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CONTENTS

English Section Papers

- Evaluation of Design Parameters for Rigid Airfield Pavements. 3
Dr. Namir K.S. AL-Saoudi
Nibrass A.H. AL-Sahhaf

- An Efficient Algorithm to Calculate Steady-State Probability, Frequency, and Mean Duration of Complex Markov Systems. 19
Eng. Ahmed M. Hussien
Eng. Hassan A. Kubba
Dr. Nihad AL-Rawi

- An Improved Method of Automatic Adjustment of Transformer and Phase-Shifter Taps for Constrained Load Flow. 34
Eng. H.A. Kubba

- Comparative Study of Thermal Performance for Various Heating System Which are Acting Passively. 50
Dr. Jamal H. Whaib

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Comparative Study of Thermal Performance for Various Heating System Which are Acting Passively

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Abstract

A numerical study has been performed on a passively heated building using a thermal storage wall.

Three different materials are used for the storage wall and these were. Trombe wall, water wall. drum wall, the aim of the study was to judge which of these materials is most suitable for the weather of Iraq and what is the best thickness of the wall needed to maintain the comfort temperature in the zone which is being simulated. This zone had the dimensions (6 * 5 * 4)m.

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.

Numerical calculations have been carried out for a typical cold day in Baghdad on 19-January 2000. It is found to be the best: 0.1 depth water.

دراسة مقارنة الأداء الحراري لعدد من أنظمة التدفئة العاملة بالأسلوب السلبي

د. جمال حميد وهيب
المعهد الفني العسكري

الخلاصة

هذه الدراسة النظرية أجريت لمعرفة الأداء الحراري لمنظومات التدفئة التي تعمل بالأسلوب السلبي لاستخدام جدار خازن للحرارة، إذ استخدم ثلاثة أنواع مختلفة من المواد لبناء هذا الجدار – جدار ترومب من الكونكريت – جدار مائي (ماء + كونكريت) – جدار مئي فقط – لتدفئة ثلاث غرف بأبعاد (4 * 5 * 6) متر بنفس المواصفات الفيزياوية وتحت ظروف مناخية متشابهة خلال فصل الشتاء 19/January/2000.

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

ومن خلال الحسابات تم التوصل إلى إن الجدار المائي (ماء + كونكريت) هو افضل من الجدارين الآخرين (الكونكريت بسمك 0.1m، والمائي 0.1m).

1- Introduction

Passive space heating is accomplished by direct gain or thermal storage. While the main advantage of the direct gain approach is its simplicity and low cost. Its disadvantages lie in its providing large temperature swings besides strong directional day lighting, glare and ultraviolet degradation of the house material. The introduction of a thermal storage wall between direct solar radiation and the living space alleviates the disadvantages of the direct gain approach mentioned before.

The thermal storage wall may be made of concrete adobe or water; in case of water it is common to stack up drums full of water, one above the south is blackened and glazed, the surface gets heated by the sun during the day.

Utzinger et al[1] developed a one dimensional thermal circuit network model to determine the effects of air flow rate on the auxiliary heating energy consumption in collector – storage walls. The results of these authors show that a one dimensional model, which assumes that the air temperature varies exponentially in the flow direction, gives excellent agreement when compared with a corresponding two dimensional model. The study of Utzinger et al. is, however also based on the numerical integration has been performed using computer simulation program.

In this communication we have considered the following passive heating systems:

(1) Trombe wall.
(2) Water wall.
(3) Drum water wall.

The thermal performance of each of these systems has been evaluated in terms of heat-flux through the south wall into the house as a function of time from the hourly variation of solar intensity and atmospheric temperature: the air inside the house is assumed to vary as a periodic function and solved by Fourier series numerical results using the meteorological date for Baghdad 19-January 2000.

2- Analysis

The wall under study is built from multi layers with each layer having different thermal properties that composed the wall. It is assumed to be homogeneous isotropic solid, and the temperature changes in natural exposure are sufficiently small for the temperature dependent of thermal conductivity to be neglected. For the sake of simplicity, the following assumptions are considered.

1- All walls except southern wall are of identical materials and the same thickness.
2- The southern wall consists of outer glass sheet of 6-mm thickness, a cavity and a storage mass.
3- Heat flow into the walls/ roof is always transverse to their surface area.
4- The inside air temperature is uniform through out the room.
5- Heat transfer through window glass is not time dependent.
6- The outer surface of walls and roof are exposed to solar radiation and ambient air, which as assumed, as a periodic function of time.
7- The outside air temperatures for all walls/ roof are the same, which is fairly true for a building of moderate height.

8- The air leakage due to opening of the door, windows and other air losses, are assumed to be a fixed number of air changes per hour.

2-1 Simulation of Outdoor Condition

2-1-1 Solar Radiation

The solar intensity on the different orientation of walls and roof of the building are assumed a periodic function, and can be expressed as Fourier Series as:

$$SAR_{j,t} = SO_j + \sum_{m=1}^{\infty} S_{j,m}.e^{i\,m\,\omega\,t} \qquad (2.1)$$

Where:

$$\omega = \frac{2\pi}{24}\,hr^{-1}$$

2-1-2 Ambient Air

The readable data of the outdoor air during 24 hours in a step of one hour can be expressed as Fourier Series as:

$$TAM_t = TA + \sum_{m=1}^{\infty} Tm.e^{i.m.\omega.t} \qquad (2.2)$$

2-1-3 Sol-Air Temperature

A heat balance at a sun light surface give the heat flux into the surface per unit area$^{(1)}$.

$$Q_{,t} = \alpha 1.ID_{j,t} + \alpha 2.IS_{j,t} + h1_j.(TAM_t - TS_{j,t}) - \varepsilon_j.\Delta R_j \qquad (2.3)$$

Where $TS_{j,t}$ is the surface temperature of the sun light wall.

Since the absorption coefficients α1 and α2 are usually about the same value$^{(1)}$, thus Eqn.(2.3) can be written as:-

$$Q_{j,t} = \alpha 1.SRA_{j,t} + h1_j.(TAM_t - TS_{j,t}) - \varepsilon_j.\Delta R_j \qquad (2.4)$$

The heat flux per unit area can be expressed in another way which involve the sol-air temperature$^{(1)}$:-

$$Q_{j,t} = h1_j.(TSA_{j,t} - TS_{j,t}) \qquad (2.5)$$

Where $TSA_{j,t}$ is the soilar air temperature for different wall orientation.

From Eqns.(2.4) and (2.5)

$$TSA = TAM_t + \alpha_j \frac{SRA_j}{h1_j} - \frac{\varepsilon_j\Delta R_j}{h1_j} \qquad (2.6)$$

Eqn.(2.6) can be expressed as Fourier Series as:-

$$ST_{j,t} = TO_j + \sum_{m=1}^{\infty} TM_{j,m} \cdot e^{i\,m\,\omega\,t} \qquad (2.7)$$

And for the Trombe, water and drum water wall the heat balance of the sunlight wall can be written$^{(1)}$:-

$$Q_{j,t} = \alpha g.\tau g \frac{IT_{j,t}}{h1} + h1j.(TAM_t - TS_{j,t}) \qquad (2.8)$$

Likewise the sol-air temperature can be written as:

$$TSA_{j,t} = TAM_t + \alpha g.\frac{\tau g.SRA_{j,t}}{h1_j} \qquad (2.9)$$

2-1-4 Room Air Temperature

The temperature fluctuation equation of the inside air can be written as:

$$T_{IN} = T1 + \sum_{m=1}^{\infty} T2_m \cdot e^{i.m.\omega.t} \qquad (2.10)$$

The constants T1 and $T2_m$ are to be found for each condition of room separately see section (2.3).

2-2 Building Load

2-2-1 Simulation of Heat Storage Walls

2-2-1-1 Trombe Wall

Trombe wall is essentially thick wall, with the outer surface blackened and glazed. The storage mass may be concrete, light concrete, stone or brick. Solar radiation is absorbed by the blackened surface x=0 as shown in Fig.(2.1) and is stored as sensible heat in the wall. The temperature distribution in the wall is governed by the eqation$^{(3)}$:-

$$TCo_t = a + b.x + \sum_{m=1}^{\infty}\left(A_m e^{\gamma_m \cdot x} + B_m e^{-\gamma_m \cdot x}\right)e^{im\omega t} \qquad (2.11)$$

Where

$$\gamma_m = \sqrt{\frac{im\omega\rho c}{k}}$$

Subject to the boundary conditions at x=0.

$$-K.\frac{dTCo_t}{dx} = h_1\left[ST_{3,t} - TCo_t\right] \qquad (2.12)$$

at x=ℓ

$$-K.\frac{dTCo_t}{dx} = h_2\left[TCo_t - T_{IN_t}\right] \qquad (2.13)$$

The time dependent and independent constants for Eqn.(2.11) can be found by solving Eqns.(2.12 and 2.13) and the heat flow to the room from the inner surface of the Trombe wall can be written as:

$$QT_t = UT.A_3(TO - TI) + \sum_{m=1}^{\infty}\left(HF4_m T2_m + HS4_m.TM\right)e^{im\omega t} \qquad (2.14)$$

The constants $HF0_m$ to $HF4_m$ and $HS4_m$ to $HS0_m$ are listed in appendix (1).

2-2-1-2 Water Wall

water wall consists from outer glass, water column and storage medium. the energy balanced conditions of such a system can be written down as follows:

$$Mw.Cw.\frac{dTwt}{dt} = hw_1\left[\left(ST_{1,t} - Tw_t\right) - hw_1\left(Tw_t - TCo_t\right)\right]A_1 \qquad (2.15)$$

Where Tw_t is the water column temperature, which can be written in Fourier series as:

$$Tw_t = Tw1 + \sum_{m=1}^{\infty} Tw2.e^{im\omega t} \qquad (2.16)$$

Follow to the boundary conditions:
at x=0

$$-KT.\frac{dTC0_t}{dx} = hw_1\left[\left(Tw_t - TCo_t\right)\right] \qquad (2.17)$$

at x=1

$$-KT.\frac{dTC0_t}{dx} = h_2\left(TC0_t - TIN_t\right) \qquad (2.18)$$

The heat flux to the room from the inner surface of water wall can be written as:

$$QT_{Tt} = UT.A_3(TO_3 - T1) +$$
$$A_3.\sum_{m=1}^{\infty}(HC8_m \cdot T2_m + HC9_m.TM_m)e^{imwt} \quad (2.19)$$

The constants $HC0_m$ to $HC9_m$ are listed in appendix (2).

2-2-1-3 Drum Wall

Drum wall is based on the same consideration as Trombe wall except that it employs water as the storage medium. It consists of containers (Metalic) filled with water and kept south facing. One surface of it is blackened and glazed while of surfaces can either be in direct contact with the room.

The energy balance at the absorbing surface can be written as:

$$\alpha g \cdot \tau g.SRA_{3,t} = hw_1(T_p - Tw_t) - h_1(T_p - TAM_t) \quad (2.20)$$

And the energy balance of water mass is:

$$Mw.Cw.\frac{dTw}{dt} = [hw_1(T_p - Tw_t) - hw_2(Tw - T_{IN_t})] \quad (2.21)$$

Where T_a and T_p is the ambient and plate temperature respectively. Eqns.(2.21) and (2.22) can be combined to eliminate T_p:

$$Mw.Cw.\frac{dTw}{dt} = h_{eff}(ST_{3,t} - Tw_t) - hw_2(Tw_t - T_{IN_t}) \quad (2.22)$$

Where:

$$\frac{1}{h_{eff}} = \frac{1}{hw_1} + \frac{1}{h_1} \quad (2.23)$$

And the heat flux to the room from the inner surface of the drum wall is:

$$Q_T = UT.A_3(TO_3 - T1) + A_3.hw_2.h_2\sum_{m=1}^{\infty}\lambda_m.\frac{A1_m}{A2_m}e^{imwt} \quad (2.24)$$

Where:

$$A1_m = \frac{h_{eff}}{(im\omega.Mw + h_{eff})A2_m + h_2\gamma_m(\gamma_m.e^{\gamma_m l} + h_2.e^{-\gamma_m l})} \quad (2.25)$$

$$A2_m = \gamma_m(hw_2 + h_2)e^{\gamma_m l} + (hw_2 + \gamma_m^2)e^{\gamma_m l} \quad (2.26)$$

2-3 Heat Balance for the Inside Air

The heat balance for the room is influenced by heat flux coming into the room through different orientation walls and roof, heat conduction into the basement ground, heat loss or gain due to exchange of air with space at different temperatures and relative humidity and direct decomposition of solar radiation through windows.

The equation for the temperature of the inside air can be written as:

$$Ma.Ca.\frac{dT_{IN_t}}{dt} = \left(\sum_{j=2}^{4} Qwall_{j,t}\right) + Q_{roof} + Q_{door_t}$$
$$+ Q_{trombe\ or\ water\ or\ drum\ water\ wil}\ Qw_t - Qv_t - Qg_t \quad (2.27)$$

Where $Qdoor_t$ is determined from reference$^{(3)}$.

The left hand side of Eqn.(2.27) represents the change in heat content of the inside air mass with the time, while the right hand side of the equation represent the balance of various heat transfer rates to or from the inside air to the walls, roof, ground, windows, doors, air due ventilation and infiltration.

For a room built from triple-layered walls and four-layered roof, the temperature variation of the inside air can be found by:

$$\begin{aligned}
&i.m.\omega.Ma.Ca\sum_{m=0}^{\infty}T2_m.e^{i.m.\omega.t}=\{\sum_{j=2}^{4}[U3.A_j.(TO_j-T1)]+\\
&[Aj.\sum_{m=0}^{\infty}(H11_{j,m}.T2_m+H12_{j,m}.TM_{j,m}).e^{i.m.\omega.t}]\}+\\
&\{U4_1.A_1.(TO_j-T1)+\\
&A_1.\sum_{m=0}^{\infty}(B17_{j,m}.T2_m+B18_{j,m}TM_{j,m})e^{i.m.\omega.t}\}+\\
&\{UdAd(TO_j+T1)+UTA3.(TO_j-T1)+\\
&A_1.\sum_{m=0}^{\infty}(HF4_{j,m}.T2_m+FS4_{j,m})e^{i.m.\omega.t}\}.\\
&Ad\sum_{m=0}^{\infty}(G3_{j,m}.T2_m+G4_{j,m}.TS_{j,m})e^{i.m.\omega.t}+ \qquad (2.28)\\
&\{(\alpha a.\tau w.Aw.SO_j-h3.Aw_j.T1+h3Aw_j.TA_j+\\
&\alpha a.\tau w.Aw.\sum_{m=0}^{\infty}S_{j,m}.e^{i.m.\omega.t})-\\
&(h3.Aw_j.\sum_{m=0}^{\infty}T2_m.e^{i.m.\omega.t}+h3.Aw_j.\sum_{m=0}^{\infty}T_m.e^{i.m.\omega.t}\}-\\
&\{w1.(T1-TA)+w1\sum_{m=0}^{\infty}(T2_m-T_{j,m}).e^{i.m.\omega.t}+w2\}-\\
&\{\sum_{m=0}^{\infty}[\frac{Ag}{(\frac{1}{hg}+\frac{1}{Kg\lambda_m})}.T2_m].e^{i.m.\omega.t}\}
\end{aligned}$$

Eqn.(2.28) can be splited into two equations, one of them is time independent equation, from it T1 can be found as:-

$$T1=\frac{\alpha w\cdot\tau w\cdot Aw_j\cdot SO_j+(h3\cdot Aw_j+w2)\cdot TA-w1}{(h3\cdot Aw_j+w2)+A_1\cdot U4_1+Ad\cdot Ud+\sum_{j=2}^{5}U3_j\cdot A_j+A3\cdot UT}+$$

$$\frac{\left(\sum_{j=2}^{4}U3_j\cdot A_j\cdot TO_j\right)+U4_1\cdot A_1\cdot TO_j+UT\cdot A_3\cdot TO_3+UdAdTO_j}{(h3\cdot Aw_j+w2)+A_1\cdot U4_1+Ad\cdot Ud+\sum_{j=2}^{5}U3_j\cdot A_j+A3\cdot UT} \qquad (2.29)$$

And from the time dependent equation $T2_m$ can be found as:-

Substitute Eqns.(2.29 and 2.30), in Eqn.(2.10) yield the temperature variation equation of indoor air temperature. Heat flux to the room from different orientation walls, roof, windows, ground, ventilation and infiltration, temperature distribution through each layer of walls and roof, can be calculated using a computer program.

3- Results and Discussion

Figs.(2) to (5) show the thermal performance of Trombe, water and Drum water walls for different thickness for each wall. It is seen from Fig.(2) that the Trombe wall that built from concrete of 0.1m thickness gives maximum indoor temperature of 17.5°C while the minimum indoor temperature is equal 11°C. Water wall of 0.1m depth and 0.1m Concrete gives maximum indoor temperature of 13.2°C and 13°C minimum indoor temperature. While drum water wall gives 13.5°C maximum indoor temperature and 13.2°C minimum indoor temperature. The performance of Drum water and water wall is the same but the mean daily indoor temperature for Drum water wall is greater than that for water wall, due to the amount of heat that stored with the concrete in water wall. While Trombe wall gives higher mean daily indoor temperature compared with that of Drum wall, but with high fluctuation in the indoor temperature namely 6.5°C for trombe wall and 0.3°C for Drum water wall, thus Drum wall gives

$$T2_m=\frac{\alpha w.\tau woAw_j.S_{j,m}+(h3.Aw_j+w2)T_{j,m}+\left(\sum_{j=2}^{4}A_jH12_{j,m}.TSM_{j,m}\right)+A_1.B18_{j,m}+A_3.HF4_{3,m}TM_{3,m}+Ad.G4_{j,m}TM_{j,m}}{i.m\omega.CaMa+[\frac{Ag}{\left(\frac{1}{hg}+\frac{1}{Kg\lambda_m}\right)}+h3.Aw_j+w2-A_1.B17_{1,m}-Ad.G3_{6,m}-\sum_{j=2}^{5}A_jH11_{j,m}-A_3.FS4} \qquad (2.30)$$

steady thermal performance compared with that for Trombe wall, while Trombe wall gives higher mean daily indoor temperature, as well as the indoor temperature during off-sun shine hours is high compared with that for Drum water and water wall.

As the thickness of wall configuration above increases the thermal performance of the wall is the same, but the values of maximum and mean daily indoor temperature are varied from one thickness to another. It can be seen that from the figures mentioned above that the indoor temperature tend to stable as the wall thickness increases. From the figures mentioned above, it can be say that thin wall as a passive heating concept is useful when immediate heat transfer is required, so, for building like school, offices and business establishment where day time heating load is significant, this will become very promising. While thick wall ensures good load leveling and significant phase shift. So this system is attractive when both day and night performance, as well as, load leveling are the prime concern.

4- Conclusions

Many Conclusions can be derived from this study which can be summarized as follows:-

1- Concrete seemed to be suitable to construct the Trombe wall since it gives maximum daily indoor temperature to the room compared with that for other constructional materials the thickness of 0.1m is more suitable for concrete wall.
2- Water and Drum Water wall gives a steady performance to the Air Conditioning until, Since heat flux to the room from that walls is steady along the day.
3- Concrete is more suitable as a solid thermal storage in water wall other constructional materials, thickness of 0.1m for concrete seemed to be suitable.
4- Drum water wall gives a good thermal performance to the room compared with that of water wall, but Drum wall is not suitable in constructions buildings since it have poor mechanical properties such as inpact and compression.

References

1- D.M. Utizinger, S. A. Kileim and J. W. Mitchll, "The Effect of Air Flow Rate In Collector Storage Wall" Solar Energy, Vol.25, pp.511, 1980.
2- J. D. Balcomb, Simulation Analysis of Passive Solar Heating Building, Vol.20, pp.119, 1977.
3- Ashrae Hand Book, Fundamentals – 1989.
4- W. P. Johnes, " Air Conditioning Engineering", 2^{nd} Edition, Edward, England, 1973.

Nomenclature

Ad	Area of door	m^2
Ag	Area of ground	m^2
Aj	Area of walls and roof	m^2
Aw	Area of window	m^2
Ca	Specific heat of air	kJ/kg. °C
Cj	Specific heat of walls and roof	kJ/kg. °C
Cg	Specific heat of ground	kJ/kg. °C
Ck	Heat transfer coefficient of air cavity	$kJ/hr.m^2.$ °C
Cw	Heat transfer coefficient of water column	$kJ/hr.m^2.$ °C
h1, h2	Heat transfer coefficient by convection and radiation from the outer surface of walls and roof to the ambient and from the inner surface to the inside air respectively	$kJ/hr.m^2.$ °C
h3	Heat transfer coefficient between the inside air and ambient air through window glass	$kJ/hr.m^2.$ °C
hg	Heat transfer coefficient between the inside air and ground	$kJ/hr.m^2.$ °C
hw1, hw2	Heat transfer coefficient between outer plate and water and between the inner plate and water respectively	$kJ/hr.m^2.$ °C
I_D	Direct solar radiation incident on the wall	$kJ/hr.m^2$
IS	Diffused solar radiation incident on the wall	$kJ/hr.m^2$
IT	Total solar radiation incident on the wall	$kJ/hr.m^2$
j	1,2,3,4 and 5 correspond to roof, east, south, west and north walls respectively	
K_j	Thermal conductivity of walls and roof	kJ/hr.m. °C
Kg	Thermal conductivity of ground	kJ/hr.m. °C
m	number of harmonics	
Ma	Mass of inside air	kg
Mw	Mass of water column	kg
n	number of wall layers	
Qd	Heat flux through the door	$kJ/hr.m^2$
Qg	Heat flux through the ground	$kJ/hr.m^2$
Qj	Heat flux entering the room through j^{th} wall/roof	$kJ/hr.m^2$
QT	Heat flux entering the room through trombe, water and drum water wall	$kJ/hr.m^2$
Qw	Heat flux entering the room through window	$kJ/hr.m^2$
Qv	Heat flux entering the room by convection	$kJ/hr.m^2$
$SRA_{j,t}$	Solar intensity incident on walls and roof	$kJ/hr.m^2$
SO_j	Average value of solar intensity	$kJ/hr.m^2$
Sj, m	Amplitude of the m^{th} harmonic of So_j	$kJ/hr.m^2$

$ST_{j,t}$	Solair temperature of the walls and roof	°C
$SOL_{j,t}$	Readable data of solar radiation on walls and roof	kJ/hr.m^2
T1	Average value of indoor temperature	°C
$T2_m$	Amplitude of mth harmonic of T_{INt}	°C
T_{INt}	Indoor temperature	°C
TAM_t	Ambient air temperature	°C
TA	Average value of ambient air temperature	°C
T_m	Amplitude of the mth harmonic of TA	°C
Tg	Ground temperature	°C
TAM_t	Readable data of ambient air temperature	°C
TO_j	Average value of sol-air temperature	°C
$TS_{j.M}$	Surface temperature of sun light wall	°C
$TSA_{j.M}$	Sol-air temperature (calculated)	°C
$TSM_{j,M}$	Amplitude of mth harmonic of TO_j	°C
TW_t	Water column temperature	°C
Tw1	Average value of water column temperature	°C
Tw2	Amplitude of mth harmonic of Tw1	°C
t	Time co-ordinate	hr
Ud	Heat transfer coefficient for door	kJ/hr.m^2. °C
Ug	Heat transfer coefficient for window	kJ/hr.m^2. °C
UT	Heat transfer coefficient for Trombe, water and drum water wall	kJ/hr.m^2. °C
X	Wall\roof thickness	m
x	Co-ordinate normal to the walls and roof	m
y	Co-ordinate normal to the ground	m
αa	Absorption of inside air	
$\alpha 1$	Absorptance of indoor glass for solar radiation incident on outdoor surface	
$\alpha 2$	Absorptance of outdoor glass for solar radiation incident on indoor surface	
Δg	Different in moisture content between room air and out door air	kg_w/kg_a
ΔR	Different between long wave radiation incident on the surface from sky and the radiation emitted by black body at ambient temperature	kJ/hr.m^2
ρa	Density of air	kg/ m^3
ρ_j	Density of the walls, roof and door	kg/ m^3
ρg	Density of ground	kg/ m^3
τ	Transmittance of glass	

Appendix (1)

$$HS0_m = \frac{1 - \dfrac{h2}{K - \gamma_m}}{1 + \dfrac{h2}{K \cdot \gamma_m}} e^{-2\gamma_m \cdot \chi\ell} \qquad HF0_m = \frac{\dfrac{h2}{K \cdot \gamma_m}}{1 + \dfrac{h2}{K \cdot \gamma_m}} e^{-\gamma_m \cdot \chi\ell}$$

$$HS1_m = \frac{1 + \dfrac{h1}{K - \gamma_m}}{1 - \dfrac{h1}{K \cdot \gamma_m}} \qquad HF1_m = \frac{\dfrac{h1}{K \cdot \gamma_m}}{1 - \dfrac{h1}{K \cdot \gamma_m}}$$

$$HS2_m = \frac{FS0_m \cdot HF1_m}{HS1_m - HS0_m} \qquad HF2_m = \frac{HS1_m \cdot HF0_m}{HS1_m - HS0_m}$$

$$UT = \frac{1}{\dfrac{1}{h1} + \dfrac{X1}{K} + \dfrac{1}{h2}}$$

$$HS3_m = \frac{HF1_m}{HS1_m - HS0_m} \qquad HF3_m = \frac{HF0_m}{HS1_m - HS0_m}$$

$$HS4_m = h2\left(HS2_m e^{\gamma_m \cdot \chi \cdot \ell} + HS3_m e^{-\gamma_m \cdot \chi \cdot \ell}\right) \qquad HF4_m = h2\left(HF2_m e^{\gamma_m \cdot \chi \cdot \ell} + HF3_m e^{\gamma_m \cdot \chi \cdot \ell} - 1\right)$$

Appendix (2)

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

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

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

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

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

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

$$HC3_m = HC1_m . HC2_m$$

$$F3_m = HC0_m . F2_m$$

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

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

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

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

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

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

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

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

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

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

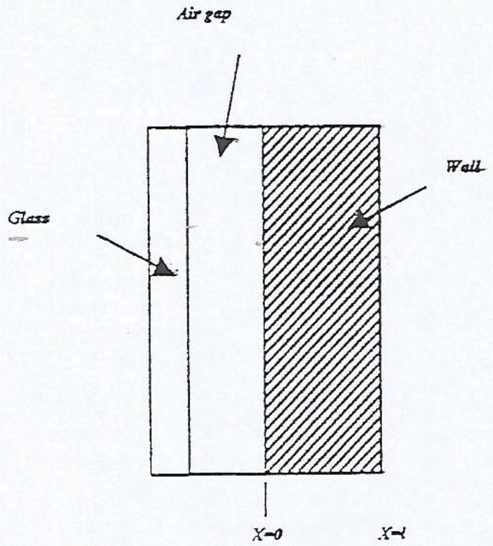

Figure (2.1): Trombe wall

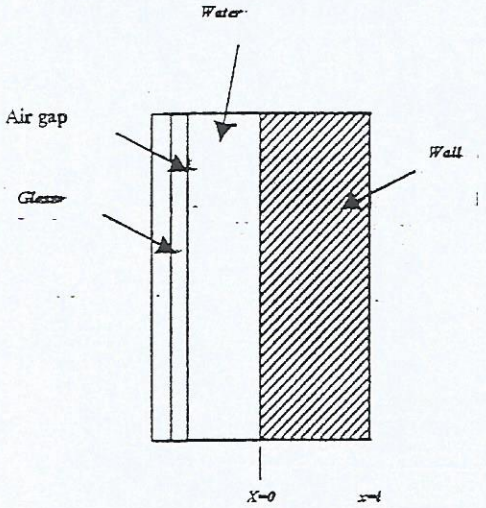

Figure (3.2): Water wall

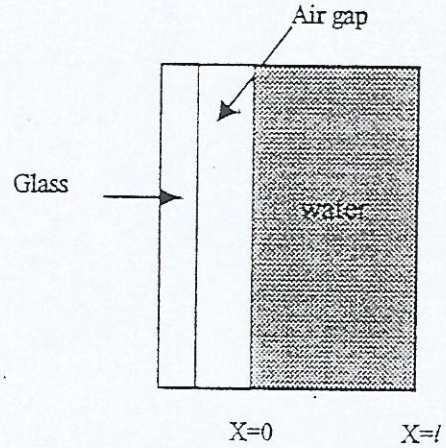

Figure (3.3): Drum wall

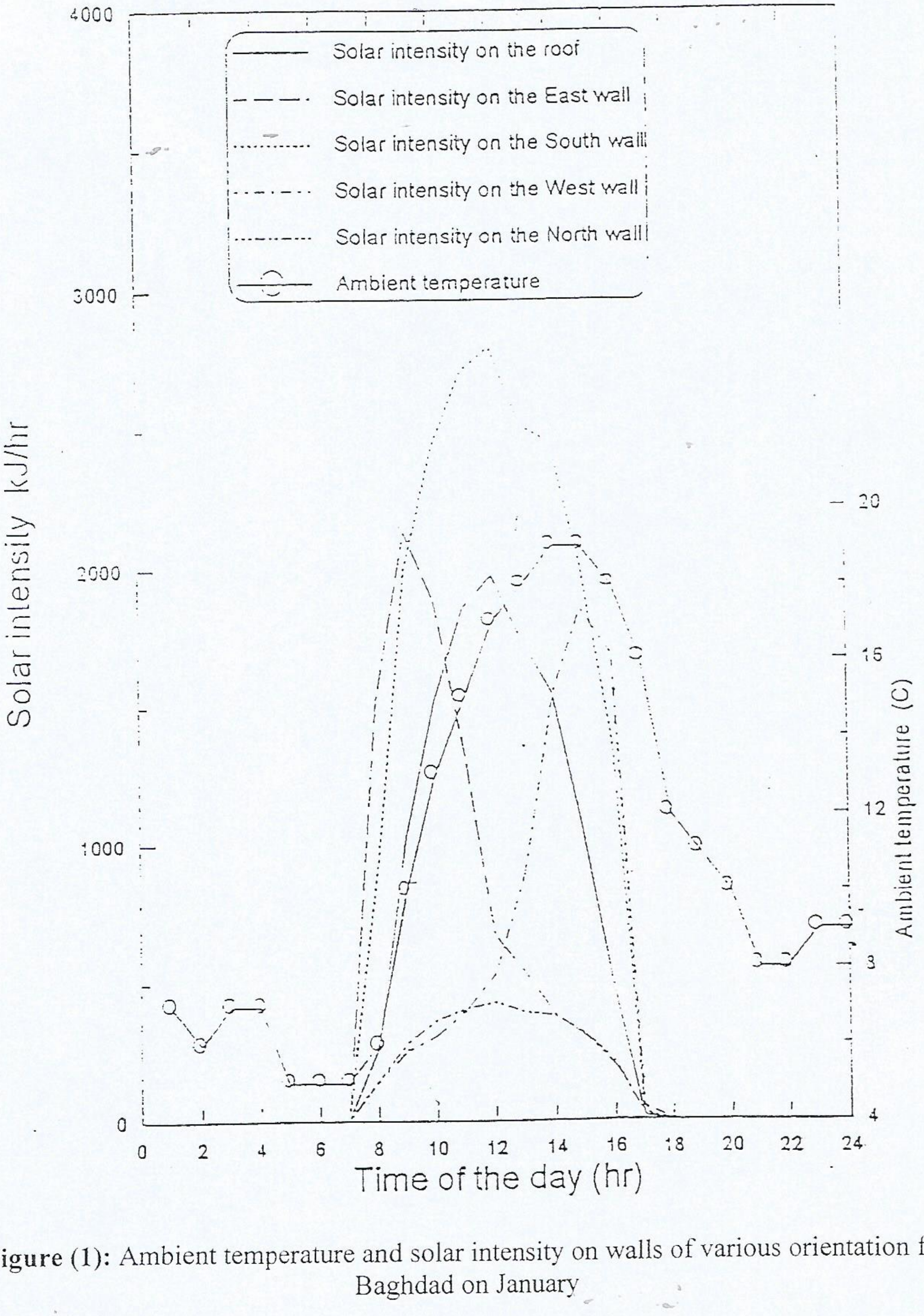

Figure (1): Ambient temperature and solar intensity on walls of various orientation for Baghdad on January

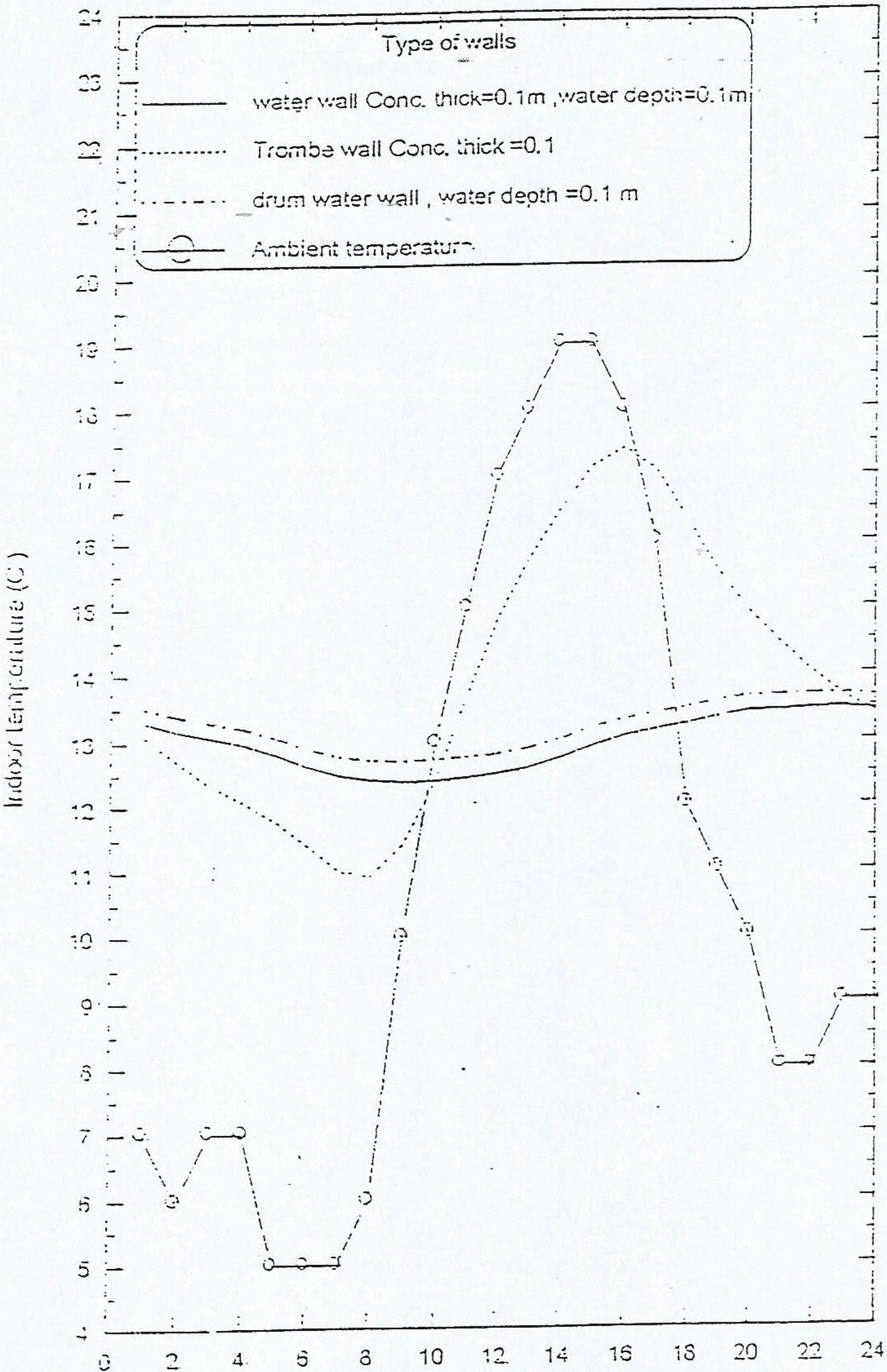

Figure (2): Effect of wall types on the indoor temperature

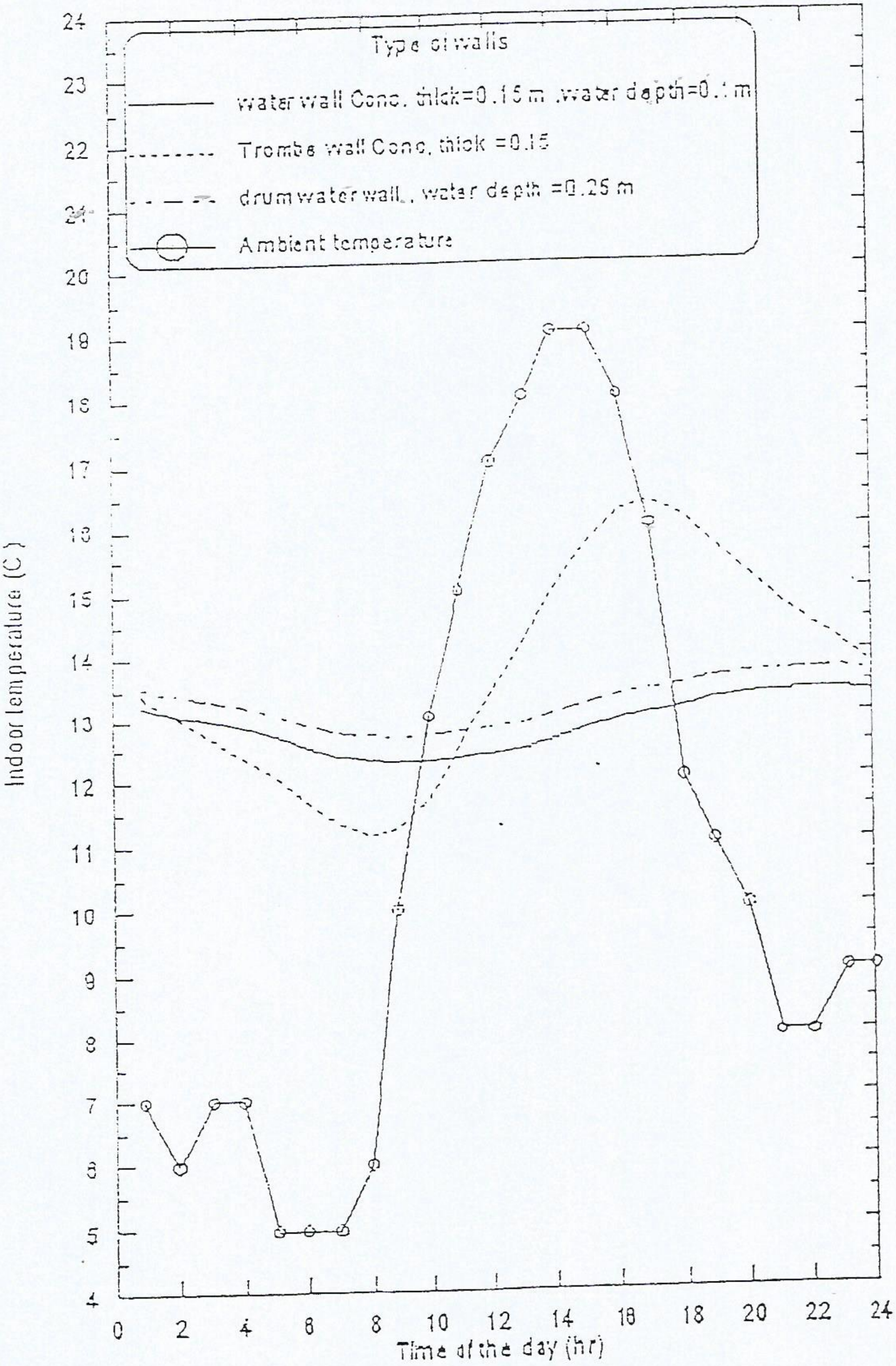

Figure (3): Effect of wall types on the indoor temperature

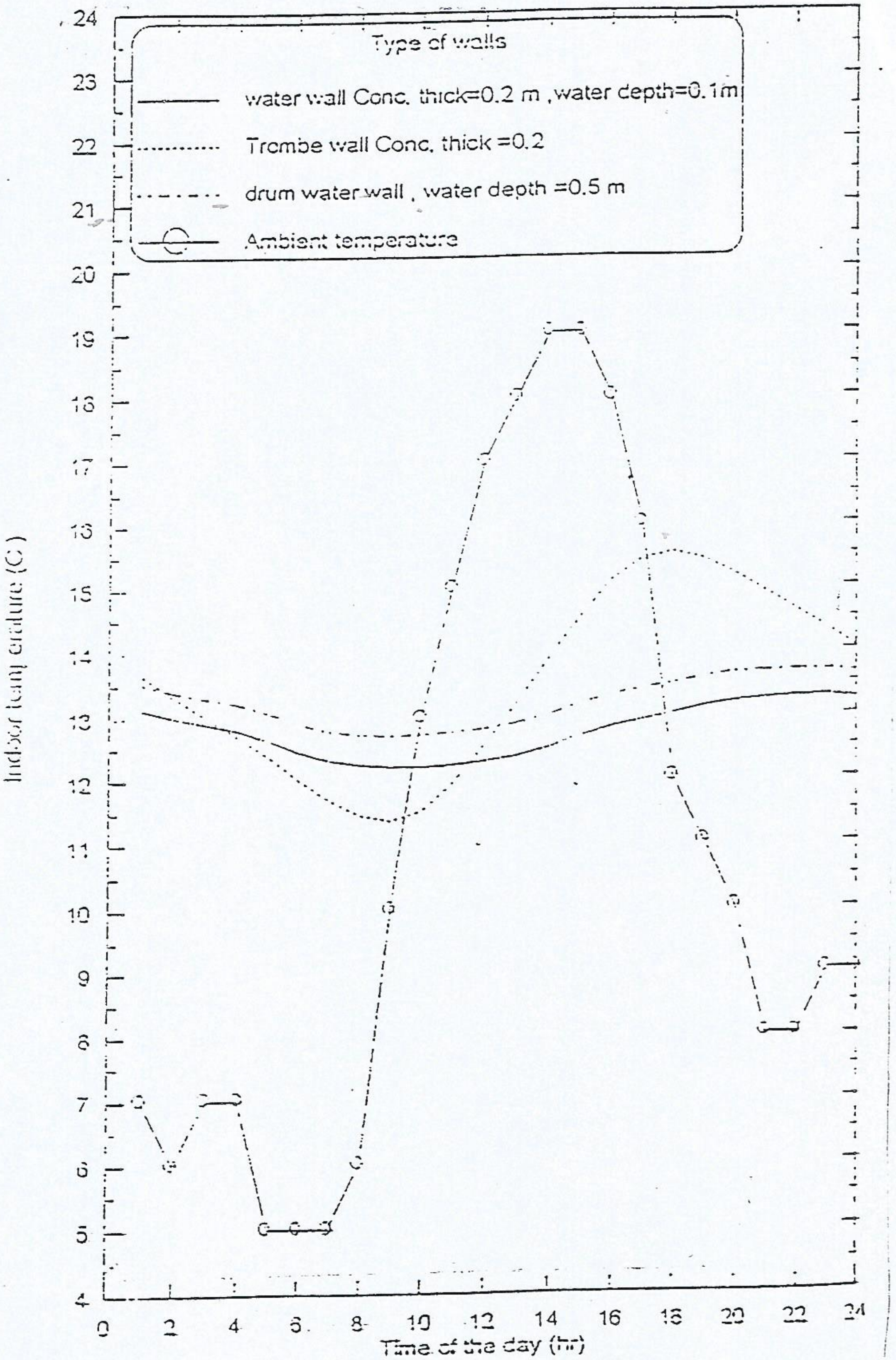

Figure (4): Effect of wall types on the indoor temperature

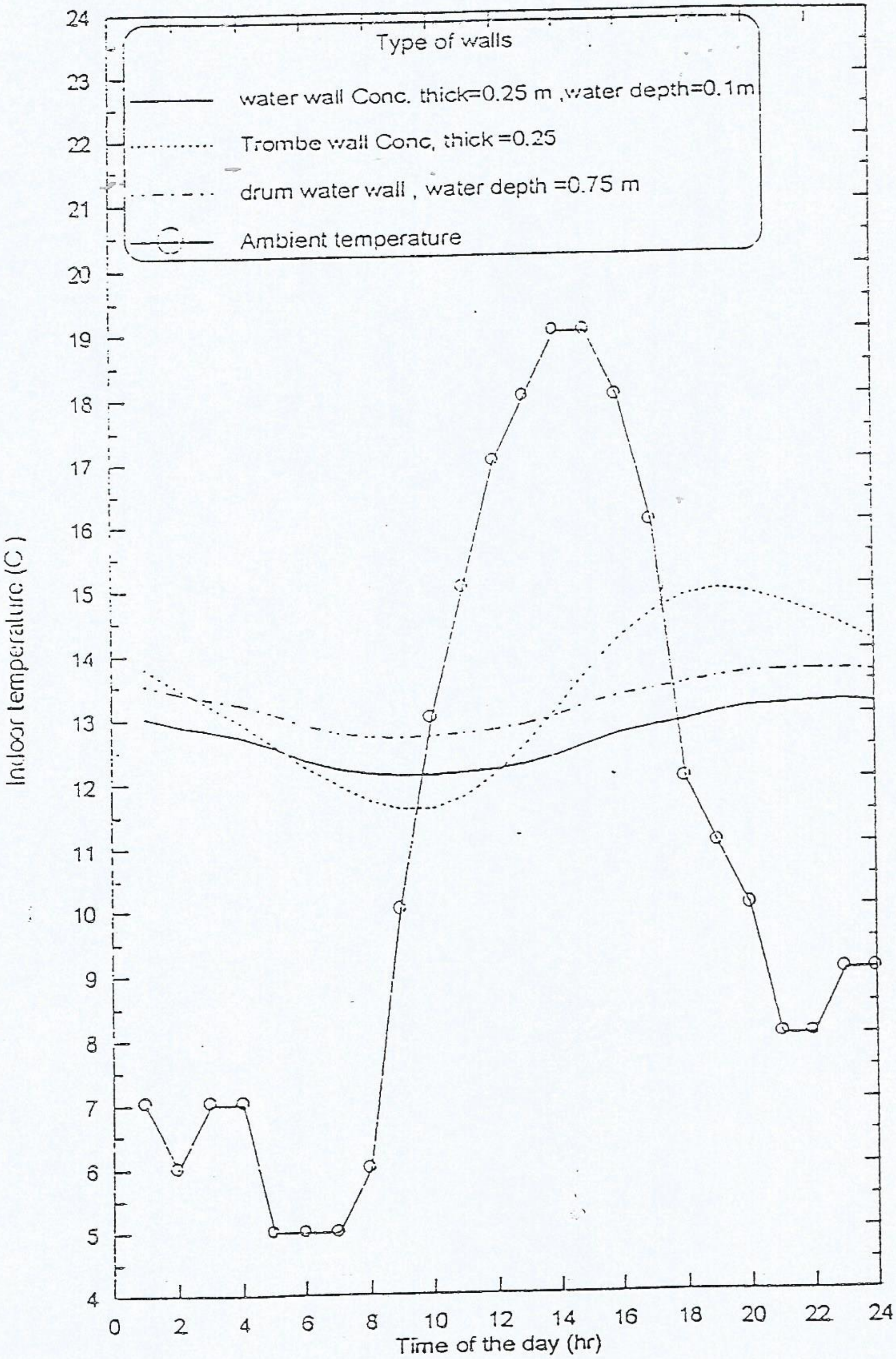

Figure (5): Effect of wall types on the indoor temperature