



Study the Long –Term Thermal performance of a simple Absorber –Storage (Trombe) Wall Solar Heating System

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Abstract

With the development of building construction engineering and the way to obtain energy from natural sources, the sun has become an important source to avail from thermal energy. This research presents a study of the long - term thermal performance of the absorber - storage wall system using the general design method, so - called Utilisability, f-chart method. The thermal performance mathematical model equations of the system have been solved using MATLAB program in order to calculate the solar fraction factor (f) of the system during four months of the winter season (November to February). The climatic conditions used in this part are the daily climatic conditions in Kut city. They are calculated on the basis of the monthly average. A number of variables affecting the wall performance have been taken into account such as solar collecting area (wall area) and wall thickness. The results of this part showed that increasing wall area and decreasing wall thickness leads to an increase in the value of the solar fraction factor. The maximum values of solar fraction factor were found during the month of November in the rate of 94.16% , at an area of 60 m² and a thickness of 10 cm, and concrete is considered the best performing material among other materials such as bricks and stones. The average value of the solar fraction factor of the passive heating system included in this study was about 0.7. This means that the solar energy according to the climatic conditions used can cover about 70% of the space heating load.

Keywords: Trombe wall, Solar fraction factor, Passive solar heating system , Utilisability ,f-chart designmethod.

الخلاصة: مع تطور هندسة تشييد المباني وطريقة الحصول على الطاقة من المصادر الطبيعية ، أصبحت الشمس مصدرًا مهمًا للاستفادة من الطاقة الحرارية. يعرض هذا البحث دراسة للأداء الحراري طويل المدى لنظام الممتص وجدار التخزين باستخدام طريقة التصميم العامة المسماة Utilisability ، f-chart method. تم حل معادلات النموذج الرياضي للأداء الحراري للنظام باستخدام برنامج MATLAB من أجل حساب عامل الكسر الشمسي (f) للنظام خلال أربعة أشهر من فصل الشتاء (من نوفمبر إلى فبراير). الظروف المناخية المستخدمة في هذا الجزء هي الظروف المناخية اليومية في مدينة الكوت ، محسوبة على أساس المتوسط الشهري. تم أخذ عدد من المتغيرات التي تؤثر على أداء الجدار في الاعتبار مثل منطقة تجميع الطاقة الشمسية (مساحة الجدار) وسماكة الجدار. أظهرت نتائج هذا الجزء أن زيادة مساحة الجدار وانخفاض سمك الجدار يؤديان إلى زيادة قيمة معامل الكسر الشمسي. حيث تم العثور على القيم القصوى لعامل الكسر الشمسي خلال شهر تشرين الثاني (نوفمبر) بنسبة 94.16%. بمساحة 60 م² وسماكة 10 سم ، وتعتبر الخرسانة أفضل المواد أداءً من بين المواد الأخرى مثل الطوب والحجر. كان متوسط قيمة عامل الكسر الشمسي لنظام التسخين السلبي المتضمن في هذه الدراسة حوالي 0.7. وهذا يعني أن الطاقة الشمسية وفقًا للظروف المناخية المستخدمة يمكن أن تغطي حوالي 70% من حمل تدفئة المكان.

1. INTRODUCTION

A Trombe wall system is one of the types that are used in the passive storage of solar energy in the conditioning of buildings. It consists of a heat-storing wall and outer surface facing the sun which is made up of one or two layers of glass, leaving an air gap between the glass and the outer surface of the thermal wall. The Trombe wall is named after Felix Trombe and Jacques Michel. They are two French inventors who developed and promoted the architectural features in (1972). According to Haider and Werner [1], this system has received great attention during the past few decades, as many theoretical and experimental researches and studies have been conducted about analysing its thermal performance and trying to improve it to become an affective system in passive solar heating for buildings. Solar power is used through the slots in the proposed thermal storage wall, and it is compared to a concrete wall used to heat a hall. The research team developed a mathematical model and program to examine heat transfer via natural phenomena and convection. Kruger et.al. [2] explained that the Trombe divider frameworks depend on the utilisation of sun-based additions and the stack impact in winter. It occurs through an air gap between a facade cladding and a partition that retains heat. The sun-based direction of the divider and the upward point ought to permit sunlight-based additions in winter while limiting this effect in summer. Chaichan and Abaas [3] studied the Trombe wall concept by designing and fabricating a Trombe wall. The wall was constructed using simple, available, and inexpensive materials. Winter wall experiments were performed in Baghdad, Iraq (Dec-2014 and Jan-2015). It was investigated whether such a wall would be suitable for Iraqi homes. The findings revealed that the engineered wall is appropriate for use in Iraq during the winter. The use of PCM in such a wall yielded positive results. In addition to its availability and low cost, using paraffin wax as PCM provided adequate storage media.

As Chaichan and Kazem [4] put it, a sun-powered water radiator with stones acting as heat storage media was concentrated basically and conceptually. The evaluation created two different conditions for the course of a strong and a fluid stage, with the coordination of conditions and it was tackled mathematically. The hypothetical outcomes were indistinguishable from the functional outcomes. The focus also investigated the plan of different sorts of warm warming dividers and the highlights of each model and the method of utilizing every one of them .

In Dimassi and Dehmani's [5] opinion, a further developed Trombe divider would offer work on warm execution, particularly in regular convection. The idea proposed is to cover the protective divider with a delicate dark copper panel supported by a black-painted divider. The study led to Borj Cedria, Tunisia, where there are continually warming prerequisites. Taffesse et. al. [6] developed the modeling of a semitransparent photovoltaic Trombe wall for thermal heating for the winter season in New Delhi. The proposed definition included direct and indirect (convection from the PV back) gains to the blackened surfaces. After the Trombe wall absorbed thermal energy, the energy was transferred to the room through conduction to increase the air temperature of rooms. The cabin was 30 m² in size, and a matrix of 4 X 4 was created for the periodic state of solar intensity and ambient air temperature using various energy balance equations. Based on calculations, the optimum wall thickness for thermal heating was 0.3– 0.4 m if the load-leveling of 1% and a decrement factor about 1% and zero, respectively. Xiao et. al. [7] numerically studied a two-dimensional model on thermal efficiency and air purification of the Trombe wall. Multiple physical fields were solved using the coupling relations and distribution formed between the free convection heat transfer and diffusion-convection equations. The numerical findings matched the experimental data in the relevant literature very well. Environmental influences, operating conditions, and geometric structures all affected the thermal performance and formaldehyde degradation rate of the Trombe wall. The results revealed that solar radiation and ambient temperature increased, so did thermal efficiency, but the opposite was true for air inlet temperature and ambient wind velocity. However, as the channel width rose, the thermal performance rose first, then it decreased. The maximum thermal efficiency was 53 percent when the width was 0.04 m. All factors in the rate of air purification showed a pattern of increasing first and then decreasing. Bendong et.al. [8] clarified that a few hypothetical and trial studies have analysed the warm exhibition of the Trombe divider sun-oriented warming framework. Some of these investigations are referenced below.

An article proposed a clever sunlight-based slope usage photocatalytic-Trombe divider framework. It is capable of comprehending the elements of room warming and evacuation of indoor formaldehyde. The day-by-day air warming productivity was 0.351, and day by day created clean air, and mass of formaldehyde was 164.0 m³/(m² day). He et. al. [9] proposed an innovative hybrid solar system use (PTC-Trombe) photocatalytic thermal catalytic Trombe wall, which recognised the coupled purposes of air purification and space heating. Firstly, a mass and

thermal model of the PTC-Trombe wall was developed based on past researches on thermal-catalytic-Trombe (TCTrombe) and photocatalytic-Trombe (PC-Trombe wall). Second, based on the daytime experimental results, performance comparisons between three Trombe walls were made. Third, the impact of solar radiation energy on the PTC-Trombe wall's device output was addressed. Finally, the energy efficiency of three Hefei walls was measured. The results showed the total reduced heat loads for the PCTrombe wall, TC-Trombe wall, and PTC-Trombe wall were 309.8, 204.7, and 29 MJ/m², respectively. Wang et. al. [10] introduced an innovative envelope for passive solar buildings connecting with variable thermal performance. Field testing was conducted to confirm the feasibility of using a transparent building envelope with a step operation to control strategy for creating a suitable indoor climate, particularly in cold areas of the plateau. Even in severe climate conditions, the experimental results revealed that the proposed building envelope ultimately enhanced heat gain while maintaining a reasonably comfortable indoor temperature in the examined case. The studied room average indoor air temperature was 13.0–14.0 °C, with the maximum temperature reaching 21 °C.

The envelope of the suggested building efficiency was below the phase control activity strategy for raising the indoor temperature which was further improved by numerical simulation using Design-Builder software. The simulation results followed the same pattern as the actual measurements. The activity technique of opening a window at 10:00 a.m. and closing it at 5:00 p.m. provided the highest solar gain while also raising the indoor temperature significantly. The average room temperature with the suggested envelope mode was 2.0 °C (sunny day) and 1.5 °C (cloudy day), higher than that of the other three passive solar envelope running modes, because of a reasonable balance between thermal resistance and solar heat gain coefficient. In general, the proposed variable thermal efficiency building envelope has a high potential to boost the indoor thermal climate in cold plateau areas at a low price .

In this study, the general design method of Absorber-storage (Trombe) wall called Un-utilisability was used to predict the long-term thermal performance of a passive solar heating system (a simple Trombe wall without ventilation opening). This is done by calculating the solar fraction factor of the system used to heat a space with a design heating load of 1 kw, depending climatic conditions of the city of Kut (Iraq) during the winter months from November to February. The study was carried out at different sizes (area and thickness) of the concrete Trombe wall.

2. OBJECTIVE AND PURPOSE

By observing previous studies, it was found that many publications focus on numerical analysis to develop Trombe wall modeling. Furthermore, the storage capacity of this wall was one of its most important features. Some researchers have also improved the energy efficiency of the wall using heat flow measurements and enthalpy balances. The main aim of this study is the thermal analysis of the absorber- storage wall system (Trombe wall system) and to study the long-term thermal performance of this system. Thus, the precise aims of the study are as follows:

1. To solve the equations of the long-term thermal performance model of the wall at different solar collecting areas and different construction materials in order to calculate the solar fraction factor of the system using the MATLAB program.
2. To construct a practical test model for the Trombe wall system and to conduct experiments on it using the climatic conditions of Kut city/ Iraq and to compare the results obtained from these experiments with the theoretical results of this study.

In order to conduct these tests, a model of a test space was built with dimensions of 1.5 m * 1 m * 1 m. It was made of iron structure and covered with insulated panels (sandwich panels). The side of the space facing the geographical south contained a simple Trombe wall consisting of a single glass panel (4 mm thick and 1 m * 1 m dimensions), an air gap (15 cm thick) separating the glass façade from the absorber-storage wall (Trombe wall) made of concrete mixture with a thickness of 30 cm. The front surface of the wall facing the solar radiation was painted with an ordinary black paint. Figure (1) represents a plate of the test space used in the study.



Figure 1 Plate of the Test Space Model.

3. MATHEMATICAL MODEL OF THE SYSTEM

The simple general tactic for predicting the monthly direct gain's performance solar passive system was updated at the University of Wisconsin. It was extended by Mosen, Klein, and Beckman [11] to form a general design method for absorber-storage (Trombe) wall Solar system. In this study, the values of the solar fraction factor (f) were calculated for a passive solar heating system called a simple Trombe wall system.

To solve the heat transfer equations in this wall, some assumptions must be made to fit the case under study such as:

- The heat transfer process through the wall is unsteady
- In one direction only (x-direction)
- Two-dimensional analysis
- Laminar flow
- Constant physical properties of materials
- Indoor (room) temperature equal 20 °C

Figure (2-a) shows the monthly energy flow in an absorber-storage wall building.

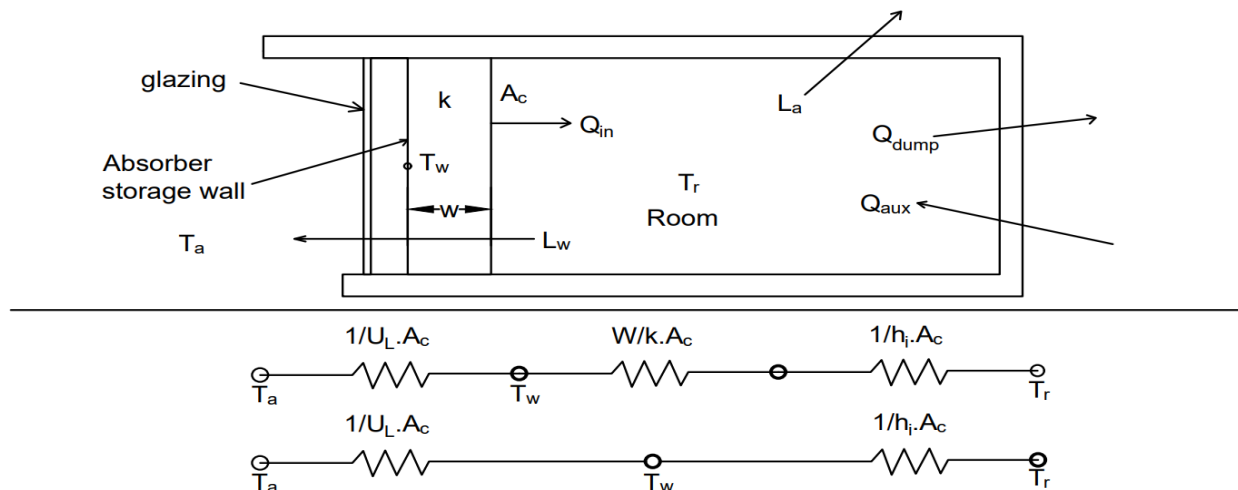


Figure 2 Wall System Collecting and Transferring Heat.

L_a = is the building's monthly energy loss in case of replacing the absorber-storage wall with an adiabatic wall and when the temperature of the interior space is constant at T_r . It can be defined by the integral:

$$L_a = \int_{month} [(UA)_a(T_b - T_a)]dt \tag{1}$$

Where:

$(UA)_a$ = the overall heat-transfer coefficient and multiplying it by the area of a building structure (with the adiabatic absorber-storage wall).

T_a = outside ambient temperature

$$T_b = \text{inside base temperature } (^{\circ}\text{C}) = T_r - \frac{\dot{g}}{(UA)_a}$$

\dot{g} = the rate of internal heat generation (Kw).

If $(UA)_a$ and \dot{g} are constants, L_a can be obtained from

$$L_a = (UA)_a(DD)_b \tag{2}$$

$(DD)_b$ = is the monthly degree-day estimated at T_b , ($^{\circ}\text{C}$).

L_w = is the building's monthly energy loss from out of the absorber-storage wall, supposing that the glazing's solar radiation transmissivity is equal to zero. L_w can be estimated by:

$$L_w = U_w A_c (DD)_r \tag{3}$$

Where

A_c = absorber – storage wall area (m^2).

$(DD)_r$ = monthly degree – days assessment at T_r , ($^{\circ}\text{C}$).

U_w = overall heat-transfer coefficient from internal to external via the wall and glazing referring to figure(1-b), ($\text{W}/\text{m}^2 \cdot \text{k}$).

$$U_w = \frac{1}{(1/\bar{U}_L) + (W/K) + (1/h_i)} \tag{4}$$

h_i = heat transfer coefficient of the internal wall surface = $8.3 \text{ W/m}^2 \cdot \text{K}$ (ASHRAE recommended value)

\bar{U}_L = monthly average overall heat- transfer coefficient from the external wall surface through the glazing to outdoor

=3.7, 2.5, and $1.9 \text{ W/m}^2 \cdot \text{K}$ (typical values) for one, two, and three glazings respectively.

\bar{U}_L : can be calculated from the relationship:

$$\bar{U}_L = (1 - f_1)U_L + f_1 \left(\frac{U_L}{1 + R_i U_L} \right) \quad (5)$$

f_1 = fraction representing the number of hours of use of the night insulation in relation to the number of 24 hours of the day.

A monthly average daily energy balance on the external wall surface gives:

$$\bar{H}_t (\bar{\tau}\alpha) = U_K (\bar{T}_w - T_r) \Delta t + \bar{U}_L (\bar{T}_w - \bar{T}_a) \Delta t \quad (6)$$

Where:

\bar{H}_t = The monthly average of the total daily solar radiation falling on the inclined plane of the solar collector per unit area. ($\text{J/m}^2 \cdot \text{day}$).

\bar{T}_w = monthly average external wall surface temperature ($^{\circ}\text{C}$).

Δt = the day's number of the seconds ($^{\circ}\text{C}$).

U_K = overall heat- transfer coefficient from the external wall surface to the inner space ($\text{W/m}^2 \cdot \text{k}$).

Referring to Figure (2-c)

$$U_K = \frac{1}{(w/k) + (1/h_i)} = \frac{h_i k}{w * h_i + k} \quad (7)$$

Referring to equation (6) to calculate \bar{T}_w , thus:

$$\bar{T}_w = \frac{\bar{H}_t (\bar{\tau}\alpha) + (U_K T_r + \bar{U}_L \bar{T}_a) \Delta t}{(U_K + \bar{U}_L) \Delta t} \quad (8)$$

$\bar{\tau}\alpha$ = The value of the monthly average of the product of multiplying the permeability of the glass and the absorbance of the wall.

Q_{in} = represents the net monthly heat transfer through the absorber-storage wall to the interior space (MJ), it can be given by :

$$Q_{in} = U_K A_c (\bar{T}_w - T_r) \Delta t N \quad (9)$$

Where N= is the month's number of days

The amount of energy that must be removed from the space in order to prevent the interior space temperature from exceeding the low thermostat set point, can be expressed as Q_{dump} . If the building, including the absorber-storage wall has no energy storage capacity, and the monthly energy dumping is given by:

$$Q_{dump} = \frac{\bar{H}_t \bar{\Phi} N U_K A_c (\tau \alpha)}{U_L + U_K} \quad (10)$$

Where $\bar{\Phi}$ = is the monthly average of daily utilisability (or the aptly, un-utilisability).

It has been obtained by Klein [12] and Mitchell et al. [13] that the amount of $\bar{\Phi}$ can be determined completely in terms of monthly clearness index (\bar{K}_T) as well as two other variables which are the geometry factor (\bar{R}/R_n) and the monthly average critical ratio \bar{X}_c , as follows:

$$\bar{\Phi} = \{ [A + B (R_n/\bar{R})] (\bar{X}_c + C \bar{X}_c^2) \} \quad (11)$$

Where:

$$A = 7.10 - 20.00 \bar{K}_T + 12.08 \bar{K}_T^2$$

$$B = -8.02 + 18.16 \bar{K}_T - 10.68 \bar{K}_T^2$$

$$C = -1.02 + 4.10 \bar{K}_T - 1.96 \bar{K}_T^2$$

\bar{R} = is the monthly ratio of total radiation on a tilted surface to total radiation on a horizontal surface .

R_n = is the ratio of total radiation at noon on the tilted surface to that on a horizontal surface based on a monthly average .

\bar{X}_c = Monthly average critical radiation.

C = Specific heat (Kj/kg $^{\circ}$ k).

$$\bar{X}_c = \frac{H t_c}{r_n R_n \bar{H}}$$

R_n = The ratio of the total radiance at apex on an inclined surface to the total radiance at aphelion on the horizontal plane.

r_n = The ratio of total radiance at apogee to daily total irradiance. (day/hr).

\bar{H} = The monthly average of the total daily solar radiation falling on the horizontal level of the unit area. (J/m² .day)

$\bar{H}_{t,c}$ = is the critical radiation level, which can be defined in this analysis by following relation :

$$H_{t,c} = \left[(UA) a \left(\frac{UL}{Uk} + 1 \right) \left(\frac{Tb - \bar{T}a}{Tr - \bar{T}a} \right) + ULAc \right] \frac{Tr - Ta}{(\tau \bar{\alpha}) Ac} \quad (12)$$

The fraction of the monthly heating load of the building covered by solar energy through the wall system that collects and transmits heat, which is denoted by the symbol (F), can be calculated by the following relationship:

$$F = \min [PF_{\infty} + 0.88(1 - P)(1 - e^{-1.26F_{\infty}}) \cdot 1.0] \quad (13)$$

Where:

$$F \text{ infinity} = \frac{Lw + Qin}{La + Lw} \quad (14)$$

$$P = [1 - \exp(-0.144 Y)]^{0.53} \quad (15)$$

Y = Empty storage ratio (silent), In which:

$$Y = \frac{S_b + 0.047 S_w}{Q_{dump}} \tag{16}$$

Where:

S_b = the building's monthly thermal storage capacity

$$S_b = C_b (\Delta T) N \tag{17}$$

N = The month's number of days.

In which, C_b = the effective building thermal capacity and ΔT = allowed indoor temperature swing

S_w = the Trombe wall's monthly thermal storage capacity

$$S_w = \frac{(\rho c p) W^2 Q_{in}}{2k \Delta t} \tag{18}$$

Where:

ρ = Density (kg/ m³).

W = Wall thickness (m).

k = Thermal conductivity coefficient of the wall material. (W/m .°k).

4. RESULTS AND DISCUSSION

For the purpose of studying the thermal performance of Trombe wall system used in passive solar heating of buildings, the mathematical model equations of the system mentioned above were solved using a computer program (MATLAB program) for a building located in the city of Kut (Iraq) (32.54 °N latitude) at different operational conditions, represented by:

- Different climatic conditions during the months of winter season November, December, January, and February. The climatic conditions used in the program represent the daily conditions based on the monthly average.
- Different solar collecting areas (different wall area), (20,30,40,50,60) m².
- Concrete was used as the structural material for the construction of the wall.
- Different wall thicknesses (10,15,20,25,30) cm.

To determine the value of the solar fraction factor of the passive heating system, which indicates the contribution of solar energy through the operation of this system in balancing the building's monthly heating demand.

Table (1) shows the climatic conditions data of the site used in this study.

Table 1 Climate Conditions of the Site (Kut city/ Iraq).

Month	Recommended .average day	\bar{H} MJ/m ² .day	\bar{H}_t MJ/m ² .day	\bar{K}_t	\bar{T}_a °C	DD °C.day/month	$T_r = T_b$ °C
January	17	10.73	15.13	0.55	10.08	307.1	20
February	16	12.69	13.45	0.52	12.52	212.9	20
November	14	10.05	12.56	0.49	16.96	106.7	20
December	10	9.68	14.42	0.53	11.14	274.6	20

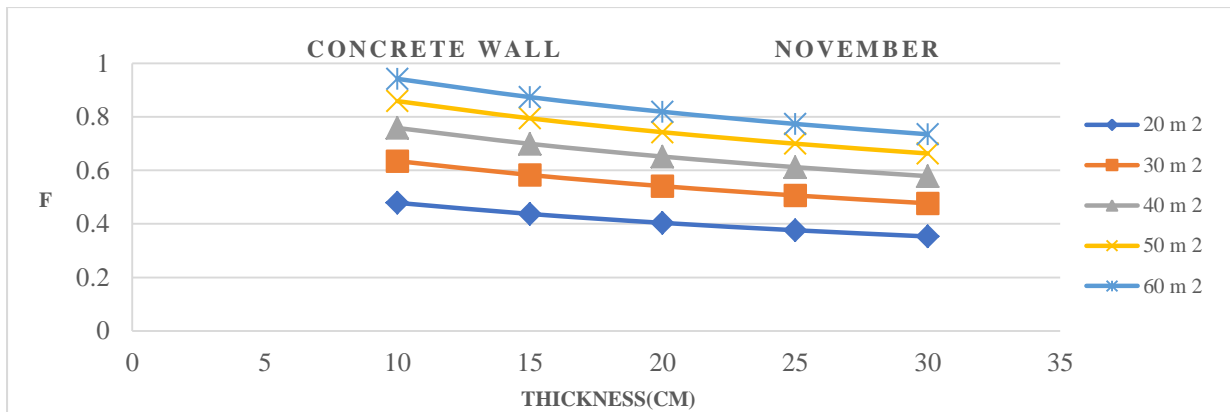


Figure 4 The Value of the Solar Fraction with the Change of Thickness.

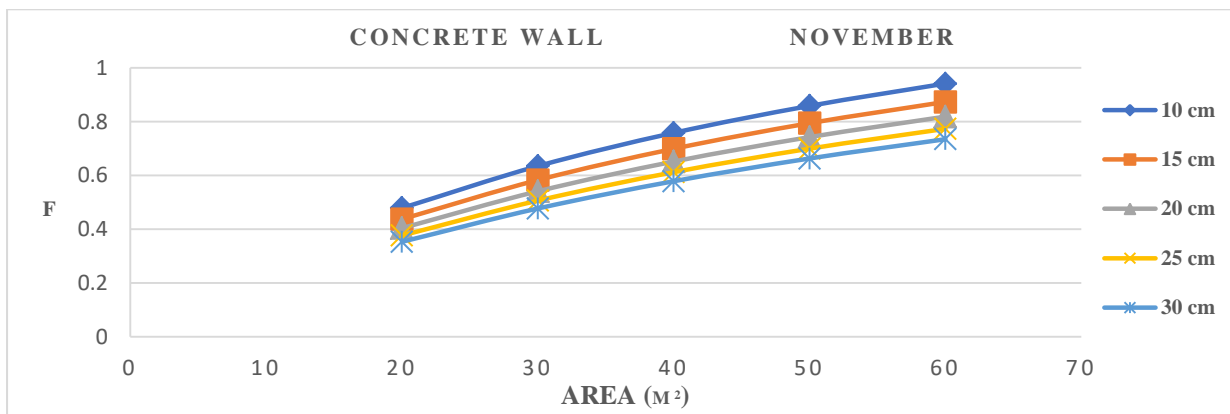


Figure 5 The Value of the Solar Fraction with the Change of Area.

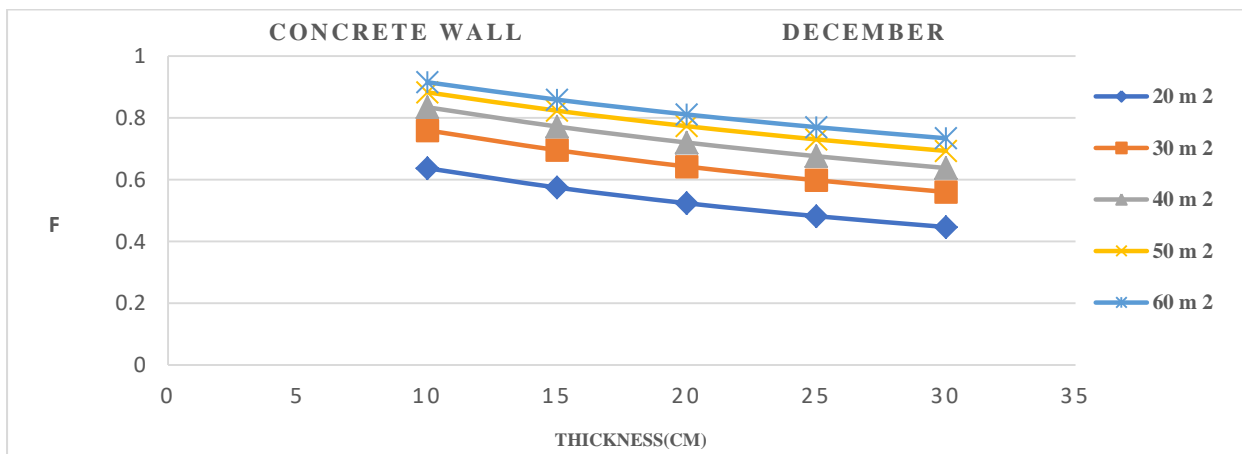


Figure 6 The Value of the Solar Fraction with the Change of Thickness.

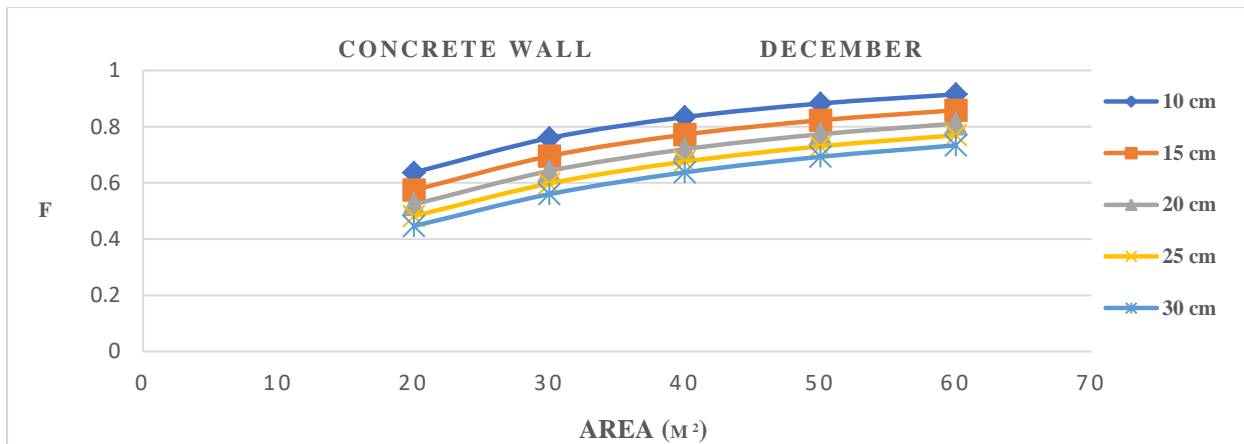


Figure 7 The Value of the Solar Fraction with the Change of Area.

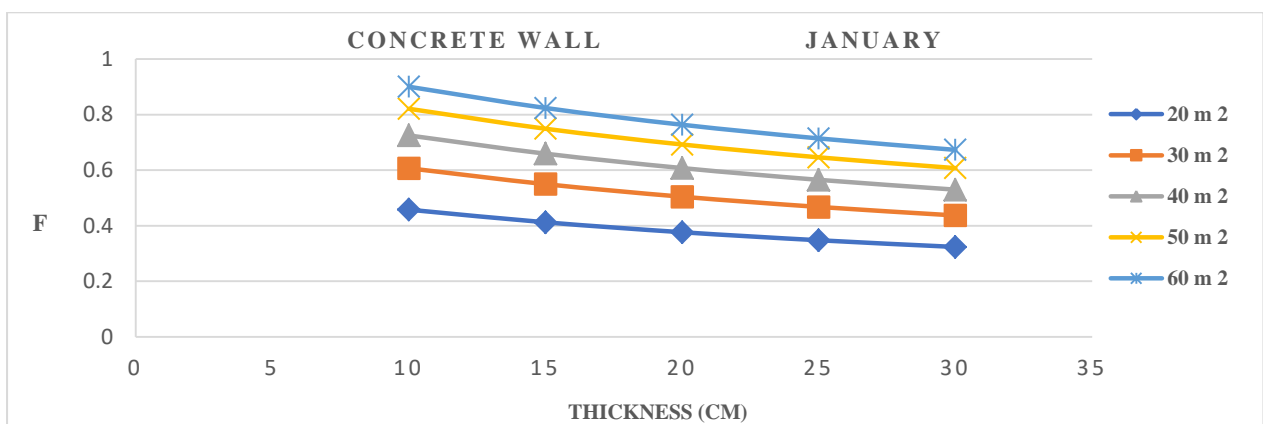


Figure 8 The Value of the Solar Fraction with the Change of Thickness.

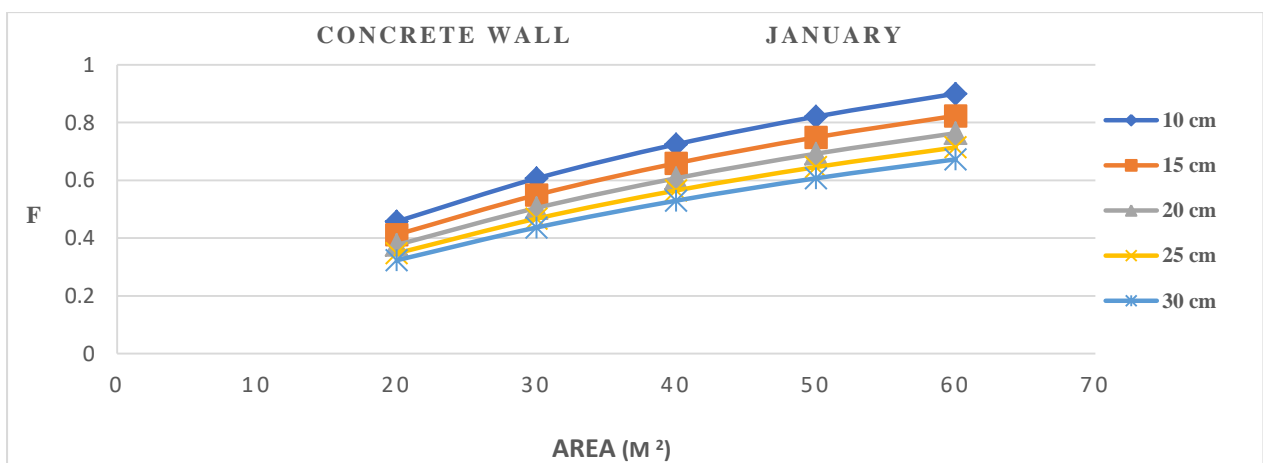


Figure 9 The Value of the Solar Fraction with the Change of Area.

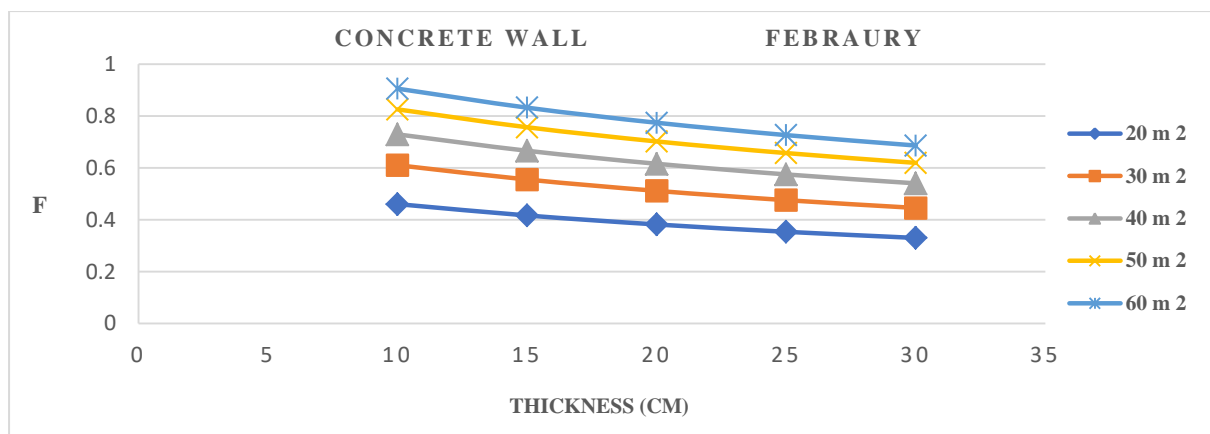


Figure 10 The Value of the Solar Fraction with the Change of Thickness.

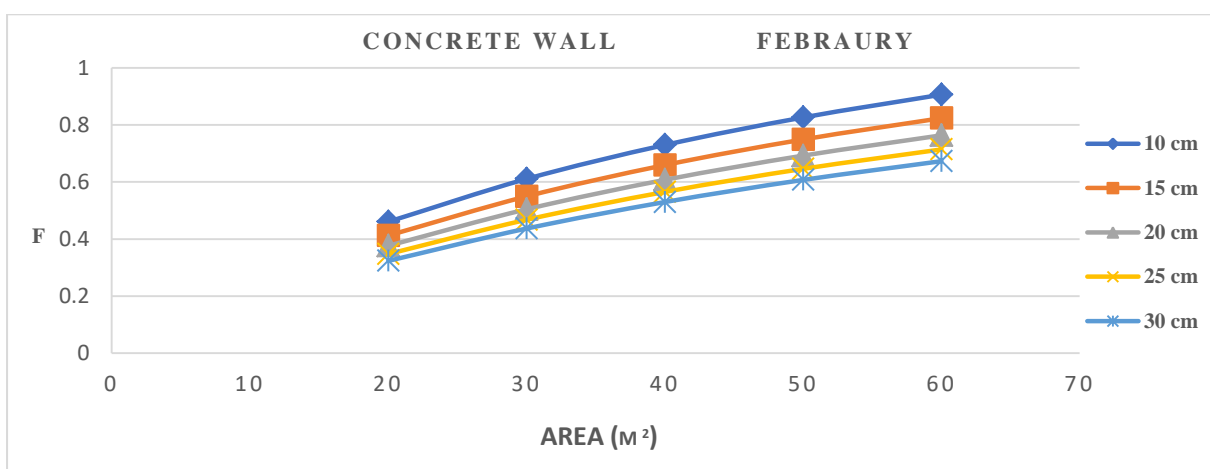


Figure 11 The Value of the Solar Fraction with the Change of Area.

Figures (4 to 11) illustrate the results obtained. Figures 4,6,8, and 10 show the relationship between the system’s solar fraction factor (f) with wall thickness (w) at different values of the solar collecting area(A_c). While Figures 5,7,9, and 11 show a relationship between the the system’s solar fraction factor with the area of solar collection at different values of wall thickness. In general, it is noted from these figures that the solar fraction factor increases with the raise in the area of solar collection and decreases with the increase in the wall thickness.

This can be explained by referring to the equations of the mathematical model shown in paragraph 3. Increasing the solar collecting area (A_c) leads to a rise in the value of Q_{in} (net monthly heat transfer through the absorber-storage wall into the indoor space) equation [9]. As for the increase in the wall thickness (w), it leads to a decrease in the value of the coefficient U_k (overall heat transfer coefficient from the outer wall surface to the inner space) equation [7] and accordingly, a decrease in the value of Q_{in}.

An increase in the value of Q_{in} leads to a rise in the value of the parameter F∞ and vice versa. The value of this parameter is included in the determination of the solar fraction factor (f) as shown in equation [13]. It is observed from the equation then, an increase in F∞ leads to a growing in F. The situation is reversed with a decrease in the value of F∞, as this leads to a decrease in the value of F.

The curve of the relationship between the solar fraction factor and the solar collecting area is a good tool that can be employed by the designers of solar systems. Through this relationship, the designer can choose, according to economic considerations, between increasing the size of the solar system or increasing dependence on additional auxiliary energies to equalise the thermal load of the space.

Figures (12) represent the change in the value of the solar fraction factor of the system with the solar collecting area for wall made of concrete, at four months in the heating season, respectively. It is generally noted in the figure that the value of the solar fraction factor for concrete material was the highest during the month of January. It is also noted that the values of solar for the wall and during the four months are very closed to each other when the solar collecting area is about 60 m². It is expected that increasing the collection area higher than 60 m² while the operating conditions of the system remain constant, will not lead to a significant increase in the solar fraction factor.

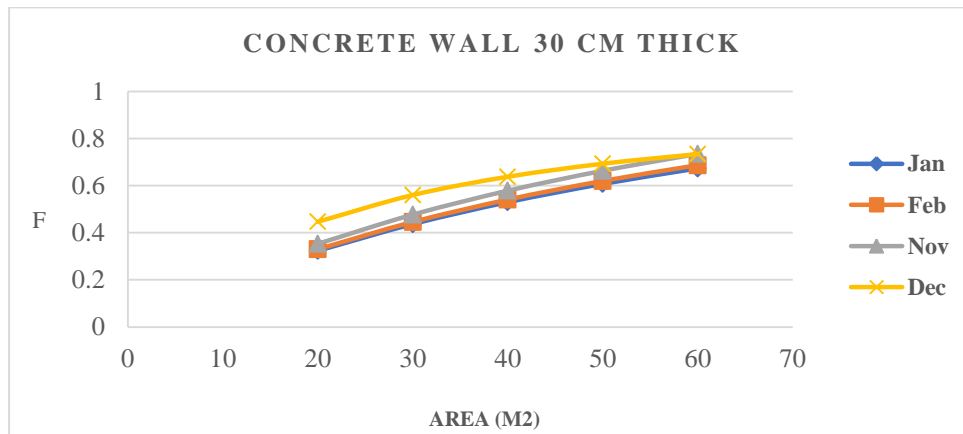


Figure 12 Relation between the solar fraction factor and the solar collecting area for a 30 cm thick concrete wall at different months.

5. VALIDATION WITH OTHER REFERNCES

In order to verify the accuracy of the results obtained, the daily heat rates transmitted from the inner surface to the heated space of a concrete wall with different thicknesses (10, 20, and 30) cm were compared with the daily heat transfer rates that were obtained by [14] as a numerical solution method called the control volume method (Patinker method), was used.

Figure (13) shows the comparison in the results between the current study and the reference [14]. As it appears from this figure, there is an acceptable convergence in the results. The error ratio for the daily heat rates

$q_{10} = 6.4\%$, $q_{20} = 2.4\%$, $q_{30} = 5.6\%$ This means that there is an acceptable convergence between the theoretical and other refernces results.

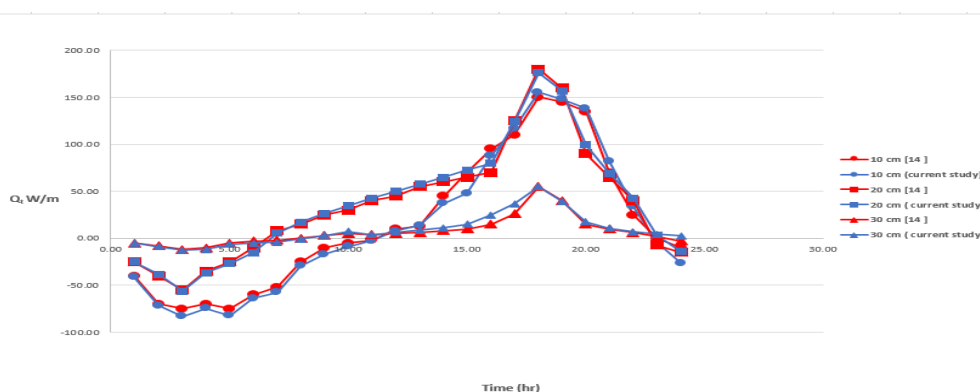


Figure 13 Comparison of the results between the current study and reference [14] for a concrete wall of different thickness.

6. CONCLUSIONS

Based on the results obtained, a number of conclusions can be drawn, as follows:

1. Absorber - storage wall (the Trombe wall) represents a simple and effective method of passive solar heating for buildings.
2. According to the findings of the study (using MATLAB program), the values of the system solar fraction factor (f) increased with the increase in the solar collecting area (wall area) and decreased with the increase in the wall thickness.
3. According to the daily climatic conditions calculated on the basis of the monthly average for the city of Kut /Iraq, which were used in the calculations, the highest values of system solar fraction factor were obtained during the month of November.
4. The average value of the solar fraction factor of the passive heating system included in this study was about 0.7. This means that the solar energy according to climatic conditions used can cover about 70% of the space heating load.

7. RECOMMENDATIONS

For the future extension of this study, the following recommendations can be proposed, which can be considered as a continuation of this study:

1. Through the obtained results, it can be recommended to use the Trombe wall system as an effective system in heating buildings and in treating heat space loads, especially in the regions that have high solar radiation intensity such as Arab's regions in general and Iraq's region in particular.
2. Study of the Trombe wall system which contains upper and lower ventilation holes in the wall that allow the air of the heated space to circulate through the air cap and create instantaneous heating of the space by convection.
3. Study the effect of changing the thicknesses of the air cap to reach the optimum thickness which gives the best thermal performance of the system.
4. Study the effect of using more than one transparent glass layer in front of the outer surface of the wall or using a moving night - time insulator system on reducing heat losses from the system to the outside environment and on improving its thermal performance.

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