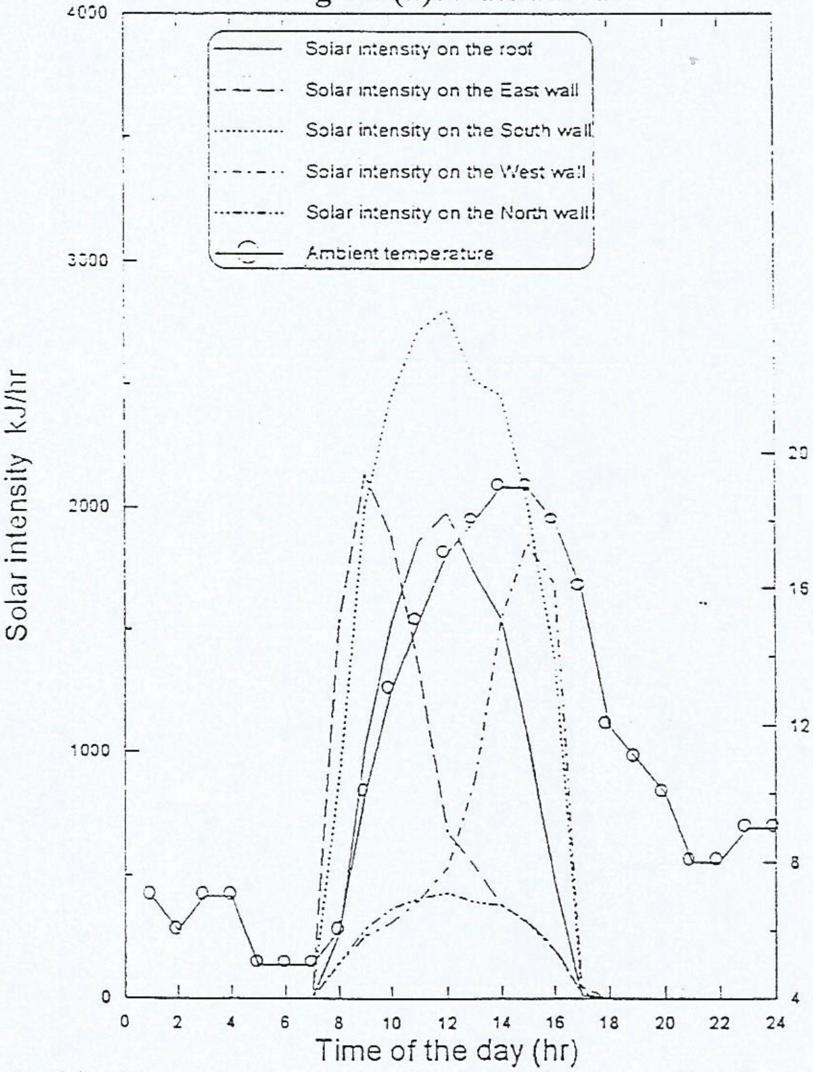

Figure (2): Ambient temperature and solar intensity on walls of various orientation for Baghdad on January.

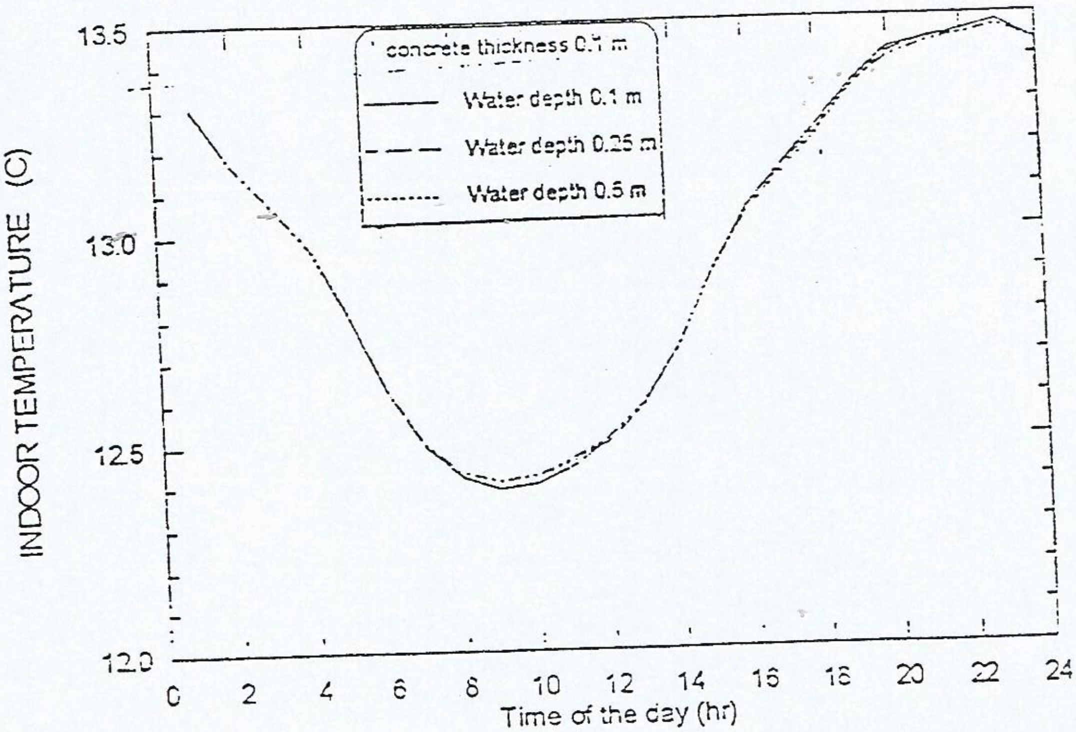

Figure (3): Effect of water depth of the water wall on the indoor temperature

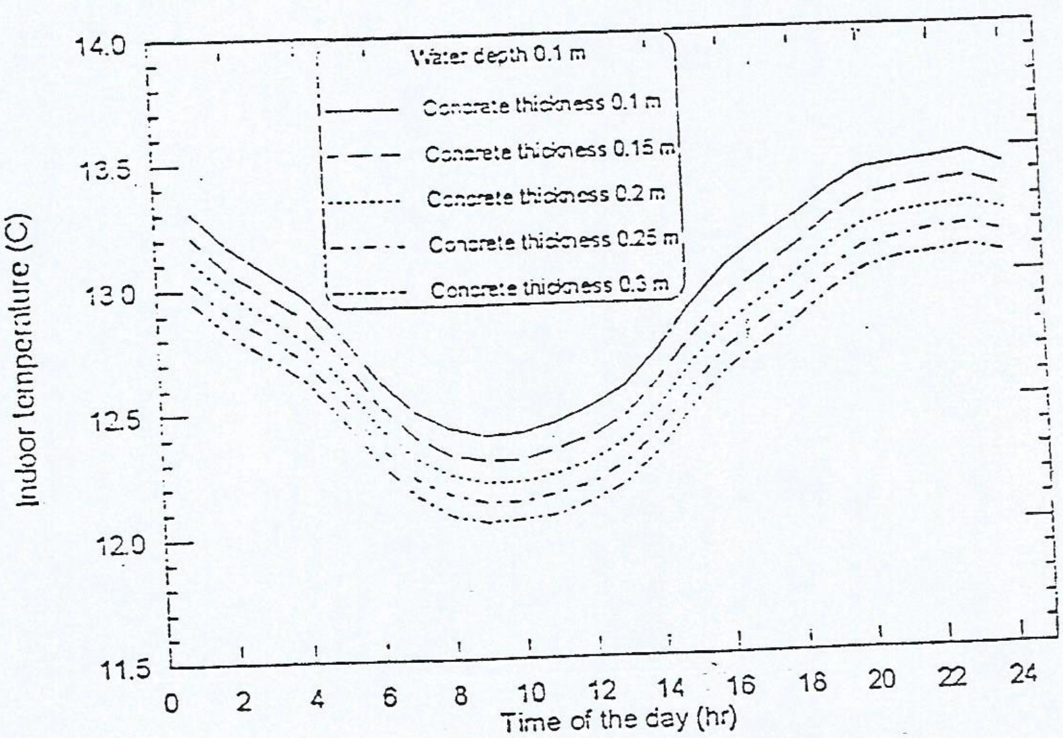

Figure (4): Effect of concrete thickness of the water wall on the indoor temperature

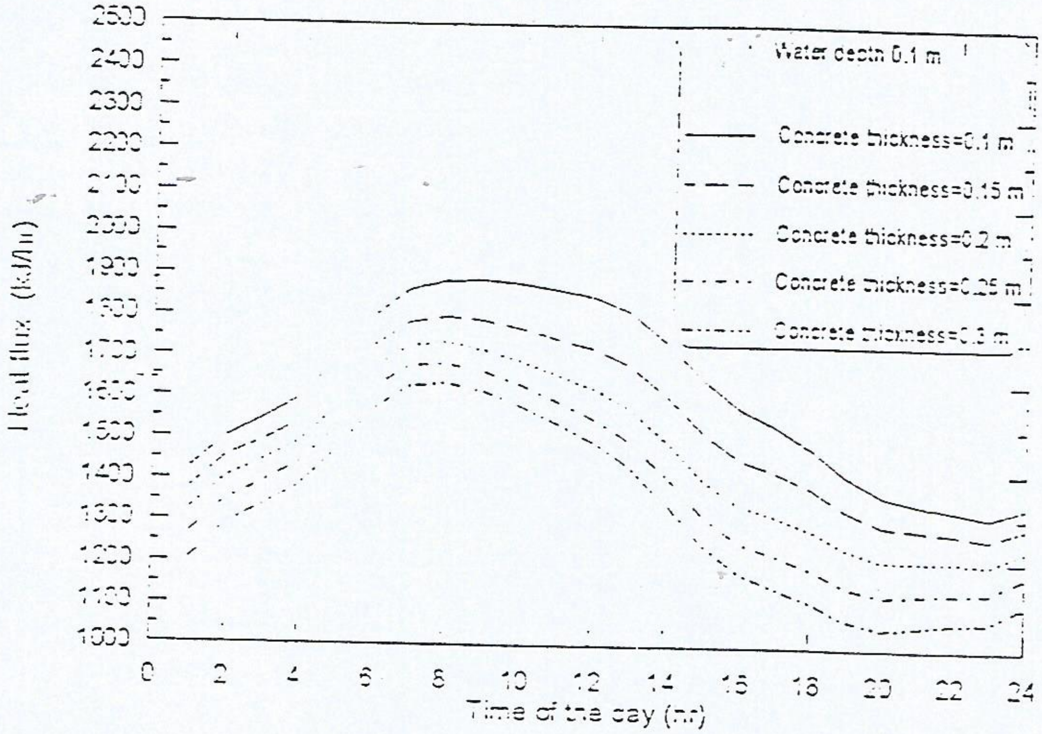

Figure (5): Heat flux to the room from the water wall for different concrete thickness

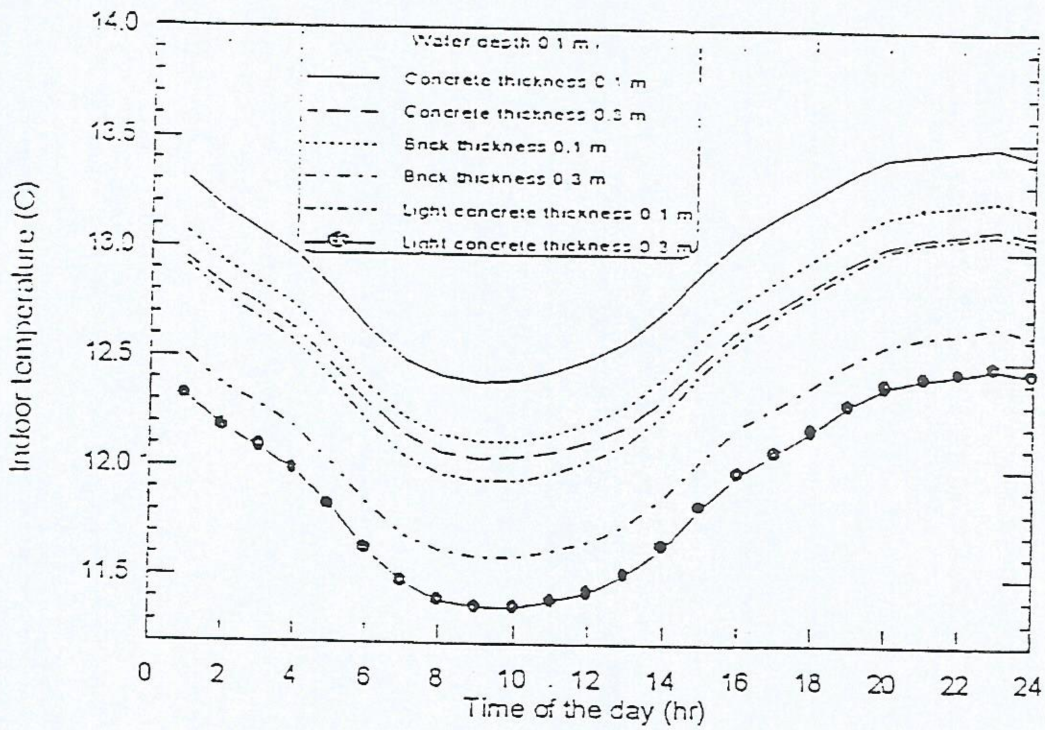

Figure (6): Effect of wall materials of the water wall on the indoor temperature

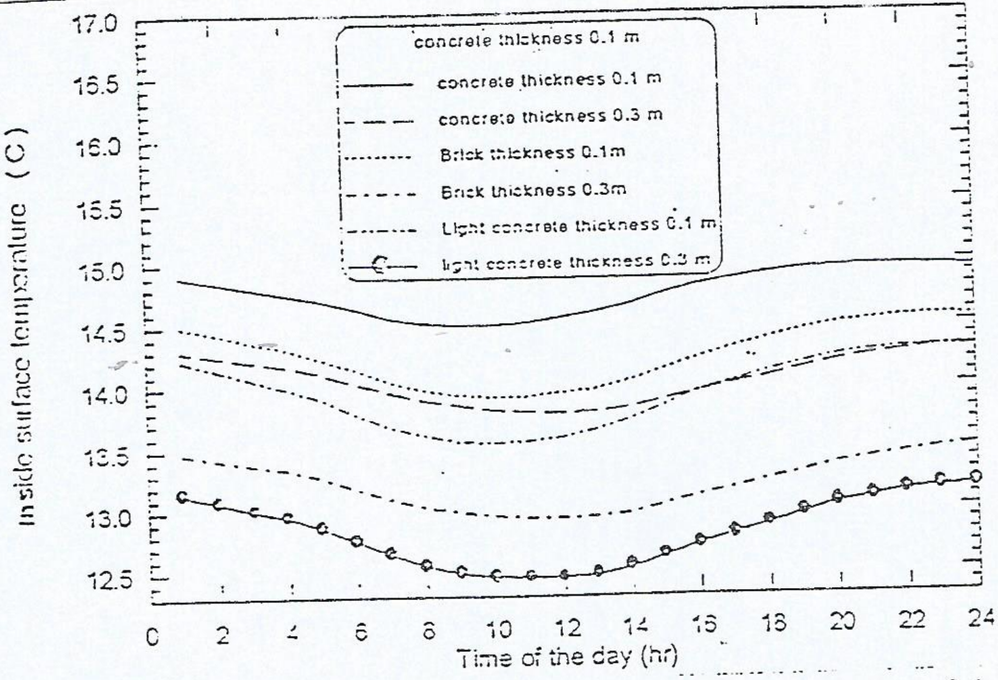

Figure (7): Effect of building materials on the inside surface temperature of the inside wall

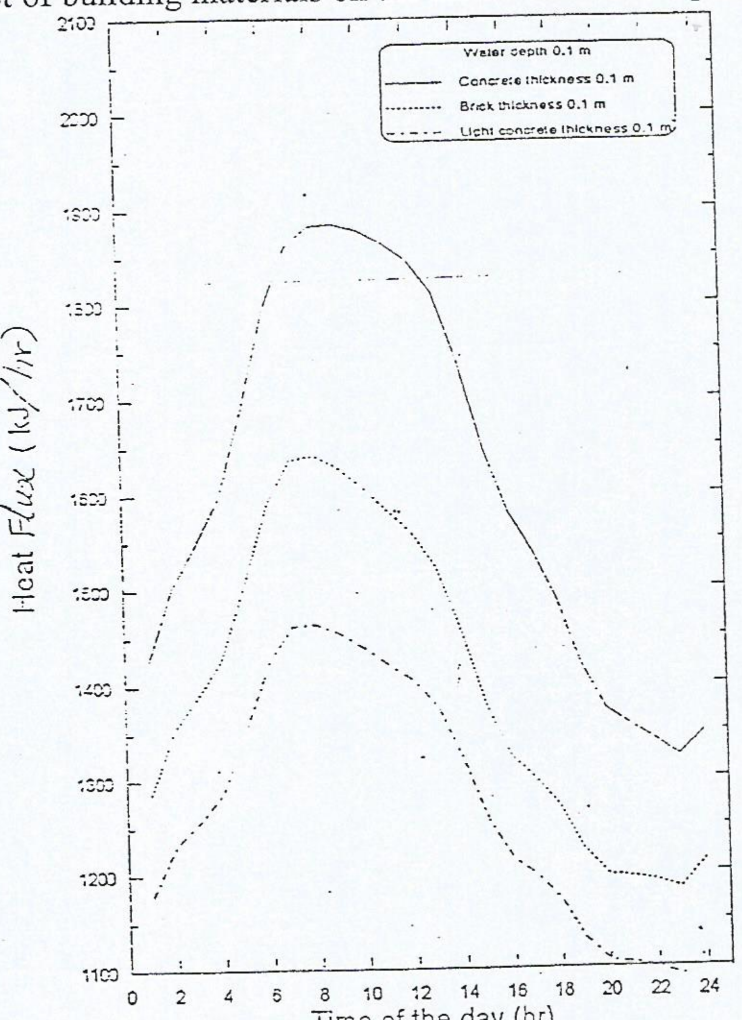

Figure (8): Hourly variation of heat flux to the room through water wall of different building materials