International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Thermal Performance Enhancement for a Simple Solar Wall

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Abstract**—** *Solar energy and its various applications play an important role in reducing dependence on fossil fuels. Solar applications are developing day by day. In this study it was suggested, manufacturing, and inspecting a simple thermal storage wall. The proposed wall area is 0.8281m2. It faces south and consists of a wooden box and a transparent glass cover with a thickness of 3 mm. 18 plastic bottles with a capacity of 2.25 liters filled with water were placed and distributed harmoniously inside the box to increase its thermal capacity. This design was tested for several cases, with insulation increased after sunset, a reflective mirror was used to increase the solar radiation falling on the wall in the morning and the same reflector was used as a cover for the wall at night. The wall was actually tested in the city of Kirkuk for two months, representing the winter from mid-December to mid-February during 2017 and 2018.*

The results of the practical tests showed that the proposed wall has the capacity to store solar energy in the morning since sunrise. High water temperatures were reached in the wall with the highest water temperature reaching 64.6 ° C, which proves that the chosen location of the device (city of Kirkuk) has a suitable solar radiation for the work of this wall in the winter.

Keywords**—** *Solar energy, Trombe wall, thermal storage, water.*

I. INTRODUCTION

There are many issues that are important for the operation of the movement of society; the most important of these is the provision of the necessary energy, and we mean the electrical energy used in the walks of life of the home and economic [1]. The increasing population as the need for comfort increases and makes the need for communities to energy double at a high rate [2]. To date, the primary source of energy is fossil fuels, whether solid, liquid or gas. This depleted fuel, which has not stabilized during the past 20 years, has become a heavy burden on societies due to the fluctuation of the price and the pollution of the environment [3]. The most dangerous result of the use of fossil fuels to produce energy is the emergence of ozone hole, acid rain, global warming and above all climate change has come to cast a bleak shadow on the future of all humanity [4, 5].

The great environmental problems caused by human activities, which caused high pollution of the air and caused increased water salinity and increase desertification and reduce the global animal mass [6]. These catastrophic results have prompted the world to look for new types of environmentally friendly fuels that will reduce pollutants and the resulting damage. Many alternative fuels such as natural gas [7], liquefied petroleum gas (LPG) [8], biodiesel [9], and hydrogen have been proposed [10, 11]. Many scientists also suggested switching to renewable energy-friendly energies such as solar and wind and working to produce and use new and more efficient systems [12, 13].

Sun is the first cause of life on earth. It equips this planet with the warmth and heat necessary to move the wind and the formation of clouds and rain and the spread of life in all the corners of the earth [14]. Solar energy, which can be obtained from sunlight, is clean, free and available in most parts of the globe [15]. Hence, the interest increased in this energy, which has many applications and proved success. Electricity can be produced using a solar chimney [16, 17]. It can also be produced using solar concentrated power plants that have spread around the world [18, 19]. The output of electricity from the sun can be easily used by photovoltaic cells [19, 20]. These cells are affected by different weather conditions such as solar radiation [21], cell temperature [22], humidity [23, 24], and dust [25, 26]. The researchers worked hard to minimize the effects of atmospheric variables on cell productivity and have now reached a hybrid photovoltaic hybrid system (PVT) [27, 28]. The photovoltaic cell through this system can supply electricity and operate as a solar heater and thus provide two solar applications in one device [29, 30]. Direct sunlight can also be used to heat water for domestic or industrial purposes [31, 32]. This temperature is used today to heat the air for comfort [33]. It is also used to heat saline water to reach the high temperatures used in various applications [34, 35]. Solar radiation is used in distillation of water [36, 37], which is considered one of the most important applications of energy and fuel [38]. The substitution of a free card to provide net water is an essential branch in the development of human tissue [39, 40]. At last but not least, the solar system is used in thermal storage [41, 42].

The solar radiation that reaches the surface of the earth changes from the lowest sunrise value to the highest at the dahir and then decreases to the lowest value at sunset (43). The process of storage of heat energy derived from solar radiation at peak periods for later use gives the possibility of matching the supply with the demand at times when both are not available at the same time, making the process of matching the different loads of supply and demand as easy and possible [44].

Solar energy is available for a few hours a day and the intensity of solar radiation during it is fluctuating; therefore, the heat sink ensures continuous supply after the sun sets or the heat source is interrupted by clouds or dust storms. The thermal storage of solar radiation gives the water stored in the solar collector the heat needed to meet the demand for a hot bath that is filled in just a few minutes [46]. Today, thermal

Sabah I Abass, "Thermal performance enhancement for a simple solar wall," *International Research Journal of Advanced Engineering and Science*, Volume 3, Issue 2, pp. 210-217, 2018.

storage technology relies on the storage of a reasonable amount of heat by heating a substance such as water, rocks or variable phase materials. For economic and environmental reasons, passive solar heating has become increasingly important in recent years. One of the elements that represent this group and which has increased interest is the Trumpy wall. This wall can become an acceptable alternative to heating and ventilating homes, thereby reducing the energy consumption of heating, either as fuel for the operation of boilers or electricity that operates the hydra. This wall proved its great potential to operate in areas where heating is more important than cooling [48].

It can be considered that the effect of excessive thermal gain in summer by this wall is one of the disadvantages that should be eliminated, especially in hot summer areas [49]. In order to increase the possibility of using Trombe walls in hot areas, this wall should be constructed and tested in practice. Currently, there are many designs in which thermal storage can be reduced through the reservoir wall and improved ventilation of internal spaces for heat elimination [50, 51]. The use of solar energy to heat the buildings was done by heating the water or heating the air before Trombe began his famous work around this wall, offering four different configurations of the wall and its advantages and disadvantages [52].

Any solar thermal storage system should be able to convert solar radiation into useful heat and store it for use in storage materials to be used when needed. In the literature, there are many ways to store solar energy as a sensible heat and latent heat [53, 54]. One of the advantages of sensible thermal storage is that the materials used for this application are available in local markets and inexpensive. Examples of these heat-conserving materials are water and stones. The Trombe wall is also a collector of solar energy and stores the heat derived from the sun as a sensible heat [55]. With the advent and use of transparent insulators in the structure of the wall, the amount of thermal storage has become very high. During the heating period, this wall enables positive energy to contribute to the heating of the building, i.e., it is not expected to complete the storage then the heating process begins. In the successful design of such a wall, the delayed release of heat stored in the wall and the thermal gains resulting from the direct sunlight through the windows are combined [56].

Several previous studies have shown that there are many variables and climatic conditions that affect the thermal performance of the Trombe wall. As mentioned above, there is an urgent need for a comprehensive understanding of the heat transfer process, which is currently using many simulation techniques and software to optimize the performance of the Trombe wall. Hence, there was an urgent need to study heat transfer across the wall and its spread within the air-conditioned space [57, 58].

The interest in the manufacture of the Trombe walls containing water as a reservoir is for scientific and aesthetic architecture considerations. Everyone knows that water has a good specific heat material and is an acceptable heat transferring agent, so this material will act as a good thermal storage material. Water has been used as a thermal block in many heat-conserving applications, and one of the most important applications of solar collectors on rooftops and buildings to provide hot water to heat the building or to provide hot water for domestic purposes. One of the benefits of aesthetics of water in the wall is its transparent properties of light, which allow seeing outer space from within the air-conditioned space. The liquid, by its liquid nature, provides many beautiful forms of design [60].

In this study, a new type of Trombe wall was proposed. The main part of the reservoir consists of water bottles. The design of this wall has been emphasized in the simplicity of construction, and the cheap cost of construction, the possibility of extending a period of currency and its use in summer and winter. A comparison of the temperature of the components of the device will be conducted here in the currency of specific days in the winter of the Iraqi city of Kirkuk for the season 2017-2018.

II. EXPERMINTAL SETUP

The simple Trombe wall proposed for this study consists of a wooden box with a surface area of 0.8281m^2 manufactured using wooden panels of 2 cm thickness to form the ribs and sides of the box. The inner walls of the box were covered with 2mm aluminum sheets, which were painted in dark black. From the outside, the external surfaces of the box were insulated with glass wool with thickness of 1 cm, and this insulation was for all sides and the background of the box. The box was packed with water bottles (18 plastic bottles, 2.25 liters per bottle). These bottles have been fixed firmly to prevent movement and vibration. The front façade of the wall consists of transparent glass with a thickness of 3 mm. In order to preserve the heat gained and stored in the wall, a wooden cover was used to cover the glass surface of the wall after sunset. In the lower right side of the wall, seven holes of 1 cm diameter were made to enter cold air into the wall. Seven similar holes were made in the upper left side of the wall and the hot air came out. This design was chosen for the purpose of forcing the cold air inside the wall to pass through the walls of a possible road inside the wall to make sure it is heated. A small air fan with a diameter is set at the top openings to pull hot air out of the wall. Several thermocouples have been installed on the different wall sections to measure the variable wall's parts temperatures. These thermocouples have been calibrated before use. The thermocouples were divided and distributed as follows: three were installed in the water bottles on three levels low, medium, and high, and five thermocouples were fixed on aluminum sheets and their arithmetic mean was taken as the temperature of the aluminum panel. One thermocouple was used to read the temperature of the cold air entering the wall, and other thermocouple was used to measure the temperature of the hot air outside the wall.

A series of tests were carried out. First, the wall was tested without any additions in its condition without the addition of its glass wool insulation to evaluate the effect of this addition on the stored energy and to verify the quality of the thermal storage of the wooden box as insulation. Fig. 1 shows a schematic diagram of the thermal wall used in this study.

In the second stage, glass wool was used to isolate the box to indicate differences in thermal insulation. In this case, a detailed study of stored thermal energy was carried out. In the final stage, the solar energy that was added to the proposed wall was increased by using reflectors made of aluminum paper with an area equal to the surface area of the wall. The aluminum paper used as an inverter was fixed on two panels of wood. These panels were used as a cover upper face of the wall at the sunset. This procedure was proposed to reduce the heat lost through the glass surface by convection and radiation to the outside air. These covers open at sunrise in the morning and were fixed at an angle of 60° from the horizon. The tests were carried out in Kirkuk-Iraq winter days, at December 2017, and January 2018.

The following equations were used to evaluate the wall performance. The stored energy was achieved by:

Where:

Q_s = stored energy in wall bottles.

m_w = water quantity in wall bottles.

C_w =water specific heat.

$(T_{t+1} - T_t)$ = temperature increase after one hour passed during sunrise period (K).

This equation indicated that all the fallen radiated energy was gained by the bottles only, as the wall was totally isolated from its back and all sides. The summation of all the stored energies in the wall through the working hours starting from sunrise to sunset, the total gained energy in the day time can be calculated by:

$$Q_{total} = Q_{6-7} + Q_{7-8} + \ldots + Q_{16-17} \quad (2)$$

The Iraqi meteorology tables for Kirkuk City supplied the solar intensity data from which Q_{in} was evaluated as:

Q_{in}= I A

Where I= the solar radiation intensity for each hour/day in W/m^2, and A= the front area of the wall in m^2.

The wall daily efficiency (ηd) can be calculated from the equation:

$$\eta_d = Q_{total} / Q_{in} \quad (3)$$

As the water mass specific heat is constant while the temperature varied, so the stored heat will be proportion with temperature variation only, Because of this point, the temperature-time relationships were used to reveal the thermal storage changes.

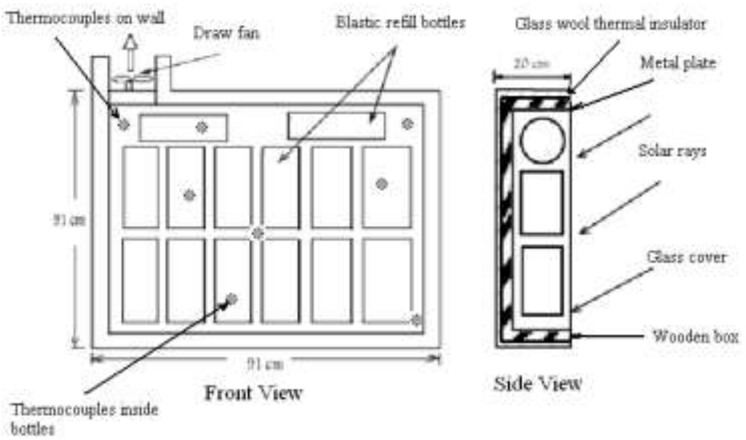

Fig. 1. Sketch diagram for the front and side views of the studied wall

III. Results and Discussion

The Trombe wall has been fixed to the south so that the glass cover can receive most of the solar radiation during the day. Solar heat absorbed by solar radiation is stored in two areas of the wall: the aluminum plate and the water bottles. The heat transfer of these two parts to the air to be heated is obtained through convection and thermal conductivity. The relatively cold air coming from the room that needs to be warmed was entering through the lower openings. This air passes through the water bottles channel and is returned to the room through the upper openings. The fan installed near the upper holes ensures this air movement. This air circulation provides a direct thermal path to the room, causing heat transfer by connecting from the wall to the room in time delay, increasing the working time of the wall.

Figures 2, 3 and 4 illustrate the measurements taken in the atmosphere of the city of Kirkuk-Iraq in practice. These measurements were made during the month of December 2017 in 09/12, 18/12, and 27/12, respectively. These days were chosen because of the purity of the atmosphere. The test was carried out according to the above method without adding the glass wool insulation around the water wall without covering the wall after sunset.

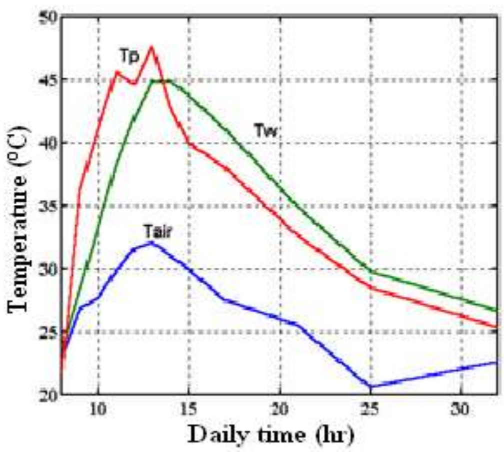

Fig. 2. Temperature distribution at 09/12/2017

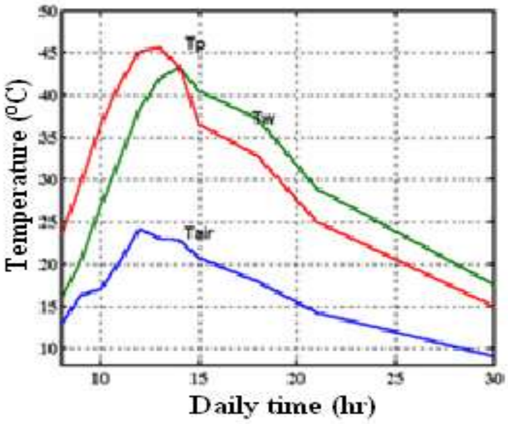

Fig. 3. Temperature distribution 18/12/2017

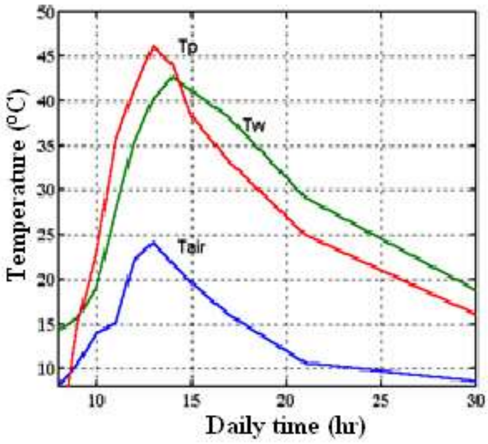

Fig. 4. Temperature distribution at 27/12/2017

The temperature of the aluminum wall (Tp) was increasing, as well as the temperature of the water in the plastic bottles (Tw). However, the temperature of the Tp has been more than Tw since the sunrise until it reached its maximum value between 1 and 2 PM. Tp then drops faster than Tw because the specific heat of water is higher than that of aluminum. In the evening, the heat loss becomes fast for both the black-walled and the water in bottles.

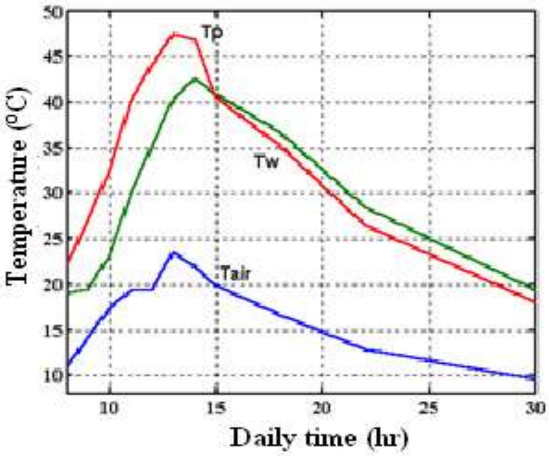

Fig. 5. Temperature distribution at 17/12/2017

Fig. 5 shows the studied wall parts' temperature at 17/12 after adding glass wool insulator to cover the outside walls of the wooden box. The temperature readings declare an increasing in the temperature for black aluminum plate and plastic bottles' water. The temperature variations were reduced between T_p and T_w that indicates better energy conservation inside the proposed Trombe wall due to lower thermal loss from side and rear walls by convection heat transfer to ambient.

Figures 6, 7 & 8 show the temperature practical measurements for the tests conducted in 2018 at 03/1, 13/1 and 23/1. The measurements were taken in case when the wall was covered after sunset. This procedure was conducted to reduce heat leakage from the transparency glass cover and from other sides of the wall by radiation and convection. This procedure has succeeded in reducing the high temperature decline of the aluminum plate and water temperatures inside wall. Also, it increased the difference between them and the ambient air temperature. This result from lowering the amount of energy lost from the front side of the wall (the glass cover).

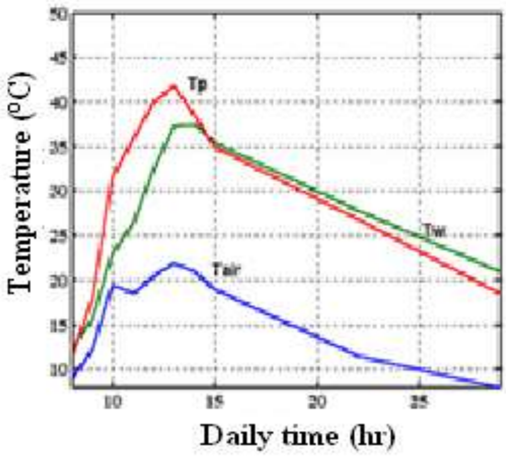

Fig. 6. Temperature distribution at 03/1/2018

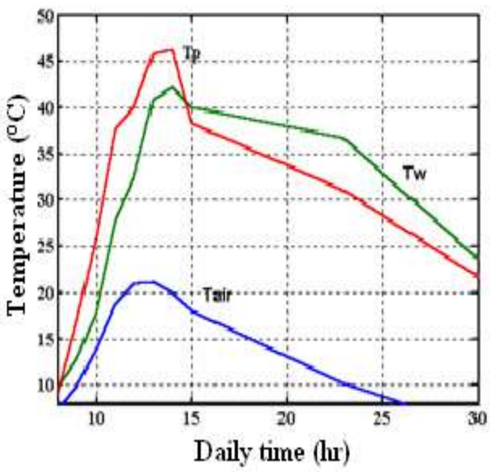

Fig. 7. Temperature distribution at 13/1/2018

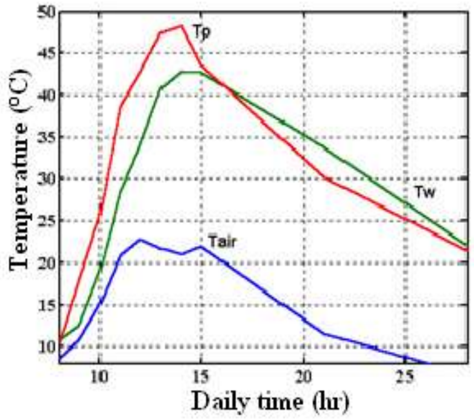

Fig. 8. Temperature distribution at 23/1/2018

Figures 9 and 10 show the results 09/1 and 19/1/2018, in these tests the aluminum paper reflectors were used during sunrise to increase the solar radiation concentration on the wall parts. This procedure proved its great impact by increasing the water and rear black plate temperatures highly compared with the former cases.

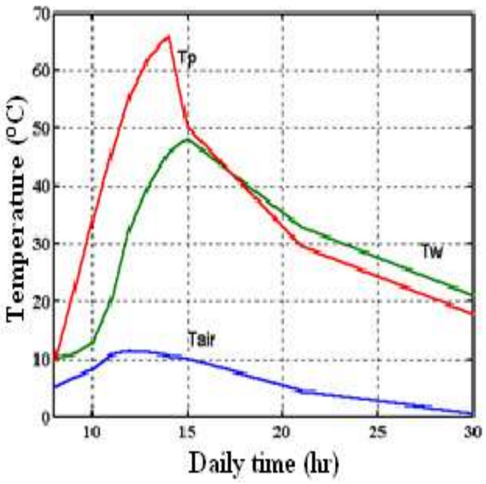

Fig. 9. Temperature distribution at 09/1/2018

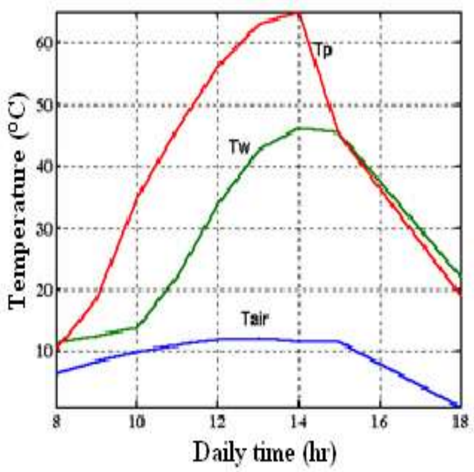

Fig. 10. Temperature distribution t 19/1/2018

Figures 11 and 12 show the temperatures measured through the test conducted at 21/12/2017 and 15/1/2018. In these tests, reflectors were used to improve the solar radiation concentrations, and the wall front was covered by them after sunset. The resulted temperatures increase in this procedure highly whether for the water or the aluminum plate. This result clarifies that the thermal energy loss after sunset was reduced significantly.

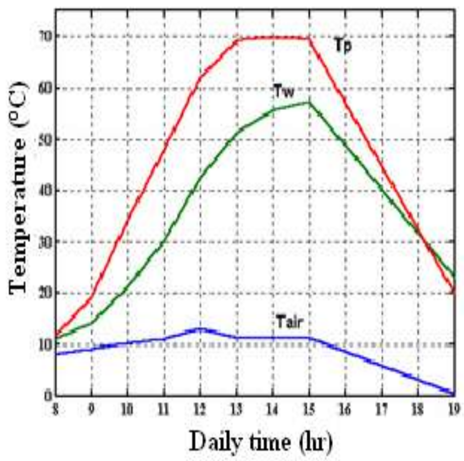

Fig. 11. Temperature distribution at 21/12/2017

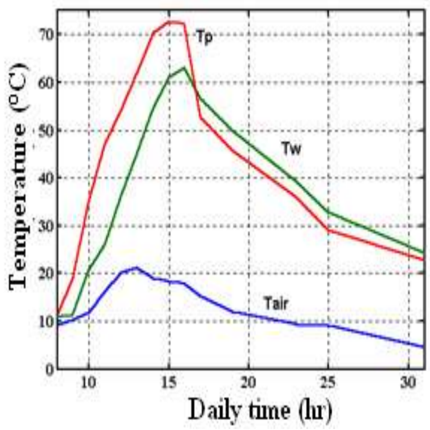

Fig. 12. Temperature distribution at 15/1/2018

When calculating the energy stored in the wall we find that in the first case it reached 1213 W/m^2 in the test on 09/12 (Fig. 2). This energy increased to 1450 W/m^2 when adding glass wool. Contact this value in experiments on 17/12 (Fig. 5). The thermal storage in the wall increased to 1844 W/m^2 in case of wall cover after sunset as in 03/1 (Figure 6). In the test on 19/1/2018 the stored thermal energy reached 3045 W/m^2 (Fig. 10). These calculations showed that the daily efficiency of the wall increased from 37.4% to 69.6% in normal conditions. Table 1 illustrates the stored energy in the proposed wall for all the conducted tests clarifying the climate conditions of each test for comparison purposes.

TABLE 1. The wall stored energy in each test with its climate conditions for comparison

Test date	Wall condition	Climate condition	Stored energy W/m^2	Wall daily eff. (%)
09/12/2017 18/12/2017 27/12/2017	Without insulation	Partial cloudy cloudless cloudless	1213 1315 1343	37.4 39.2 39.9
17/12/2017	With insulation	cloudless	1450	41.1
03/1/2018 13/1/2018 23/1/2018	With insulation+ wall covering	cloudless cloudless cloudless	1844 1857 1824	42.8 43.2 41.7
09/1/2018 19/1/2018	With insulation + wall covering+ black colored plate	cloudless cloudless	2236 2268	48.3 48.5
21/12/2017 15/1/2018	With insulation + wall covering+ black colored plate+ aluminum reflector paper+ reflecting plate	cloudless cloudless	3045 3120	59.7 69.6

IV. CONCLUSIONS

In this study, a thermal storage wall (Trombe wall) was design and manufactured from simple materials, which are available in the local markets and in cheap price. Experiments were conducted on the wall in the winter climate of the city of Kirkuk-Iraq of 2017-2018. The measurements and the results of the tests carried out during the mentioned period showed that the proposed wall is suitable for serving as an efficient heat storage wall which can be used to heat the building rooms to late hours. Practical experiments have shown that the energy stored in the wall has increased with the status of the reflectors. The highest temperature of water measured 64.4 degrees Celsius at 4 PM while the rear aluminum panel has reached 74.4 degrees Celsius under the same conditions. Increasing heat insulation, painting the aluminum plate with black color, and covering the glass cover after sunset have largely affected the increase in energy storage and reduced the good insulation from losing it to the atmosphere again.

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