Thermal insulation of walls by using multiple air gaps separated by aluminum sheets

Saja Hashim Faraj [1], Hassan Kareem Abdullah [2]

Abstract

Thermal insulation in the building walls is an important factor to reduce heat transfer from the external environment, thus reducing the demand for air conditioning and achieving thermal comfort. In order to improve the thermal performance of building walls, the present work aims to construct hollow (double) walls experimentally; which are made of several air layers separated by thin aluminum sheets, and to find the extent of their impact on improving or reducing heat gain. Tests were conducted on a model room of sandwich panel with dimensions of 2 m length and 2 m width, and 2.4 m height (32.5 latitudes) in kut city, Iraq, in August. A hole was drilled in the southwest wall with the following dimensions: (1 m long, 0.3 m wide). Three models of hollow walls with a 6 cm air gap were built in this hole; one was left with a 6 cm air gap (without dividing), the second was divided into two parts by placing a thin sheet of aluminum 1 mm thick, and the third wall's air gap was divided into three parts by placing two thin sheets of aluminum. The experimental results showed that the quantity of heat gain was lowered when the air layers were increased. The heat gain decrease was 11.5 % and 21 %, respectively, when comparing the wall with a cavity of 6 cm (without splitting) with the two walls in which the air gap was divided into two and three layers.

الخلاصة: يعد العزل الحراري في جدران المبنى عاملاً هامًا لتقليل انتقال الحرارة من البيئة الخارجية ، وبالتالي تقليل الطلب على تكييف الهواء وتحقيق الراحة الحرارية. نتيجة لذلك ، يهدف البحث الحالي إلى تطوير جدران مجوفة (مزدوجة) لزيادة الأداء الحراري لجدران المبنى ، والتي تتكون من عدة طبقات هوائية مفصولة بصفائح رقيقة من الألومنيوم ، ومعرفة مدى تأثيرها في تحسين أو تقليل اكتساب الحرارة . أجريت الاختبارات على غرفة نموذجية من الألواح العازلة بأبعاد ٢ م طول وعرض ٢ م وارتفاع ٢.٤ م (٣٢.٥ خط عرض) في مدينة الكوت ، العراق ، في شهر أغسطس. تم حفر حفرة في الجدار الجنوبي الغربي بالأبعاد التالية: (١ م طول ، ٠.٣ م عرض). تم بناء ثلاثة نماذج من الجدران المجوفة بفجوة هوائية ٦ سم في هذه الفتحة ؛ تم ترك أحدهما بفجوة هوائية ٦ سم (بدون تقسيم) ، وتم تقسيم الجزء الثاني إلى جزأين عن طريق وضع صفيحة رقيقة من الألومنيوم بسمك ١ مم ، وتم تقسيم فجوة الهواء في الجدار الثالث إلى ثلاثة أجزاء عن طريق وضع صفيحتين رفيعتين من الألومنيوم . أوضحت النتائج التجريبية أن كمية الكسب الحراري تنخفض عند زيادة طبقات الهواء . عند مقارنة الجدار بفجوة ٦ سم (بدون انقسام) مع الجدارين احدهما فيه طبقتين من الهواء والأخر ثلاث طبقات من الهواء بلغ انخفاض كسب الحرارة ١١.٥٪ و ٢١٪ على التوالي.

1. INTRODUCTION

The external walls of the building are considered a thermal interface between the external and internal environments, and the demand of buildings for energy is closely related to their thermal performance, so it is necessary to build high-performance external walls to reduce heat gain and ensure low energy consumption.

The research shows the design of a wall incorporating layers of air gap as a thermal insulator separated among themselves by aluminium sheets. It also explains the effect of air layers on reducing the cooling load resulting from heat gain and researching its effect on internal and external surface temperatures.

The air gap in a closed form can act as an insulating layer and increase the overall resistance of the installation because the thermal conductivity of air is much lower than that of other building materials. The amount of thermal resistance is determined by a number of elements, including (the cavity thickness, the air cavity inclination, the direction of heat transfer, the cavity temperature, and the emission of long electromagnetic waves for the cavity surface). The part of heat transfer by convection and conduction is affected by (the location of the air cavity, the direction of heat transfer, the difference in temperature of the two surfaces, and the thickness of the air cavity), while the part connected to radiation is affected by the temperature and characteristics of the boundary surfaces (absorption, transmittance, and reflectivity) [1].

The study of Zhang and Yang included a numerical simulation for transmission of heat across the air layers. To improve the air layer's thermal insulation, two measures were determined: the optimum thickness of the air layer and the reduction of surface emissivity. It was found that the optimal thickness of the air layer was 20-30 mm according to the conditions of the temperature limits, and that the thermal resistance of the air layer improved by 87.15 - 172.73% when the emissivity decreased from 0.95 to 0.2 [2].

 Ujma and Umnyakova conducted the thermal protection of the air gap is affected by the temperature difference on both sides of the surface of the gap and according to the thickness of the gap. When the thickness of the air gap was small, the thermal protection was not affected by the temperature difference between the two sides of the air gap, but with the increase in thickness, the effect of the difference between the temperatures on both sides of it increased. This is due to the increase in heat exchange by convection. The surface emissivity also has a substantial impact on the thermal protection of the air layers. When the emission decreases from 0.6 W/m^2K^4 to 0.2 W/m^2K^4, the thermal protection of the air gap increases by 4 times [3].

Lorente and Bejan studied the possibility of improving the internal structure of a hollow wall by combining thermal insulation with its mechanical strength, as they found that reducing the natural convection currents to a minimum enhances the wall's total thermal resistance. As a result, the ideal number of air cavities will grow when the influence of natural convection increases and the wall stiffness lowers [4].

Lapena and Kara developed the thermal insulation system by dividing the air gap inside the building envelope into multiple layers using reflective and low-emission panels. The sheets of low emissivity aluminum and polyethylene were examined with a heat box, where the air gap with a thickness of 40 mm was divided into two parallel cavities using a sheet of aluminum and polyethylene with a thickness of 2 mm. This led to an increase in the thermal resistance calculated from 0.34 m^2K/W to 1.357 m^2K/W [5].

Antar and Baig studied heat transfer (conductivity and normal convection) through a hollow block is numerically investigated. The results indicate that increasing the number of air gaps to two and then to three, while keeping the total block width constant, reduce the air velocity inside the air gaps by 30.34% and 40.56%, respectively, and increases the total thermal resistance by 28% and 36%, respectively [6].

Researches had shown that the effect of the thickness of the air gap in the double walls on the decrease of its surface transmission coefficients. The amount of reduction increased from 23.44% in the single wall to 38.7% in the double wall [7].

The research indicates that when an aluminium plate with a thickness of 1 mm is installed on the south and east facing walls, in addition to an air gap confined between the plate and the wall, the heat flow of the east and south facing wall will decrease by 20% and 23.5%, respectively, [8].

2. The EXPERIMENTAL WORK

The experimental work included the construction of a room-model to know the thermal insulation of the layers of the air gap separated between them by thin aluminum sheets in the walls of the building and to know the extent of their impact on the inner and outer temperatures within 24 hours in (August 2021). This room was built to be in touch directly with the sun's rays at Wasit University (Kut city) and a wall oriented to the southwest was chosen for this work.

2.1. Description of the room-model

The present investigation was conducted in a small room-model. The roof and all of the room's walls are composed of sandwich panel material with a thickness of 5 cm and a thermal conductivity of (0.034W/m K), while the floor is 17 mm thick wood. The room's dimensions are (2 m long, 2 m wide, and 2.4 m high) and all of its walls in close contact with the environment. In the southwest wall, an opening of dimensions (1 m in height and 0.3 m in width) was made as in Figure (1).

Figure 1 Room model

This opening was divided into three sections. In each section, a model of a double brick wall was built (brick thickness 10 cm, K = 0.54 W/m K) containing an air-enclosed cavity (6 cm) thick ,5cm thick cork insulation fixed between each section (Figure 2). The first wall model kept with 6 cm air gap, while in the second wall the air gap was divided into two equal parts, and in the third wall it was divided into three sections by placing aluminum sheets with a thickness of 1 mm. The three walls were encased with cement from the exterior (Ficus, k = 0.72 W/m K) with a thickness of 1 cm after which it was painted white because it reflects the most falling solar radiation and thus gives the lowest external surface temperature [9], while from the interior it were encased with plaster and gypsum (k_p = 0.36 W/m K, k_g = 0.81 W/m K) with a thickness of 2 cm Figure (3).

Figure 2 Cavity walls with air gap layers

[a] External surface   [b] Internal surface
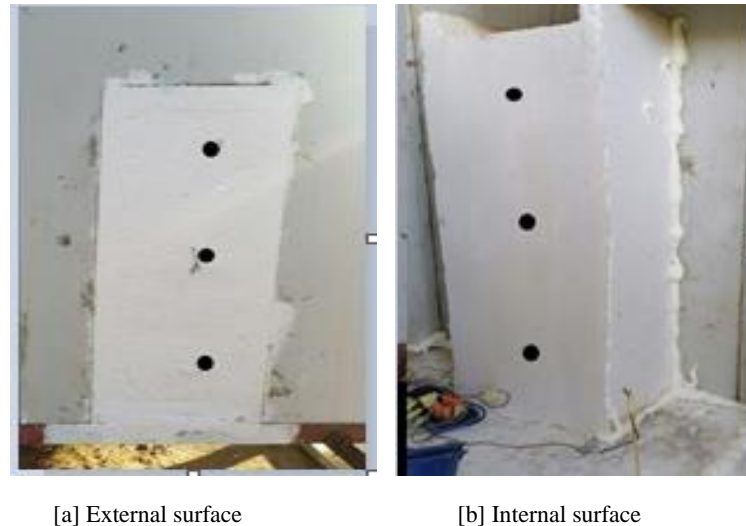
Figure 3 Cavity wall surfaces and thermocouple sites

4. MEASURING DEVICES

4.1.Temperature measurement

The temperature of the walls was measured using TP-01 K thermocouples. Two thermocouples were employed in each of the three walls: one to measure the inner surface temperature of the wall (T_i) and the other to measure the outer surface temperature (T_o). As shown in Figure (4), one thermocouple was put inside the room at a height of 1 m to measure the room's temperature (T_r), and another was placed outside the room (in the shadow) to measure the ambient air temperature (T_a).

An electronic data recorder of the type (Pico log) model (TC-08) produced in the UK was used to record temperature values. Thermocouples are attached to a data logger that has eight sensors with a temperature measurement precision of ($\pm 0.2\%$)°C and is connected to a computer to record readings.
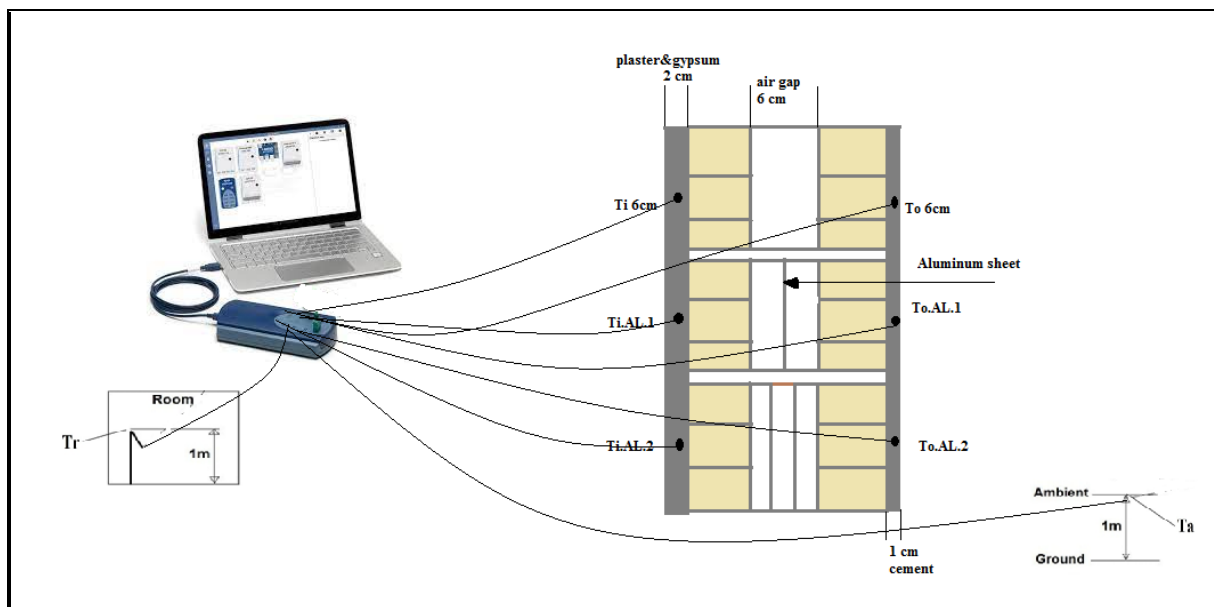
Figure 4 Indicate to connection temperature measurement equipment.

4.2.Solar power meter

Throughout all tests, a solar energy meter of the type TES-1333R is used to detect solar radiation intensity in W/m^2 during the day.

4.3.Air-condition unit

A cooling unit was used inside the room (split unit) with a capacity of 3500W, LG.Company, to maintain a consistent room temperature (23-25 °C) during the experiment.

5. RESULTS AND DISCUSSIONS

5.1.Inner surface temperature of the walls (T_i)

 Previous studies demonstrated the effect of natural convection and surface emissions on heat transfer through walls. In this study, the air cavity was divided into layers by placing aluminum sheets between them, because these sheets are reflective insulators, which are characterized by low thermal radiation. The presence of multiple layers of air improves the thermal insulation of the air cavity, due to the restriction Air movement within the gap, thus raising the overall resistance of the wall.

Figures (5 and 6) demonstrate the influence of increasing air layers in cavity walls on the inner surface temperatures over the summer. In these graphs, four values were displayed; Ti for three cavity walls to compare (T_{i6} & $T_{i.AL.1}$) and (T_{i6} & $T_{i.AL.2}$), room temperature (Tr) and solar radiation (Ir). In all cases, room temperature (varying from 23 to 25 °C) and solar intensity followed the same pattern, increasing at sunrise at 7 a.m. to a peak at midday, then gradually decreasing till reaching zero at sunset. The major sources of heat gain that raise wall temperatures are solar radiation and ambient temperature.

Figure (5) shows the inner surface temperatures of the test that was conducted on the two hollow walls with a cavity thickness of 6 cm T_{i6}, one of them was divided into two hollows by placing an aluminum plate $T_{i.AL.1}$ to compare them. The temperature of the internal surface of the two walls has been observed to rise as of sunrise at 7 a.m. and keeps rising until it reaches its peak value at 6 p.m (28.60 °C for T_{i6} and 26.2 °C for $T_{i.AL.1}$), hence the difference was (2.4°C), this is due to heat gain through the wall caused by an increase in solar radiation (Ir), which begins to rise at 32.5 W/m^2 at 7 a.m. and reaches a peak of 773.4 W/m^2 at 12 p.m. The reduce in the temperature curve of the inner surface of the wall containing two layers of air was within a 24-hour period, where the average inner surface temperature in it $\overline{Ti.AL.1}$ is (24.6 °C), While the average inner surface temperature of the wall with an air layer with a thickness of 6 cm $\overline{Ti6}$ is (26.85 °C), i.e. the amount of decrease achieved is equal to (2.25 °C), as a result of the decrease in the effect of natural convection inside the air layers.

Figure (6) shows the inner surface temperatures of the test performed on two hollow walls with a cavity thickness of 6 cm T_{i6}, one of which was divided into three air layers by placing two aluminum plates ($T_{i.AL.2}$) to compare them. Since sunrise at 7 a.m., the temperature of the inner surface of the two hollow walls has been rising, reaching a maximum value at 6 p.m. (28.78°C for Ti6 and 25.35°C for $T_{i.AL.2}$), as a result, the difference between them was 3.43°C, The reason for this increase is heat gain through the wall caused by an increase in sun radiation (Ir), which starts at 36 W/m^2 at 7 a.m. and peaks at 790 W/m^2 at 12 p.m. The reduce in the temperature curve of the inner surface of the wall containing three layers of air was within a 24-hour period, where the average inner surface temperature in it $\overline{Ti.AL.2}$ is (24.3 °C), While the average temperature of the inner surface of the wall with an air layer with a thickness of 6 cm $\overline{Ti6}$ is (27.42 °C), i.e. the reduction is equal to (3.14 °C), as a result of the decrease in the effect of natural convection inside the air layers.
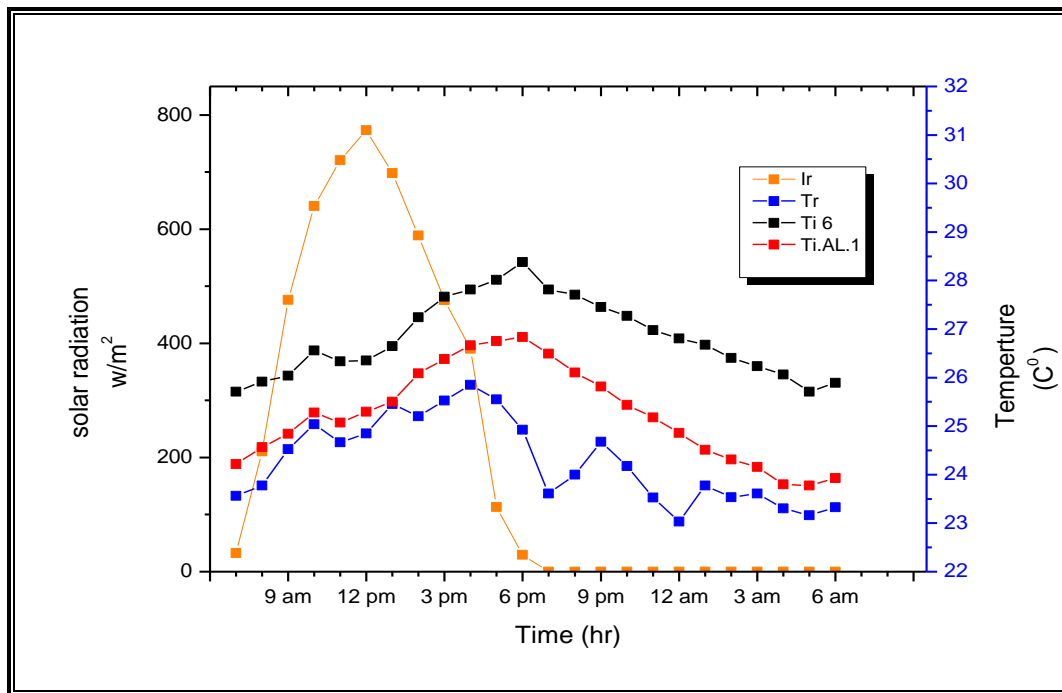
Figure 5 Inner surface temperature of the wall with air layers, room temperature and solar radiation (Ir) at (17-Aug. -2021).
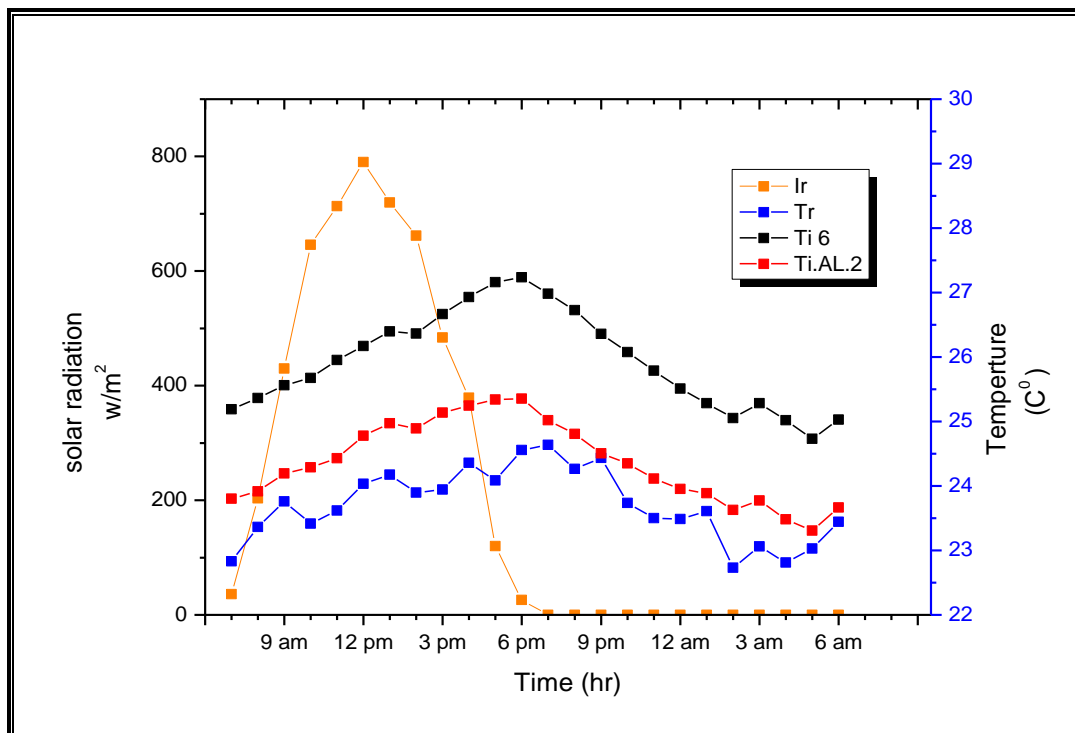
Figure 6 Inner surface temperature of the wall with air layers, room temperature and solar radiation (Ir) at (19-Aug. -2021).

5.2. External surface temperature of the walls (T_o)

Figures (7 and 8) indicate that the comparison of the external surface temperature of the two hollow walls with ambient air temperature and solar radiation. It can be seen that changes in the number of air layers had no effect on the temperature of the external surface of the hollow wall, where they are almost identical and had the same rate as the increasing or decreasing since the surfaces were all subjected to the same environment condition.

Figure (7), illustrates a comparison of two hollow walls' exterior surface temperatures with a cavity thickness of 6 cm $T_{out.6}$, one of them was divided into two air layers by laying an aluminum plate $T_{out.AL.1}$, solar radiation (Ir) and

ambient air temperature (T$_a$) for 24 h. The temperature of the two walls' exterior surfaces began to increase at 7 a.m., reaching a maximum of 49 °C at 4 p.m., corresponding with the rise in ambient air temperature, which reached a maximum of 45 °C at 4 p.m. The cause for this increase is due to solar radiation (Ir), which begins to increase at 32.5 W/m^2 at 7 a.m. and peaks at 773.4 W/m^2 at 12 p.m.,after then, it starts to decrease. After 12 am, the temperature of the outer surface of the walls drops more than the temperature of the ambient air. The reason for this decrease is that the wall releases the heat stored in it to the environment at night, so the ambient air temperature will rise. At 7 p.m., (Ir) reaches zero, resulting in a drop in (T$_{out.6}$ and T$_{out.AL.1}$) and ambient temperature (Ta) until they reach at least 27 °C and 28 °C, respectively, at 5 a.m.

Figure (8), illustrates the exterior surface temperatures of two hollow walls with a cavity thickness of 6 cm T$_{out.6}$, one of which was divided into three air layers for 24 hours by putting two aluminum plates T$_{out.AL.2}$, solar radiation (Ir) and ambient air temperature (T$_a$). The temperature of the two walls' exterior surfaces began to climb at 7 a.m., reaching a maximum of 50 °C at 4 p.m., corresponding with the rise in ambient temperature, which reached a maximum of 47 °C at 4 p.m. The cause for this increase is due to solar radiation (Ir), which begins to increase at 36 W/m^2 at 7 a.m., peaks at 790 W/m^2 at 12 p.m., and then begins to fall. It drops to zero around 7 p.m., causing a drop in exterior surface temperatures (T$_{out.6}$ and T$_{out.AL.2}$) as well as the ambient temperature till they reach a minimum of 29 °C and 31 °C at 5 a.m.
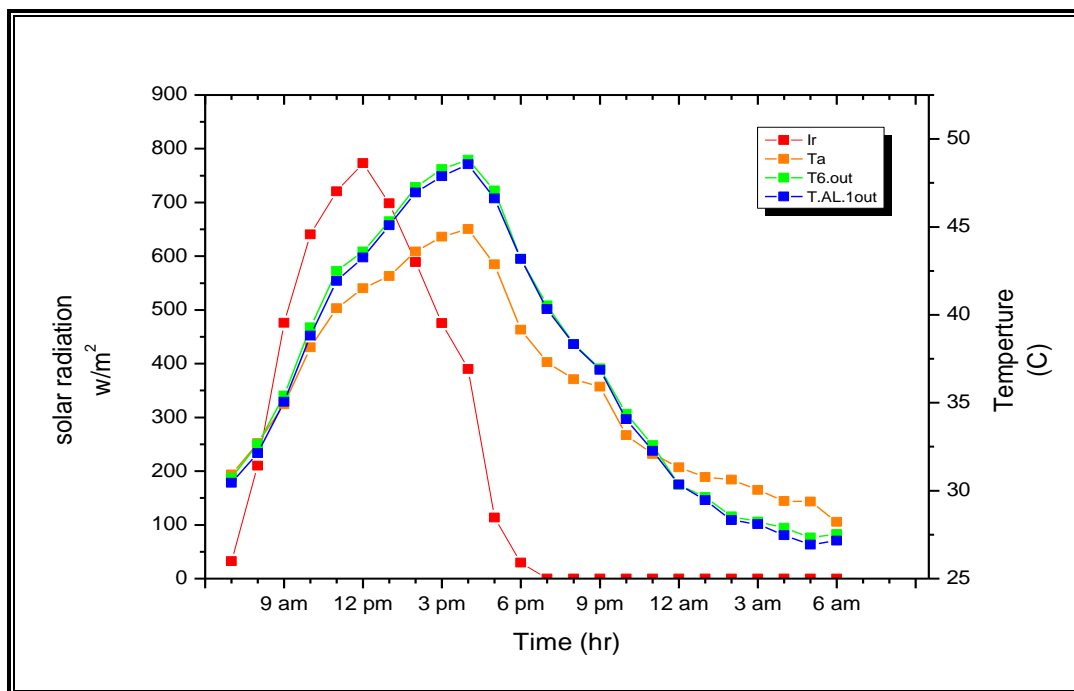
Figure 7 Outer surface temperature gradient of the wall With air layers, ambient temperature, and solar radiation at (17-Aug. - 2021)
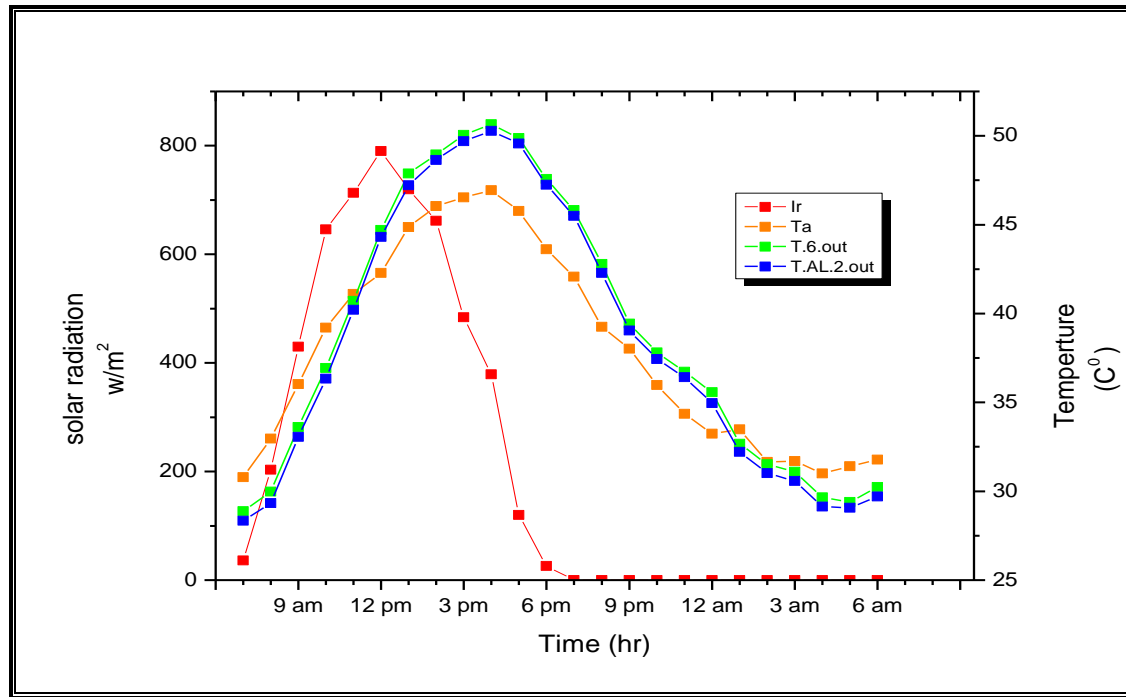
Figure 8 Outer surface temperature gradient of the wall With air layers, ambient temperature, and solar radiation at (19-Aug. -2021)

5.3. Heat gain through cavity walls(Q)

The Radiant Time Series (RTS) method was used to calculate heat gain through the walls that is derived from the heat balance [1].

Conductive heat loss of using Conduction Time Series

$$Q_{i,\theta-n} = UA(T_{e,\theta-n} - T_{r,\theta-n}) \qquad (1)$$

Where:

$Q_{i,\theta-n}$: Hourly conductive heat gain for wall, W.

U: Overall heat transfer coefficient for the wall, $W/(m^2 K)$.

A: Surface area, m^2.

$T_{e,\theta-n}$: Sol-air temperature n hours ago, °C.

$T_{r,\theta-n}$: Presumed room air temperature n hours ago, °C.

The conductive heat gain through the walls can be calculated using conductive heat input for the current hour and for the past 23-hours.

$$Q_\theta = C_0 Q_{i,\theta} + C_1 Q_{i,\theta-1} + C_2 Q_{i,\theta-2} + C_3 Q_{i,\theta-3} + .. + C_{23} Q_{i,\theta-23} \qquad (2)$$

Q_θ: Hourly conductive heat gain for the wall, W.

$Q_{i,\theta}$: Heat input for the current hour, W.

$Q_{i,\theta-n}$: Heat input n hours ago, W.

C_0, C_1, etc.: Conduction time factors.

Figure (9) illustrates the heat gain of two hollow walls with a cavity thickness of 6 cm, one of which was separated into two air layers by the placing of an aluminum plate. When compared them, the heat gain curve of the two-layer wall shows a reduction over 24 hours, where the average heat gain rate of the wall with two air layers $\overline{QAL.1}$ was 16.8 W/m², while the average heat gain rate of the wall with an air gap of 6 cm $\overline{Q6}$ was (19 W/m²), indicating that the rate of reduction relative to the heat gain was 11.5 %.

Figure (10) displays the heat gain rate of two hollow walls with a cavity thickness of 6 cm, one of which was separated into three air layers by putting two aluminum plates in the cavity. When compared them, the heat gain

curve of the three-layer wall shows a reduction over 24 hours, where the average heat gain rate of the wall with three air layers $\overline{QAL.\,2}$ was 17.4 W/m^2, while the average heat gain rate of the wall with an air gap of 6 cm $\overline{Q6}$ was (22 W/m^2), indicating that the rate of reduction relative to the heat gain was 21%.

It can be concluded that when the air layer is divided into more than one layer, the heat gain through the wall will be decreased due to the increased thermal resistance of layers by reducing the convection motion of air trapped inside the layers.
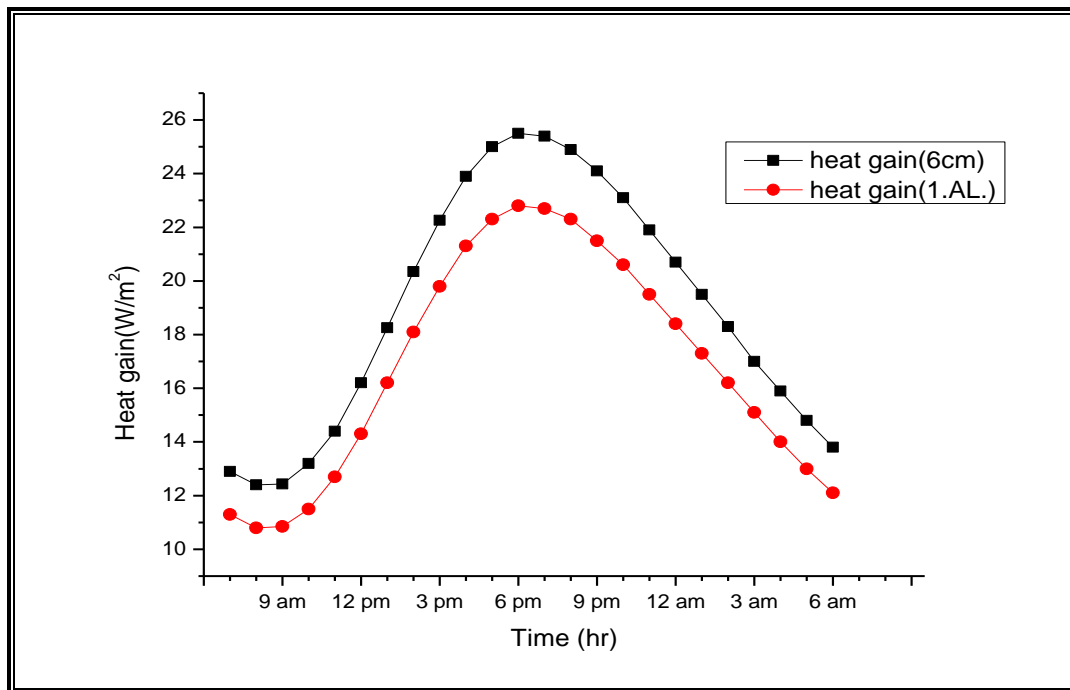
Figure 1 Comparison of heat gain through walls with air layers at (17-Aug. -2021).
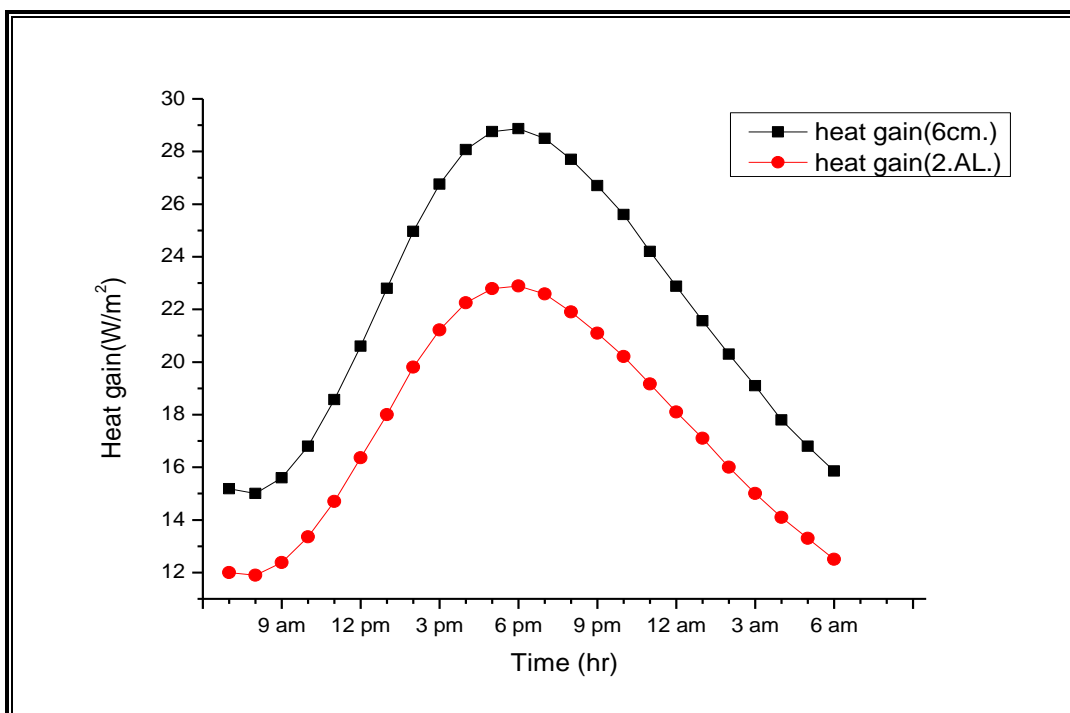
Figure 10 Comparison of heat gain through walls with air layers at (19-Aug. -2021).

5. CONCLUSIONS

Through the results of experiments conducted on hollow walls with a cavity thickness of 6 cm, and this cavity was divided into layers separated by aluminum sheets with a thickness of 1 mm, oriented towards the southwest during the month of August, the following was concluded:

1. The average interior surface temperature is reduced by using closed air layers in the walls. The higher number of air layers, the lower the average inner surface temperatures, where the average inner surface temperature of the wall that contains three air layers was (24 °C), It is close to room temperature, which means less heat gain through the wall.

2. As a result of the thermal resistance demonstrated by the air layers, the average interior surface temperature decreases as the number of insulating air layers in the wall increase. Where the amount of reduction for walls containing a cavity with a thickness of 6 cm when compared once with the wall in which the air cavity was split into two parts and once with the wall where the air cavity was split into three parts were 2.24 ° C and 3.14° C respectively.

3. The temperature of the outer surface of the hollow walls did not change when the air layers were increased, therefore the difference between them may be ignored in all studies.

4. The more layers of air, the less heat gain through the walls as a result of its role in reducing the natural load currents, and thus the thermal resistance of the wall increase. The rate of decrease in heat gain between ($\overline{Q_6}$ & $\overline{Q_{AL.1}}$) and ($\overline{Q_6}$ & $\overline{Q_{AL.2}}$) were 11.5% and 21% respectively.

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