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Experimental study of using solar energy storage wall for heating Iraqi houses purposes

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دراسة تجريبية لاستخدام جدار خازن للطاقة الشمسية لأغراض التدفئة المنزلية في العراق

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الخلاصة

تم في هذا البحث بناء جدار حراري بسيط خازن للطاقة الحرارية القادمة من الشمس، واختبر في الظروف الشتوية لمدينة بغداد، مساحة الجدار ٠.٨٢٨١ م^{٢} مواجه للجنوب، الجدار مكون من صندوق خشبي مغطى بغطاء زجاجي سمكه ٣ملم، وتم صف ثمانية عشر علبة بلاستكية داخل هذا الصندوق سعة كل منها ٢.٢٥ لتر، ثقب السقف السفلي والعلوي للجدار بعدد من الثقوب لتدوير الهواء على الأوعية البلاستيكية المملوؤة بالماء لغرض زيادة السعة الحرارية، وقد تم استخدام مروحة هواء صغيرة لتدوير الهواء خلال الجدار. اختبر الجدار في مدينة بغداد في ظروف العراق الجوية للأشهر كانون أول ٢٠٠٦، كانون ثاني وشباط ٢٠٠٧، وأظهرت النتائج إمكانية استخدام هذا الجدار كوسيلة مساعدة لمنظومة التدفئة في المنازل، أثناء الليل حتى الساعة الخامسة والنصف من صباح اليوم التالي في فصل الشتاء.

Abstract

In this article a simple type solar heat storage Trombe wall was built and tested at Baghdad winter. This wall had an area of 0.8281 m^2 and facing south, it is consisted of a wooden box covered with clear glass of 3mm thickness, and 18 plastic refill bottles (2.25 liter capacity each) arranged in this box. Many holes are made at the bottom and upper faces of the box to facilities the air circulation across the plastic bottles, which are filled with water to increase the heat capacity. A small air fan was used to increase air circulation through the box. The wall was tested at

Baghdad under Iraqi condition at December 2006, January, and February 2007. The results show the ability of this wall to assist the heating systems in houses at night up to 5:30 A.M. of the next day in winter seasons.

Introduction

Although the concept is not new, green buildings have enjoyed an increase in popularity in recent years. Green buildings are designed to be more environmentally friendly than standard buildings. Many green buildings achieve this to be more energy efficient. Passive solar design can greatly increase the energy efficiency of a building [1].

Passive solar design embodies a variety of strategies and technologies that use the free energy received from the sun for the purpose of heating and lighting building spaces. One passive solar technology for green buildings is the Trombe wall [2].

The Trombe wall is a clever device for collecting and storing heat from the sun during the day and releasing heat into a building space during the night; they are a means for free solar space heating. The wall is typically located on the south face of a building (in the northern hemisphere) to maximize its solar exposure throughout the year. Overhangs are used to shade the wall during the summer to prevent overheating but allow sunlight at lower angles to heat the wall during the winter. Heat is collected and stored in the thick concrete wall. One or more layers of glazing on the exterior and an optional selective surface turn the wall into a one-way heat valve. The glazing forms an air gap between the wall surface and the outside air that helps to insulate the wall from outside convection. The selective surface is adhered to the wall surface and is characterized by a very high absorptivity and very low emissivity, allowing solar radiation to be absorbed but preventing it from being re-emitted as long wave radiation [1, 3, and 4].

However, solar energy is intermittent, unpredictable, and available only during the day. Hence, its application requires efficient thermal energy storage so that the surplus heat collected during sunshine hours may be stored for later use during the night. Similar problems arise in heat recovery systems, where the waste heat availability and utilization periods are different, requiring some thermal energy storage. In thermal energy storage, the useful energy from the collector is transferred to the storage medium where it is transformed into an internal energy [5, 6].

This may occur in the form of latent heat, sensible heat, or both. One major drawback of sensible heat storage is the large volume required, especially when the allowable temperature swing is small. Latent heat storage is more attractive than sensible heat storage because of its high storage density with smaller temperature swing. However, many practical problems are encountered with latent heat storage due to low thermal conductivity, variation in thermo-physical properties under extended cycles, phase regression, subcooling, incongruent melting, volume change and high cost. These problems have to be technically resolved before latent heat storage can be widely used [7, 8].

Previous work reveals that there are many parameters and different climatic conditions that affect the thermal performance of the Trombe wall, full understanding of the heat transfer process is required and the simulation technique of Trombe wall performance then can be used properly. Therefore, there is a need to further study the convection heat transfer [9].

Our interest in water Trombe walls is both scientific and aesthetic. We know that water is a very conductive material and therefore acts as a good thermal mass. It has been used as a thermal mass in many different situations, but information about how much water, what kinds of glass to use, etc. is difficult to come by. Even less information is out there about using water as a mass in a Trombe wall [10, 11].

Water also has aesthetic benefits. Its translucent properties will allow light to penetrate to the space beyond, and the water itself provides many potential design opportunities. We concluded that before one could effectively design a space using water walls, understanding the optimal thickness would be a key [12].

The purpose of this work is to study the possibility of using solar collector wall in worming closed places in Iraq, calculate the energy could be supplied by the designed wall, supplying time and different effective conditions affecting its performance.

Experimental Setup

Figure 1 represents the thermal wall used in this investigation, simple Trombe wall was manufactured consisting of wooden box with 0.8281m^2 (2 cm thickness from back and all sides), aluminum plate (2 mm thickness) painted with dark black is adhered to all box inside walls. The outer surface of the box is isolated by glass wool (1cm thickness) from all sides and back, the box is filled by 18 plastic refill bottles (2.25 liter each), these bottles are fixed tightly to prevent its movements, they are covered with transparent glass (3mm thickness). This part from the wall was covered by wood wall after sunset, seven holes (1 cm dia each) was drilled in the bottom of the wall, as inlet cold air vent, and the same thing at the upper side as outlet hot air vent, so the air will take a longer roadway inside the wall. Small air drawer (7 cm dia) was fixed near the upper holes to draw hot air out of the wall. Many copper constantan thermocouples are used to measure temperatures after it were calibrated, three are placed inside the water on three levels, five are fixed on aluminum plates, one thermocouple is fixed to read the inlet cold air temperature and another for outlet hot air. Many tests were carried out in Iraqi winter days, at the last two weeks of December 2006, all January and February days from 2007.

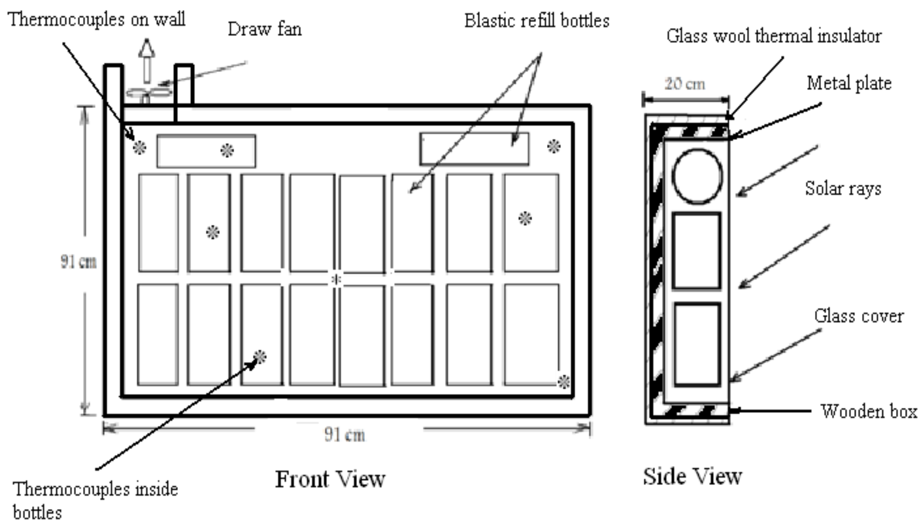


Figure 1, Sketch diagram for the front and side views of the studied wall.

The stored energy in the tested wall during sunrise hours (for one hour) was calculated by the equation:

$$Q_s = m_w \, C_w \, (T_{t+1} - T_t) \qquad \text{……….} \ (1)$$

Where: Q_s = the storage energy inside wall bottles (kW)

m_w = water quantity in wall bottles (kg)

C_w = water specific heat (kJ/ kg. K)

$(T_{t+1} - T_t)$ = The increase in water temperature between each two hours from daylight (K).

The stored energy for the whole day was calculated by the equation:

$$Q_{S.\ Total} = Q_{7\text{-}8} + Q_{8\text{-}9} + \ldots + Q_{3\text{-}4} \quad \ldots\ldots \quad (2)$$

For the drawn energy by the fan during its operation time was calculated by the equation:

$$Q_u = m_a\, c_p\, (T_{air\ out} - T_{air\ in}) \quad \ldots\ldots. \ (3)$$

Where: Q_u = the drawn energy from water bottles in the wall (kW).

m_a = drawn air quantity (kg/s).

c_p = air specific heat (kJ/kg.K).

$T_{air\ out}$ = the outer air temperature delivered by the fan (K).

$T_{air\ in}$ = the temperature of the air moving inside the wall (K).

The total drawn energy for one day was calculated by:

$$Q_{u\ total} = Q_{u\ 4.5\text{-}5.5} + Q_{u\ 5.5\text{-}6.5} + \ldots. \quad (4)$$

The air quantity can be calculated depending on fan diameter and air velocity and air density, as follow:

$$m_a = A\, V_a\, \rho_a \quad \ldots\ldots.. \ (5)$$

Where: A = the air drawer area (7 cm dia) (m^2).

V_a = outlet air velocity (m/s).

ρ_a = air density (kg/ m^3).

Discussion

Solar energy is intermittent, unpredictable, and available only during the day. Hence, its application requires efficient thermal energy storage so that the surplus heat collected during sunshine hours may be stored for later use during the night.

Our interest in water energy storage walls is both scientific and aesthetic. We know that water is a very conductive material and therefore acts as a good thermal mass. It has been used as a thermal mass in many different situations; it is very cheap compared with masonry, and it stores about three times more heat by volume, with a lower thermal resistance.

Water also has aesthetic benefits. Its translucent properties will allow light to penetrate to the space beyond, and the water itself provides many potential design opportunities.

Figures 2, ٣ & 4, show the average temperatures measured in the last two weeks of December 2006 (figure 2), all January 2007 (figure 3) and all

February 2007 (figure 4). In these figures T_w (average water temperature inside the bottles), T_p (average aluminum plate temperature) and T_{air} (average atmospheric air temperature) are defined. The curves represent that water and plate temperatures were increased starting from sunrise, the maximum average water temperature reached in December was 63.1°C, while the plate temperature reached 72.6°C. In January water temperature was 64.6°C, plate temperature was 74.4°C, as indicated in figure 3. In February, where most its days were dusty and cloudy, the maximum average water temperature reached was 58.1°C, the plate's temperature reached 60.2°C, as shown in figure 4. Although February days warmer than January days, the average water and plate temperatures were less than that for January days, because in most of February days the weather was cloudy or dusty, which mean that wall storage efficiency reduces in these weathers, and these results indicate that this type of wall absorbs direct and indirect heat, which may be reflected from neighbor walls, grounds and surfaces. The plate temperature increased before water temperature with about an hour, after that, both temperatures started to reduce for all components due to thermal losses to outer ambient air by all heat transfer ways.

In this article, the maximum water storage wall temperature reached was 64.6°C at 3.5 PM in December days, while the best recorded temperature was by Torcelline & Pless [11] who constructed concrete solar thermal storage wall; the interior maximum wall storage temperature reached was 54°C at 3 to 4 PM at USA weather conditions. The water heating storage wall is distinguished by the homogenous temperatures distribution inside the wall, because of natural convection, while this property in the concrete wall cannot be fulfilled.

The figures show that the used wall gathered high levels of energy in daylights. This solar energy can be used in heating spaces, to compensate part of heating sources used, like electrical power or fossil fuel. This gained energy increased when ventilated naturally, while using air blowers or drawers (as in this paper) accelerated the loss of gained heat.

Air drawer was used to draw air from the space, and allow it to pass through the water bottles, the air then was let out to the heating space, to improve heat transfer from water to the heating space. The time selected to start this operation was 4.30 PM, which is near the time for sunset in winter days, and the wall was covered with wooden doors, to prevent reversal heat transfer from the wall to ambient air. These doors were

opened at 7.30 AM of the next day, which is the time selected to stop the air drawer, where the sunrise and new heat storage operation started.
Figures 5, 6 &7 show the average $T_{air\ in}$ and $T_{air\ out}$ temperature variations tests. Figure 5 shows that the average $T_{air\ out}$ for December days was 44.4°C, at 4.30 PM when start using the drawer, and reduced to 16°C at 7.30 AM of the next day, while the average $T_{air\ in}$ was 9.6°C at that time. In figure 6, average $T_{air\ our}$ (for January days) was 39°C at 4.30 PM, and reduced after using air drawer to 16.3°C at 7.30AM of the next day, where average $T_{air\ in}$ at that time was 8.3°C. In figure 7, $T_{air\ out}$ (for February days) was 38.5°C at 4.30 PM when start using air drawer, decreased to 17°C at 7.30 AM of the next day, while the average $T_{air\ in}$ was 9°C. These results demonstrate that the drawn air temperatures from the wall, at the beginning of drawing operation were high, then it reduced with time, so by adjusting drawing air, for example by dividing the wall into slices, and arranging the use of these slices in an order preserve the stored energy for the longest possible time.
Storage energy calculations for the December results show that wall energy storage was 2977 watt/m^2 day, and the heating supplied energy after the air drawer was used at 4.30 PM, was 2330 watt/ m^2 day. In January set of tests, the storage energy was 3045 watt/ m^2 day, the heating supplied energy after using air drawer at 4.30PM was 2497 watt / m^2 day. In February set of tests, the wall storage energy was 2236 watt/ m^2 day, the heating supplied energy after using air drawer at 4.30 PM was 1777 watt/ m^2 day.
These results show the ability of this walls type to heat spaces efficiently at Iraqi winters, using the gained and stored solar thermal energy at daylight, to heat spaces starting from sunset up to 5.30 AM of the next morning day.

Conclusions

The results show that using this kind of walls is suitable for heating spaces in Iraqi weather.

1- This wall reduces the dependence on electric power and fossil fuels in heating spaces at winter days, but it will not compensate it.
2- Energy storage increases in clear days, and heating period increases.
3- Energy storage reduces in cloudy and dusty days.
4- Covering the wall at sunset preserved the stored energy for more hours.
5- Using air drawer to circulate heating space air inside the wall improve heat transfer from the water inside the bottles to the space.

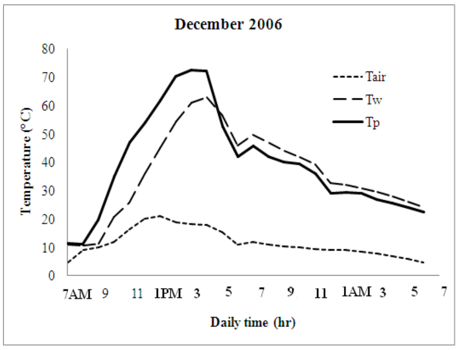


Fig (2) Average daily temperatures in December 2006

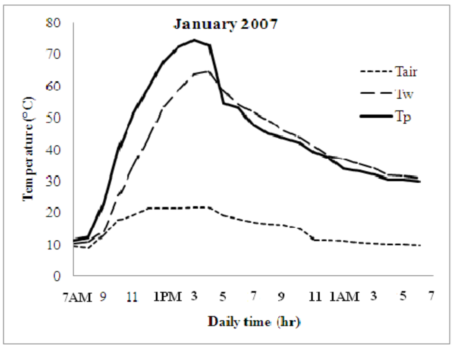


Fig (3) Average daily temperatures in January 2007

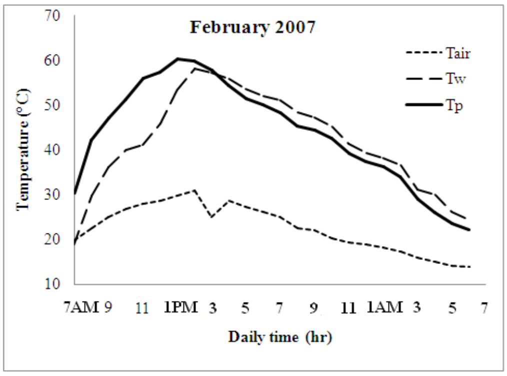
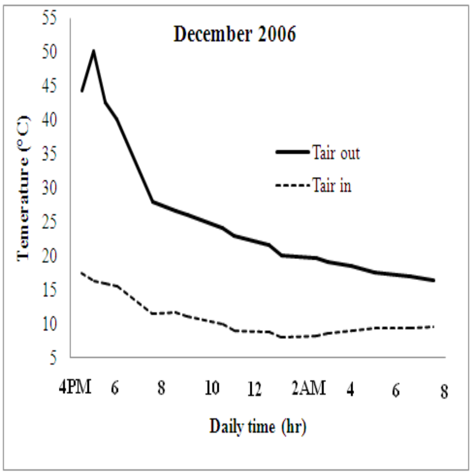


Fig (4) Average daily temperatures in February 2007



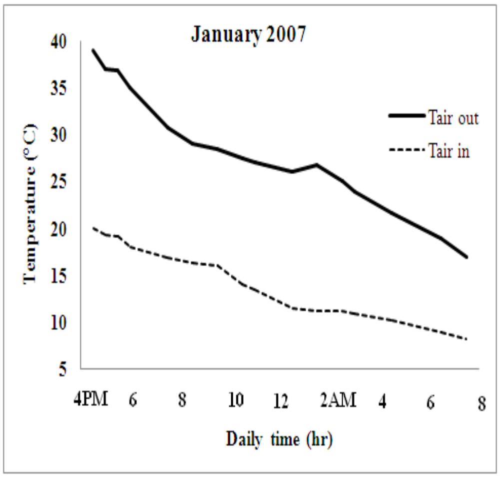


Fig (5) Average inlet and outlet air temperatures through the wall during fan using hours in December 2006

Fig (6) Average inlet and outlet air temperatures through the wall during fan using hours in January 2007

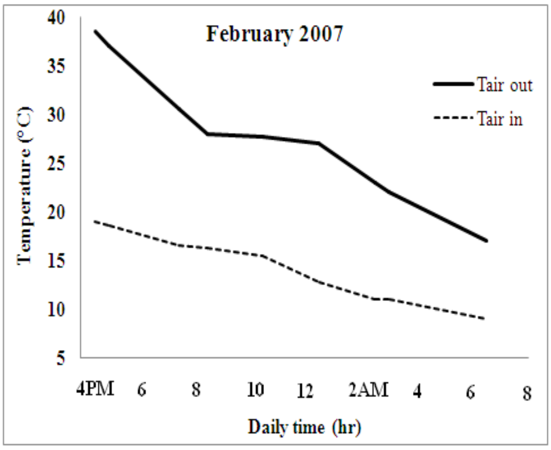


Fig (7) Average inlet and outlet air temperatures through the wall during fan using hours in February 2007

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