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# SOLAR STORAGE WALL UTILIZATION FOR POLYETHYLENE GREENHOUSES AS A PASSIVE HEATING SYSTEM

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## ABSTRACT

Trials were carried out to overcome the greenhouse air temperature drop within the cold nights of winter season, which affects the greenhouse crop production. Two different cheap materials of adobe and red brick were used as solar storage walls inside gable-uneven span type greenhouses. The greenhouses that comprised storage walls were compared with a control trial greenhouse without storing wall. Consequently the control greenhouse was compared with an open field testing. Soil covers were applied to study the effect of mulching on the soil heating under the effect of the solar storage wall presence. Crop residues of 5 cm thick, black plastic mulch of 0.2 mm thick were compared with the bare soil without covers.

Investigations were carried out through the period from 30$^{th}$ November 2004 till 22$^{nd}$ of February 2005. Effect of warming up the interior microclimate and soil of the greenhouses on the squash crop (Nile variety) production was examined. The following points were considered in the study: effect of the presence of the storage wall on the soil depth temperature, the storage wall thermal efficiency, crop production for each cultivation system and cost estimation

It was found that, squash seeds germination, plants length, number of flowers for each plant squash crop production and the dry weight inside the greenhouse with storage wall trial were greater than that inside the control one with and the open field test. The Trombe wall increased the inside air temperature by 2.2 °C and 2.6 °C above that without storage wall when using the Trombe wall of adobe and red brick, respectively.

## INTRODUCTION

There is an increase demand on the plastic greenhouse for vegetables planting to encourage and increase food production to reduce the production cost for a favorable profit (Abdel-Ghaffar and Helmy, 1988; Abdel-Latif and Helmy, 1988). A greenhouse is usually built to intensify the agricultural crops productions and to control or modify the environmental parameters affecting plant growth (Kassem, 1999). Solar radiation is a limiting factor for production, especially during winter months. The amount of solar radiation available to the plants in a greenhouse is affected by the structural frame, covering material, surrounding topography and orientation of the greenhouse (Aldrich and Bartok, 1990).

Various greenhouse features and designs are given by Hassan (1992) to show how the greenhouses are utilized for cropping production. In this respect Malquori *et al.* (1993) found that an asymmetrical roof with a shallow pitch was found performs better than a standard roof.

Meanwhile Gupta and Chandra (2002) indicated that, a gothic arch shaped greenhouse required less heating as compared with the gable and Quonset shapes during the night.

Solar radiation contributes to heat greenhouse during the daylight so air temperature inside the plastic greenhouse is fluctuated. So, the greenhouse environment a condition is differed from month to month (Yuan *et al.*, 2004). Abdel-Ghaffar and Helmy (1988) found that, the climatological variables of incident solar radiation is the most important factor that affects the greenhouse air temperature during the daylight but the ambient air temperature is sharply reduced at night.

Soil temperatures influence on many cultivation processes and biochemical reactions such as seed germination, plant growth, nutrient availability, insect populations and pesticide degradation (Unger, 1998). Straw mulch reduces water evaporation and temperature surface soil, increase soil organic content, and improves soil quality (Langdale *et al.*, 1992). Straw mulch was effective in improving soil physical conditions in tropical and subtropical environments (Cook *et al.*, 2006). Soil temperature increases due to the plastic mulches results to a decrease in sensible and latent heat fluxes and consequent increase in heat available for soil heating (Gacone and D'Emillio, 2000).

Four plastic cover colors of the greenhouse and three plastic mulches colors (black, transparent and silver) under each greenhouse, beside bare soil as a control were tested by Saleh and Medany (2003). They found that, average soil temperature was influenced by air temperature under the different types of plastic greenhouses. The average soil temperature varied according to the type of plastic mulches color as compared with uncovered soil. The plastic cover was found to be affected the plant growth in term of decreasing days from planting to emergence and the maturity of many vegetable crops including tomato and cucumber. Also, it increased the total yield and the marketable yield over no plastic mulch (Kwabiah, 2004). Dark mulches (black, red and gray) were provided higher soil warming ability than light colored mulches, Perez-Diaz *et al.* (2004). The polyethylene mulch was caused in increasing the soil temperature. Groundnut plants in polyethylene and straw-mulched plots were generally tall, vigorous and reached early flowering (Yuan *et al.*, 2004 and Ramakrishna *et al.*, 2006)

The concept of the storage wall is known as Trombe Michel wall (Trombe wall). It is a south facing concrete or brick wall black and covered on the exterior by glazing or plastic. It collects and stores solar energy. The stored energy is transferred to the microclimate inside the building. The main function of the Trombe wall is the ability to store solar energy during the daylight (endothermic body) and emit this energy at night, (exothermic body) (Taha, 2003). The effect of storage wall on the inside greenhouse air temperature was investigated by Singh and Tiwari (2000). They found that, a significant effect of the thermal storage north wall and the ground air collector on the plant and air temperature.

The passive solar wall which is usually used as the northern wall of the passive solar building consists of the wall and glazing cover. A typical wall has rectangular vents, which are equal in size and are distributed uniformly. The optimum structural thickness of the solar passive heated dwelling building is 37 cm for brick and 35-40 cm for law concrete walls, 40-45 cm for high concrete walls (Fang and Li, 2000). To enhance the thermal storage effect of a Trombe wall, various techniques was developed and used by Chen *et al.* (2005), such as installing an absorber plate in the air gap and using a black surface of the heat storage wall.

Different crops have been cultivated underneath the polyethylene greenhouses and tunnels, one of these cultivation is squash crop. Squash is an annually vegetable crop, grows in the light soils. It belongs to family *Cucurbitaceae* (Ground family). Squash roots spreads in the 30 cm depth from the soil surface. Its leaves and stem spreads around the plant with average high of 90 cm. It is affected by frost and suitable temperature range for growing squash is from 21 to 35 °C (Hassan, 2001).

The objective of this study is to drive a resolution to overcome the crises creates from the greenhouse air temperature reduction, especially in the cold winter nights.

## THEORETICAL BACKGROUND

The energy balance during daylight for a certein greenhouse can be computed using the following equations:

$$Q_{gain} = Q_{supply} - Q_{loss} \quad , \quad \text{Watt} \qquad (1)$$

For the Greenhouse inside air, the energy balance can be calculated by the following formula:

$$Q_i = Q_A + Q_{loss} + Q_{gain} \quad \text{Vatt} \qquad (2)$$

Where, $Q_i$ is the solar energy available inside the greenhouse, it can be determined as:

$$Q_i = G_t A_g \quad \text{Watt} \qquad (3)$$

$G_t$ is the total solar radiation flux incident inside the greenhouse in $Wm^{-2}$, and $A_g$ is the greenhouse floor surface area in $m^2$, $Q_A$ is the absorbed solar energy by storage wall, it can be computed as:

$$Q_A = G_T A_W \alpha_W \quad , \quad \text{Watt} \qquad (4)$$

$G_T$, is the total solar radiation intensity, $Wm^{-2}$, $A_w$ is the wall surface area, $m^2$, $\alpha_w$ is the absorptivity of wall materials for solar radiation. $Q_{loss}$ is the total heat losses from the greenhouse during daylight, it is given by:

$$Q_{loss} = q_c + q_s + q_r \quad \text{Watt} \qquad (5)$$

Where, $q_s$ is the sensible heat loss due to ventilation, $q_r$ is the heat loss by radiation and $q_c$ is the heat loss by conduction, it can be calculated from the following formula:

$$q_c = U_o A_c (T_{ai} - T_{ao}) \quad \text{Watt} \qquad (6)$$

Where, the $U_o$ is the overall heat transfer coefficient, W/m$^2$.K. $A_c$, is the total surface area of greenhouse cover, m$^2$, $T_{ai}$ is the interior air temperature, K. $T_{ao}$ the exterior ambient air temperature, K and.
During the night time $Q_{loss}$ is given by:

$$Q_{loss} = q_c + q_{inf} \quad , \qquad \text{Watt} \qquad (7)$$

Where $q_{inf}$ is given by:

$$q_{inf} = mC_p(T_{ai} - T_{ao}) \quad , \qquad \text{Watt} \qquad (8)$$

Where, $C_p$ is the specific heat of air, J/kg.K and $m$ is the mass flow rate of air, kg/s, it calculates by:

$$m = VN\rho \quad , \qquad \text{kg/s} \qquad (9)$$

Where $V$ is the greenhouse volume in m$^3$, $N$ is the air exchange rate, 1/s, and $\rho$ is the density of air kg/m$^3$

Evapo-transpiration rate in a greenhouse $Q_{ev}$, is given by:

$$q_{ev} = FRA_g G_T \quad \text{Watt} \qquad (10)$$

Where, $F$ is the ratio of ground surface area covered by plants to the total floor surface area, decimal; $R$ is ratio of evapo-transpiration to solar radiation, taken as 0.5 and $Q_g$ is the absorbed solar radiation by the floor calculated as:

$$Q_g = (1-F)A_g \alpha_g G_T \quad , \qquad \text{Watt} \qquad (11)$$

Where, $\alpha_g$ is the absorptivity of the greenhouse soil.
The ventilation rate (in kg/s) to provide and maintain the greenhouse air temperature at a desired level can be computed using the following formula:

$$m_a = \frac{Q_s - Q_A - Q_{loss} - Q_g}{Cp_a(T_{ai} - T_{ao})} \qquad \text{kg/s} \qquad (12)$$

$m_a$ should be multiplied by the specific volume of air (m$^3$/kg).

A microclimate energy blance can simply be developed to predict the storage wall temperature during daylight. It can be calculated according to different sources of energy which affects the microclimate of greenhouse by the following formula:

$$Q_A = Q_s + Q_c \qquad \text{Watt} \qquad (13)$$

Where, $Q_s$ is the solar energy stored in the storage wall in Watt. It can be calculated as follows:

$$Q_S = m_S Cp_S (T_{se} - T_{sb}) \qquad \text{Watt} \qquad (14)$$

Where, $m_S$ is the storage wall mass in kg; $Cp_S$ is the specific heat of the storage wall materials, J/kgK, $T_{se}$ is the storage wall temperature at the end of each hour, K and $T_{sb}$ is the storage wall temperature at the beginning of each hour, K. $Q_c$ is the heat loss by the natural convection from the storage wall as:

$$Q_c = h_s A_s (T_s - T_{ai}) \quad , \text{Watt} \qquad (15)$$

Where, $h_s$ is convection heat transfer coefficient, W/m$^2$K, $A_s$ is the total surface area of storage wall, m$^2$, $T_s$ is the storage wall temperature, K.
The energy balance on the thermal storage wall during daylight can be represented by the following equation:

$$T_{se} = T_{sb} + \frac{3600}{m_s Cp_s}\left[Q_A - h_s A_s (T_s - T_{ai})\right] \quad , \text{Watt} \qquad (16)$$

## MATERIALS AND METHODS

The experiments were carried out on the solar storage wall at the Faculty of Agriculture Farm, Suez Canal University, Ismailia, Egypt (latitude of 30.62°, longitude 32.27° and 5m above sea level) through the period from 30$^{th}$ November 2004 till 22$^{nd}$ of February 2005 to investigate and study the possibility of using Trombe solar storage walls as a passive energy system for polyethylene greenhouse heating during winter season. Three experimental gable uneven-span plastic greenhouses with plane dimensions of 4 m long and 3 m wide (area of 12m$^2$) were used. The northern side of greenhouse was 2 m high as shown in Fig (1), while the southern side was 1.1m high. The northern rafter of the greenhouse was tilted with the horizontal plan by 30°, while, the southern rafter was inclined with 47°. The greenhouse was oriented East-West, to face the south direction. The greenhouse door was situated in East direction as the wind direction is blown from the West direction within the experimental time (November to March). Galvanized pipes of 25.4 mm diameter were used to construct the frame of the greenhouse. A transparent polyethylene sheet of 200 µm thick was used as greenhouse covering material.

Greenhouses and open field test were divided to three piles 3 m long and 0.9 m wide. Soil was covered by black polyethylene (mulch) thickness of 100 µm, organic cover (horse bean straw) of 5 cm average length and uncovered soil.

Two different materials of solar storage wall were investigated (adobe and red brick). One greenhouse was included adobe bricks solar storage wall, while the other one included red bricks storage wall which were joined using a mixture of sand and cement. Each brick was absorptivity of 0.23 m long, 0.12 m wide and 0.06 m thick. Internal wall surface was painted with matt black paint with absorptivity of 0.93 (Norton, 1992). Meanwhile, the external surface was insulated by Styrofoam layer of 30 mm thick and 0.03 Wm$^{-1}$ °C$^{-1}$ thermal conductivity (CCR, 2001). The third greenhouse was considered as a control trial. Walls dimensions were 4.0 m long, 2.0 m high and 0.23 m thick.

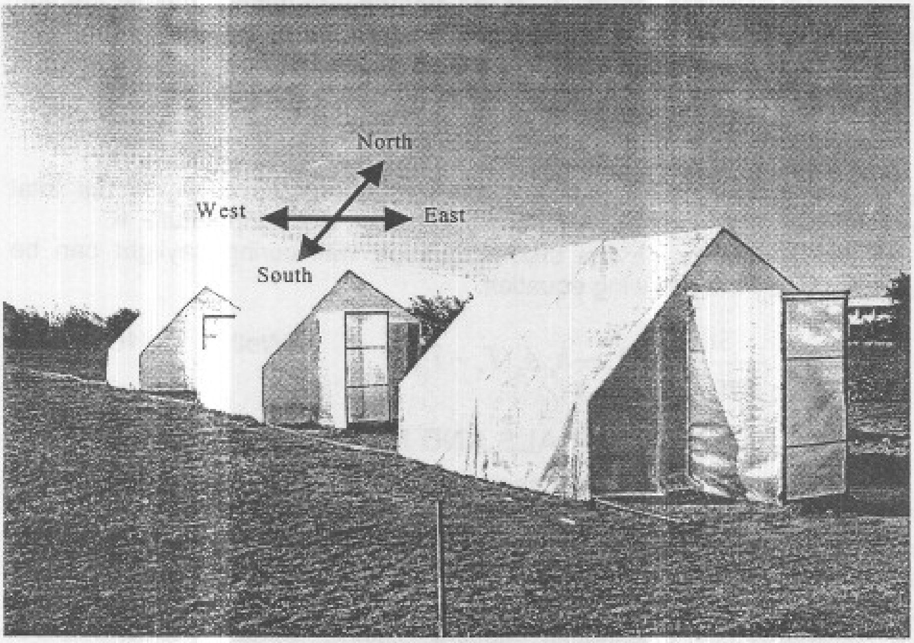



**Plate (1): Greenhouses configuration**

The mechanical analysis of the greenhouse soil and the adobe solar storage wall (ASSW), are summarized and listed in Table (1).

**Table (1): The mechanical analysis of the experimental soil and the adobe wall (ASSW) structures.**

| | Soil fraction % | | | | | Texture type |
|---|---|---|---|---|---|---|
| | Coarse sand | Fine sand | Total sand | Silt | Clay | |
| Greenhouse soil | 68.93 | 26.04 | 95.97 | 3.81 | 1.22 | Sandy |
| Adobe brick | 27.45 | 39.55 | 67.00 | 12.7 | 20.3 | Sandy clay loam |

The root medium either that inside the greenhouse or in the open field were tillged, prepared, planted and fertilized according to Hassan (2001) and El-Shatoury (2005). Nile squash variety seeds belongs to cucurbitaceae family were sown in the soil after irrigation on 28th November 2004. Three seeds were drilled into every hill at 0.5 m a part on the two sides of pile then thinned out after 14 days from the planting date, the strongest one or two plants per hill were left (El-Shatoury, 2005). Trial soil either indoors under the greenhouses or outdoors in the open field was irrigated by drip irrigation system.

**Methodology**

**Determination of the Incident radiation and the covering sheet transmitivity**

The transmitted solar radiation was measured to determine the amount of energy stored by the solar wall. The greenhouse aperture clear plastic covering sheet of 200 μm thick, which faced toward the South direction was divided into cells to determine the covering sheet transmitivity, 300 readings were measured inside and outside the greenhouse for each cell at the same time the covering sheet transmitivity was determined as a ratio between the transmitted radiation by the incident. The transmitivity of the used covering sheet was found to be 89 %.

**Solar storage wall temperatures determination**

Five distributed locations on the wall depth were selected to measure the storage wall temperatures (around the three axes X, Y and Z) with five wall thick measuring depths at the surface of 0, 5, 10, 15 and 20 cm, respectively. Four measuring points were distributed on the interior wall side; these points were far 0.30 m from the four wall-corners, while the fifth measuring point was located exactly on the wall diagonal point i.e. 2 m from X (east and west sides) and 1m from the greenhouse ground level.

**Storage wall effect on the soil temperatures**

The greenhouse soil temperatures were determined as a result of the presence of the Trombe wall. Soil temperatures were measured at the soil depths of, 0, 5 and 10 cm. These depths include the most of squash roots 20-30 cm from the surface soil (Hassan, 2001).

**Storage wall effect on the interior air temperatures**

To determine the effect of solar storage wall on the interior air temperature, the ambient air temperature was measured at different points inside the greenhouses using hangings thermometers.

**Storage wall efficiency**

Trombe wall total efficiency $\eta_t$ was computed using the following equations (Hassanain and Hokam, 2005)

$$\eta_t = \eta_{A.S} + \eta_D \quad , \quad \text{decimal} \qquad (17)$$

Where, $\eta_{AS}$ is the storing efficiency, given by:

$$\eta_{A.S} = \frac{m_w C_p \Delta T / t}{\tau \alpha A G} \quad , \quad \text{decimal} \qquad (18)$$

and the dissipation efficiency $\eta_D$ it is given as:

$$\eta_D = \frac{t}{t_{night}} = \frac{2\pi\, k\rho\, C_p \left[\frac{\Delta T_s}{\Delta Q}\right]^2}{t_{night}} \quad , \quad \text{decimal} \qquad (19)$$

Where, $m_w$ is the wall mass, kg, $C_P$, wall specific heat, $Jkg^{-1}C^{-1}$, $\Delta T$, temperature differences, °C, $t$, time, s, $\alpha$, wall absorptance, $\tau$, covering sheet transmittance, $A$, wall area, $m^2$, $G$, global radiation, $Wm^{-2}$, $k$, wall thermal conductivity, $Wm^{-1}\,{}^{o}C^{-1}$, $\rho$, wall density, kg $m^{-3}$ and $t_{night}$, night time length, sec.

**Specific heat determination**

The Trombe solar wall specific heat ($C_p$) also the greenhouse soils as well were determined in $Jkg^{-1}K^{-1}$ using a locally made calorimeter according to the method of Klute (1986). This method was applied on three samples for each of the two- Trombe walls (adobe and red bricks) and the greenhouses soil. The average specific heat was found to be 882, 588 and 924 $Jkg^{-1}K^{-1}$ for the adobe, red bricks storage walls and the greenhouse soil, respectively.

**Walls thermal conductivity (k)**

Thermal conductivity (k) of the two Trombe walls were obtained from (CCR, 2001) as 0.47 $Wm^{-1}K^{-1}$ for the adobe solar storage wall and 0.60 $Wm^{-1}K^{-1}$ for red brick solar storage wall.

**Walls density (*ρ*)**

Storage wall density ($\rho$) was assessed using the paraffin wax method (Black, 1965). It was found to be 1900 kg $m^{-3}$ for the adobe wall. Meanwhile, the red brick Trombe wall was found to be 1800 kg $m^{-3}$. The thermal conductivity (k), density ($\rho$), and the specific heat ($Cp$) were used to determine the thermal diffusivity according to Incropera and Dewitt (1996). For the two investigated Trombe wall material categories, the adobe wall thermal diffusivity was found to be $2.8x10^{-7}$ $m^2s^{-1}$, while it was found to be $5.67x10^{-7}$ $m^2s^{-1}$ for the red brick wall.

**Squash (Cucurbita Pepo L) seeds vitality**

Four indoors replicates of germination test were carried out at the same time under the lab conditions to determine the squash seeds vitality. Replicate (each included 10 seeds) were put in flat Petri- dishes. It was wetted by a piece of cotton and left at the indoor lab ambient air temperature of 13.7 °C. The average seeds vitality after 8 days from the beginning of the planting was 90 %.

**Squash crop yield**

Plant length was measured every 7 days beginning from day number 16th from planting date. Flowering measurements were taken every day through out this stage (beginning the flower appearance). Squash crop yield were collected through the period of fruit stage from 15/1/2005 to 22/2/2005. Fruits were picked up at three days intervals starting from day number 49th of planting date. The fruits were picked up at the accepted size for the Egyptian consumer taste. The picked up squash fruits had average length of 12.6 cm and diameter 3.1 cm with average standard deviation of ±1.11 cm and ±0.46 cm, respectively. It also had average weight of 75 g. The total crop in kg/$m^2$ was also determined for each treatment.

**Squash plant dry weight**

The changes in the plants growth expressed in dry weight characters after harvest according to Hassan (1997) was assessed. The dry weight was determined as follows: residual squash plants were picked up with its roots at the end of the season. It was weighted and put inside an electrical oven at

71°C for 24 hours. The dry weight was determined as the difference between the final and the initial fresh weights.

**Instrumentations**

Data were taken each two hours around the representative days within the experiments. It includes the measured weather conditions, i.e. hourly global solar radiation, ambient air temperature, relative humidity (inside and outside the greenhouse), inside greenhouse air temperature, wall temperature and temperature of the different soil depths.

**Global Positioning System**

Geographic position system (GPS) GARMINR, "eTrex" instrument was used to determine Ismailia region geographic data for the latitude longitude angles and the altitude from the sea level.

**Incident solar radiation**

Solar cell has dimensions of 75x75 mm (Kemo, 139, German made) was connected to a digital multimeter (M3800, China) to determine the incident solar radiation (G) according to Mujahid and Alamoud (1988). A previously calibration was carried out against an American made apply Pyranometer before the experimental work. The short circuit reading obtained from the cell was converted into W/m$^2$ according to Duffie and Beckman (1991).

**Temperature measurements**

Temperatures of the ambient and greenhouse interior air were measured by mercury thermometer (-10 °C up to 110 °C); also the soil depths and wall thickness temperature were measured by digital thermocouples (BTC type range -50: 120 °C) which had been previously calibrated against mercury (-10 up to100 °C) scale thermometer with standard deviation between the thermometers reading of ± 0.47 °C.

**Relative humidity**

Relative humidity was determined by the psychrometric chart using dry and wet bulb temperatures and a computer aided thermodynamic Tables 2, (CATT2) (Sonntage and Borgnakke, 1988).

**Wind speed**

A TESCO 405-V1 Hot Wire Anemometer was used to measure the prevailing wind speeds outside the greenhouse.

**Production Cost**

Costs were estimated according to the common price of 2004 in Egyptian pound. Costs of one kilogram fresh squash production were estimated for the four cultivation methods; in the open field, greenhouse without solar storage wall, greenhouse that was comprised adobe wall (ASSW) and greenhouse involved red brick storage wall according to Ghonim (1981), Johnson (1990) and Hassan (1992).

## RESULTS AND DISCUSSION

Weather conditions throughout the experiments period from 27$^{th}$ November 2004 till 2$^{nd}$ of March 2005 were averaged, summarized and presented in Table (2). The average air temperature within the investigation period was 14.2 °C, 67.6 % average relative humidity and the average solar radiation of 451.1Wm$^{-2}$.

Table (2): Average weather conditions throughout the field experimental work.

| Stage | Stage length, day | Average day length, hr | Ambient air temperature, °C | Wind speed, $ms^{-1}$ | Solar radiation intensity, $Wm^{-2}$ | Relative humidity, % |
|---|---|---|---|---|---|---|
| Germination | 12 | 10.32 | 14.8 | 0.9 | 496.7 | 74.0 |
| Vegetation | 22 | 10.30 | 13.8 | 1.1 | 407.5 | 71.0 |
| Flowering | 13 | 10.30 | 12.5 | 0.7 | 327.6 | 74.9 |
| Fruit | 32 | 10.43 | 14.6 | 1.2 | 393.3 | 59.2 |

**Trombe Solar Storage Wall Temperature**

Trombe solar storage wall acts as a heat storage, during the daylight it stored heat energy, while at night time it dissipated the stored heat to the greenhouse environment. Average solar storing walls temperatures are given in Fig. (1) for the different plant stages. The effect of storage wall on the interior ambient air temperature and soil temperature are plotted in Figs. (2) and (3), respectively.

For a day in the seeds germination stage (30$^{th}$ November), maximum temperature within the heat charging and storing period; from sunrise at 6:32 to the sunset at 16:55 were recorded at 2.00 afternoon for the adobe and red brick wall. Surface temperature of the adobe solar storage wall (ASSW) reached its maximum (within the heat charging and storing period) of 57 °C, while other thickness of the same wall were 50, 47, 37 and 27 °C for the wall thick of 5, 10, 15 and 20 cm, respectively. This affected the interior greenhouse air temperature which was found as 38.8 °C, while the outside air temperature was 22 °C. Meanwhile, for the red bricks wall (RBSSW) the beak was 66 °C for wall surface, while other wall thickness were 54, 45, 33 and 31 °C for the wall thick of 5, 10, 15 and 20 cm, respectively when the interior air temperature was 39 °C. These temperatures were obtained under the average weather conditions that were mentioned before. Taken into consideration the greenhouse soil has no green cover when these measurements were carried out on the 30$^{th}$ November 2004 (third day form seeds planting date). Moreover, the soil was kept at 50 % from its field capacity. Within the night time (the heat dissipating and discharging period) which occurred from sunset to the next day sunrise during wall recharging period the stored heat dissipated from the previous mentioned stage. It is seen from Fig. (1) that, the solar wall surface dissipates its heat faster than the other wall thickness. As within this stage, wall temperature is cooling down in opposite way of the heating or charging stage. Wall thickness temperature in this stage can be arranged in a descending order as: 20, 15, 10, 5 cm wall thick then wall surface, respectively. The adobe wall (ASSW) temperatures reached 21, 19, 17, 17, and 15 °C for the 20, 15, 10, 5 cm and wall surface thickness, respectively when the inside air temperature was 9.3 °C. Meanwhile, it reached to 20, 20, 16, 14 and 14 °C, for the 20, 15, 10, 5 cm and wall surface thickness, respectively for the red bricks wall (RBSSW) when the interior air temperature was 9 °C. The maximum solar wall temperature (within this stage) for all the Trombe wall sections were occurred after the sunset, while the minimum temperatures were measured early morning next day as shown in Fig. (1). Average wall temperatures for the adobe and red bricks wall around 24 hours (on the 30th November 2004) were found as 27.8 °C and 28.2 °C, respectively.

Results were obtained on the 20th December 2004 i.e., after 23 days from seeds planting date. Average weather conditions for the 20th December 2004 were 330.6 $Wm^{-2}$ solar radiation (from 6: 46 sunrise till 16: 59 sunset), 13.1°C ambient outside air temperature, 1.2 $ms^{-1}$ wind speed and 67.1 % outside relative humidity. Average temperatures for the adobe wall (ASSW) at 0, 5, 10, 15 and 20 cm of the wall thickness around the 24 hours with 2 hours interval were found to be 29.1, 28.3, 27.8, 27.6 and 25.4 °C, respectively when the average interior air temperature was 19.8 °C. Meanwhile, average wall temperatures for the red brick wall (RBSSW) of 0, 5, 10, 15 and 20 cm of the wall thickness around the 24 hours with 2 hours interval were found to be 29.6, 28.1, 27.3, 26.2 and 24.3 °C, respectively when the average interior air temperature was 19.5 °C. Average wall temperatures around 24 hours on the 20th December 2004 were found to be 27.6 °C and 27.1°C for the adobe (ASSW) and red brick (RBSSW), respectively.

Temperatures for the adobe (ASSW) and red brick (RBSSW) solar storage walls for a day in the flowering stage, obtained on the 13th January, 2005 i.e., after 47 days from seeds planting date. The average environmental weather conditions were: 344.9 $Wm^{-2}$ solar radiation (from the sunrise at 6: 52 till 17: 15, sunset), 11.8 °C ambient outside air temperature, 0.5 $ms^{-1}$ wind speed and 82.9 % outside relative humidity. Average wall temperatures at 0, 5, 10, 15 and 20 cm wall thickness around the 24 hours with 2 hours interval were found to be 27.1, 26.4, 26.2, 25.5 and 24.7 °C, respectively for the adobe wall (ASSW), when the average inside air temperature was 19.0 °C. Meanwhile, average red brick wall (RBSSW) temperatures for the wall surface, 5, 10, 15 and 20 cm wall thickness all the day around the 24 hours with 2 hours interval were found to be 29.5, 27.1, 26.0, 25.3 and 23.5 °C, respectively when the interior air temperature was 19.3 °C. The average wall temperatures for the adobe and red brick around the 24 hours on the 13th January 2005 were found to be 26.0 and 26.3 °C, respectively.

Average solar storage wall temperatures after 60 days from planting date within the fruit stage for the wall surface, 5, 10, 15 and 20 cm wall thickness all the day around the 24 hours with 2 hours interval were found to be 29.6, 29.1, 28.3, 28.1 and 25.5 °C, respectively when the interior air temperature was 20.5 °C for the ASSW. Meanwhile, it was found to be 31.9, 29.5, 28.0, 25.8 and 24.0 °C, respectively when the inside air temperature was 20.4 °C for the RBSSW. Average adobe wall temperatures all the day around the 24 hours on the 26th January 2005 was found as 28.1 °C, while average red brick wall temperature was 27.8 °C.

**Trombe wall efficiency**

Storage walls efficiency results were obtained for the adobe and red bricks walls on the 12th December 2004, 27th December 2004, 18th January 2005 and 17th February 2005 using Equations from (17) to (19), which applied to determine the total absorption-storing, and dissipation efficiency. Fig. (4) represents the A-S-efficiency and D-efficiency for various days on the plant stage. Meanwhile Table (3) represents the average A-S-efficiency and the D-efficiency for the adobe and red bricks walls for the emergency, vegetation growth, flowering and fruit stages. Adobe trombe wall average A-S-Efficiency was 59.2 % for the full season and the average D- Efficiency was 10.4 %. Meanwhile the average A-S- Efficiency for red bricks was 40.5 % and the average D- Efficiency was 17.0 %

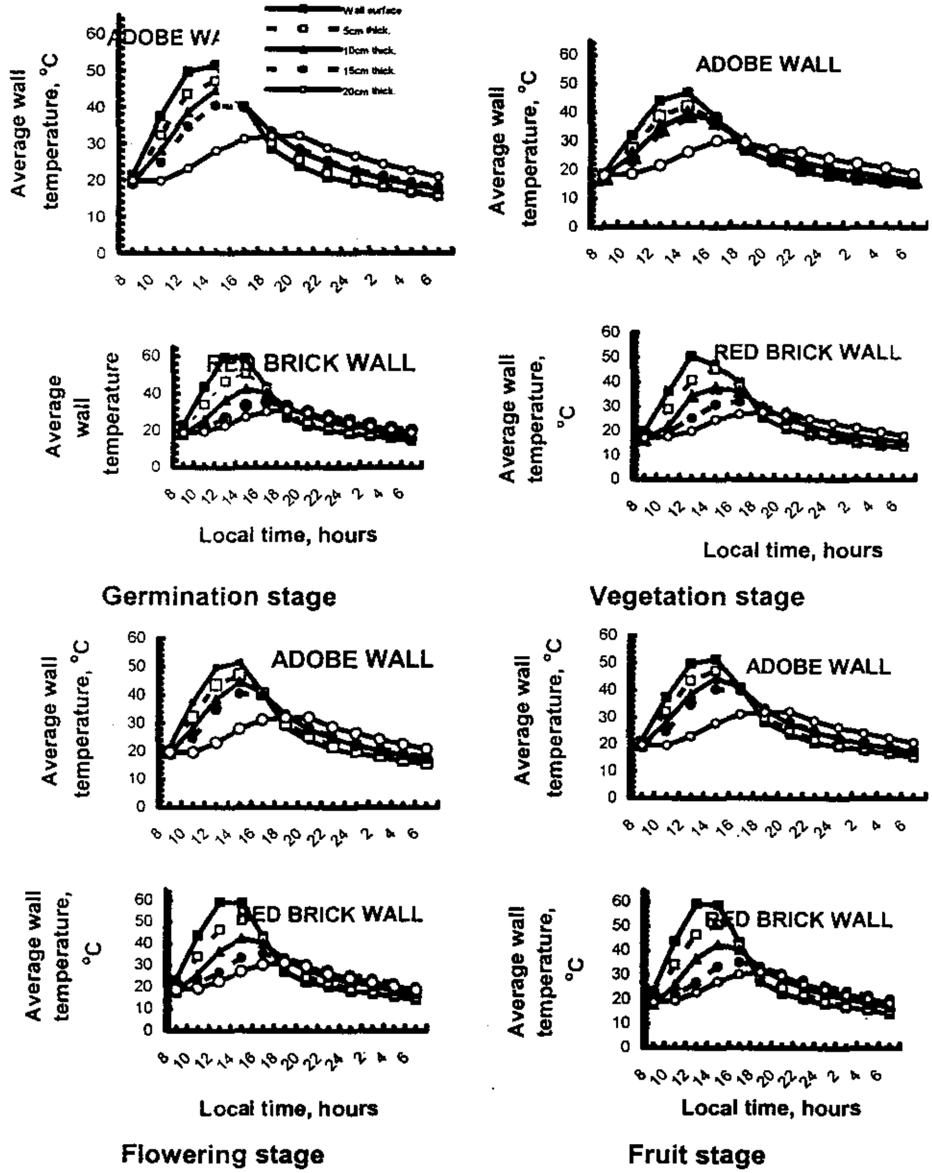



**Fig. (1): Average temperatures of solar storage wall at the different plant stages**

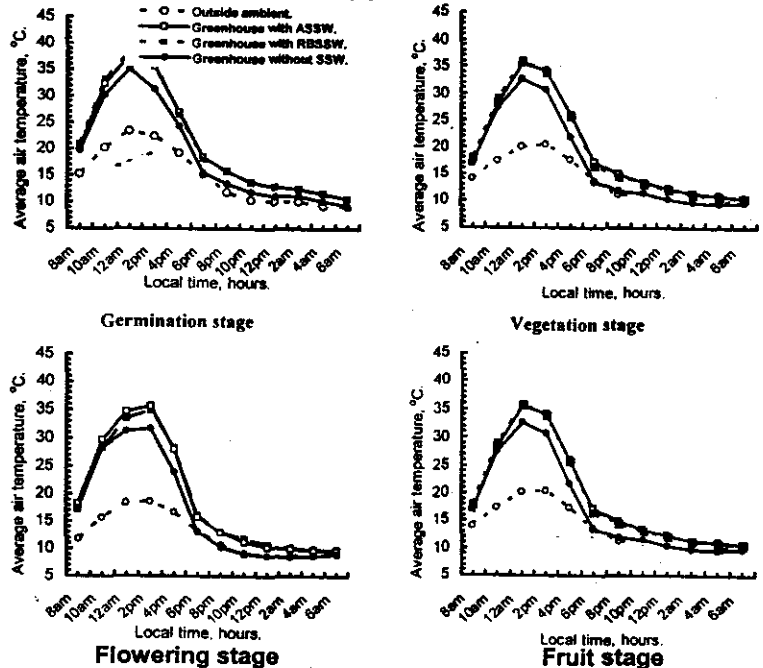



Fig. (2): Effect of the solar storage wall on the average interior air temperature for different plant stages

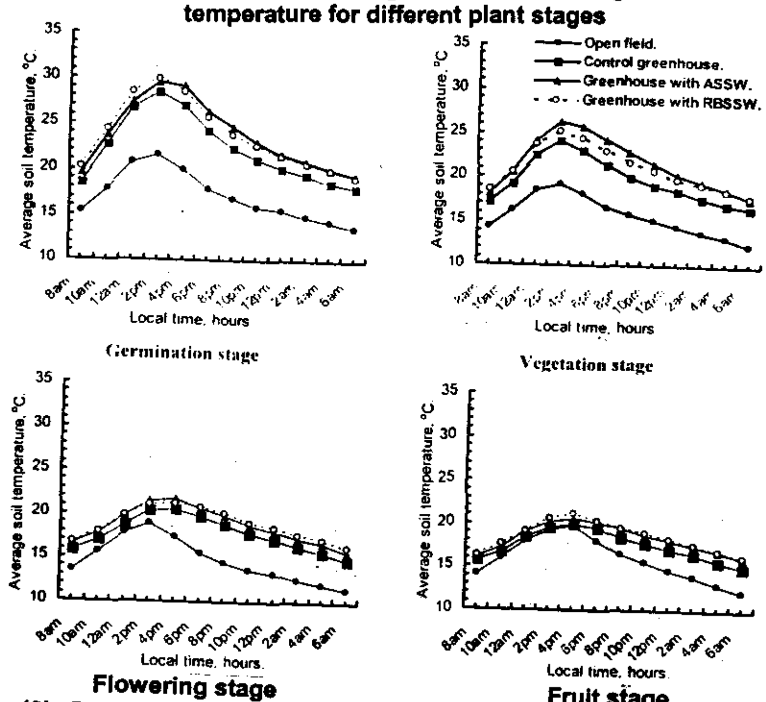
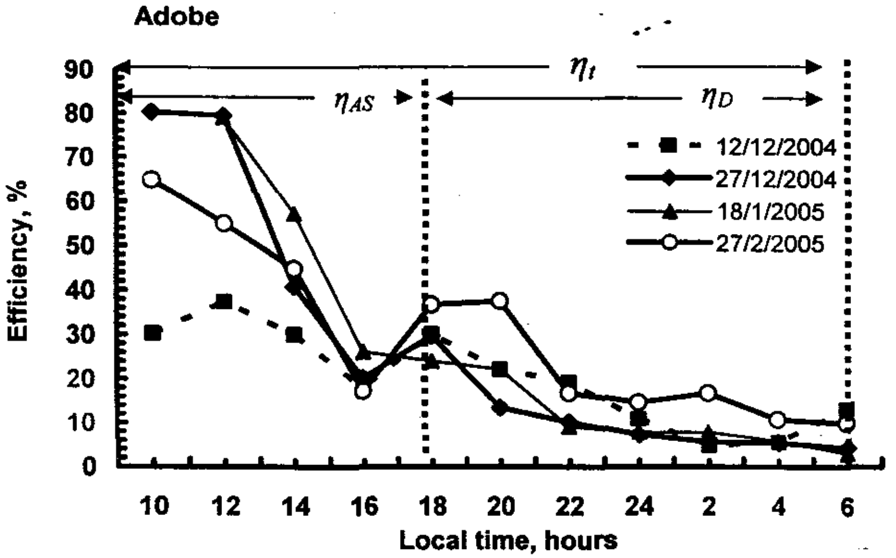



Fig. (3): Effect of solar storage wall on the average soil temperature for different plant stages



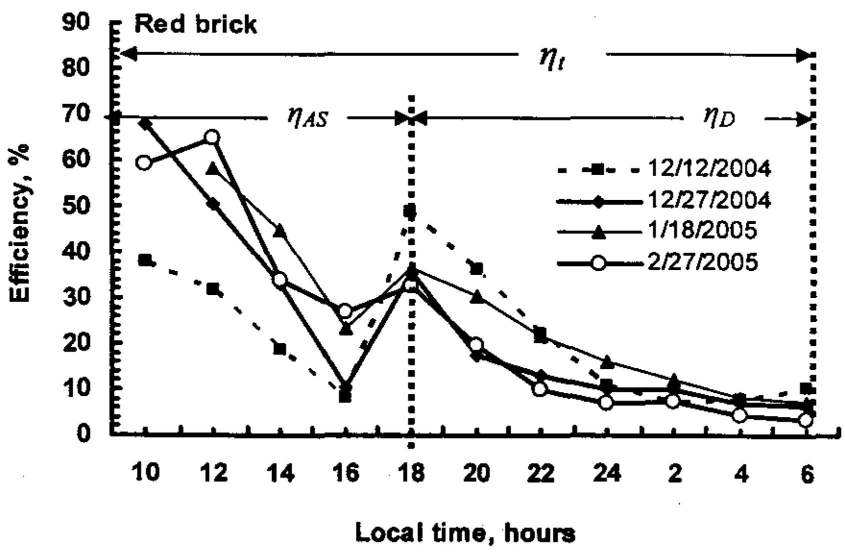




**Fig. (4): A-S and D- Efficiency for the adobe and red brick within a day in each growing stage of squash crop**

**Table (3): Average Storing, and dissipating efficiencies for Adobe and red bricks storage walls through the different plant stages period.**

| Plant stage | Adobe wall | | Red bricks wall | |
|---|---|---|---|---|
| | $\eta_{A-S}$, % (18:00- 6:00) | $\eta_D$, % (8:00-16:00) | $\eta_{A-S}$, % (18:00- 6:00) | $\eta_D$, % (8:00-16:00) |
| Germination | 56.8 | 8.7 | 32.9 | 16.2 |
| Vegetation growth | 52.7 | 9.2 | 36.9 | 15.1 |
| Flowering | 62.2 | 10.7 | 44.6 | 17.1 |
| Fruit | 65.1 | 12.8 | 47.6 | 19.7 |
| Average | 59.2 | 10.4 | 40.5 | 17.0 |

**Squash crop yield**

The crop yield for the different greenhouses and the open field is given in Table (4). The crop yield was highly affected by the storage (Trombe) wall inside the greenhouses (SSW). The average total yield for the greenhouses that was comprised adobe (ASSW) and red bricks solar storage wall (RBSSW) were increased by 22.6 and 31.4 %, respectively, above that obtained for the greenhouse without storage wall (control greenhouse).

**Table (4): Total squash crop yield as affected by the solar storage wall, kg/m$^2$**

| Greenhouse with ASSW | Greenhouse with RBSSW | Greenhouse without SSW | Open field |
|---|---|---|---|
| 2.540 | 2.724 | 2.072 | .0483 |

**Fresh and dry weight for the squash plant**

Dry weight characters are expressing the changes of plant growth. Data represented in Table (5) indicated the plant fresh and dry weight at the end of the season, which was highly affected by solar storage wall. The plant sowing under the greenhouses with solar storage wall had a greater dry weight as compared with that from the unheated greenhouse (control trials). The average dry weight was increased by 20 and 10 % for the greenhouses with adobe and red bricks solar storage walls, respectively, as compared with the greenhouse without storage wall.

**Table (5): Average fresh and dry weight of squash plants at the end of the cultivation season, kg.**

| Greenhouses | Greenhouse with ASSW | Greenhouse with RBSSW | Greenhouse without SSW |
|---|---|---|---|
| Fresh | 1.785 | 1.425 | 1.365 |
| Dry | 0.139 | 0.127 | 0.115 |

**Cost Estimation analysis**

Table (6) represents the total cost of producing 1 kg squash using the different cultivation method. The variable and fixed costs are comprised.

**Table (6): Average cost for producing 1Kg squash crop in (L.E.).**

| Open field | Greenhouse without SSW | Greenhouse with ASSW | Greenhouse with RBSSW |
|---|---|---|---|
| 4.63 | 1.60 | 1.37 | 1.33 |

## Conclusions

The study conducted to the following conclusions:-

- The solar wall surface temperature during the daylight increased rapidly as compared with the wall deep thickness and vise versa at night (dissipating period). As its heat lost faster than the other wall thickness temperatures. It lost its heat rapidly as compared with the other wall depths. It can be arranged in a descending order within the starting time as follows: the surface > 5 cm > 10 cm > 15 cm > 20 cm and vise versa within the dissipating period.
- Using the adobe and red brick storage walls led to increase the interior air temperatures above the greenhouse that without walls by 12.3, 11.8 %, 20.0, 18.0 %, 11.0, 12.0 % and 15.2, 14.6 % for the germination, vegetation, flowering and the fruit stages, respectively.
- Average A-S-Efficiency during the daylight for the squash cultivation season from the 30th November 2004 till the 22nd February 2005 under the Adobe and red brick was 59.2 and 40.5 %. Meanwhile, the D-Efficiency at night times was 10.4 and 17.0 % with total efficiency of 69.6 and 57.5 % respectively.
- Average fresh and dry weight of squash plants at the end of the cultivation season was weighty for the plants that were cultivated under the greenhouses with adobe solar storage wall above that was cultivated in the greenhouse with red brick storage wall above that cultivated inside the greenhouse without storage walls.
- Using the solar storage walls resulted in a reduction of the cost of producing 1kg of the squash crop as compared with that cultivated inside the greenhouse without walls.

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# إستخدام حوائط التخزين الشمسية كنظام لتدفئة الصوب البلاستيكية طبيعيا

**عادل سالم السيد ، أحمد على حسانين ، إسلام حسن الشيخ و سامح سعيد كشك**
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أجريت التجارب بمزرعة كلية الزراعة جامعه قناة السويس بالإسماعيلية (خط عرض ٣٠,٦٢°، طول ٣٢,٢٧° وارتفاع ٥ متر عن سطح البحر) و ذلك باستخدم حوائط التخزين الشمسية لتدفئة الصوب البلاستيكية للتغلب علي أثر انخفاض درجة الحرارة خاصة أثناء ليالي الشتاء الباردة و التى تؤثر على إنتاجية الصوب الزراعية لمحاصيل القرعيات. تم اختبار نوعين مختلفين من حوائط التخزين الحراري داخل الصوب مبنية من الطوب الني والأحمر ومقارنة تلك الصوب بصوبة بدون حوائط ككنترول للتجربة والتي تم مقارنتها هي الأخرى بتجربة في الحقل المفتوح. أجريت التجربة في الفترة ما بين ٣٠ نوفمبر ٢٠٠٤ حتى ٢٢فبراير ٢٠٠٥.

وقد تناولت الدراسة تأثير وجود حوائط التخزين الحراري على متوسط درجة حرارة التربة. و تمت دراسة تأثير وجود حوائط التخزين الحراري على درجة حرارة الهواء الداخلي للصوبة مقارنة بخارجها. و تم دراسة كفاءة الحوائط المستخدمة فى تخزين الحرارة في فترة النهار وكذا بثها خلال فترة الليل و الكفاءة الكلية. وتم دراسة مدى تأثير وجود حوائط التخزين الحراري على كمية المحصول النهائي و الوزن الجاف للنباتات. كما تم حساب تكاليف إنتاج الكيلوجرام من محصول الكوسة المستخدم فى التجربة تحت الظروف و المتغيرات التي تضمنتها الدراسة.

**وقد توصلت الدراسة إلي النتائج التالية:-**

- إزدادت درجة حرارة سطح حائط التخزين الحراري أثناء النهار (فترة الشحن) عن باقي طبقات الحائط و على العكس أثناء فترة التفريغ. ويمكن ترتيب درجات حرارة طبقات حائط التخزين الحراري تنازليا خلال فترة الشحن الحراري (فترة النهار) كالتالي: السطح > ٥ سم > ١٠ سم > ١٥ سم > ٢٠ سم.
- أدي استخدام حائط التخزين المبني من الطوب النيئ و الأحمر على التوالي إلى زيادة درجة حرارة الهواء الداخلي للصوبة عنه بالصوبة الغير محتوية على حوائط تخزين بنسبة ١٢,٣ و١١,٨ ٪ (فى مرحلة الإنبات) ٢٠,٠ و ١٨,٠ ٪ (فى مرحلة النمو الخضرى) ١١,٠ و ١٢,٠٪ (فى مرحلة الإزهار) ١٥,٢ و ١٤,٦ ٪ (فى مرحلة الإنتاج الثمرى) على الترتيب.
- متوسط كفاءة التخزين الحرارى (خلال فترة النهار) لموسم زراعة الكوسة بالصوب الزراعية المحتوية على حائط تخزين من الطوب النى و الطوب الأحمر هى ٥٩,٢ و ٤٠,٥ ٪ بينما وجدت كفاءة الانبعاث (خلال فترة الليل) ١٠,٤ و ١٧,٠٪ و كفاءة كلية ٦٩,٦ و ٥٧,٥ ٪ على الترتيب.
- إزداد متوسط المحصول الكلى ٢٢,٦ و ٣١,٤ ٪ للصوب المحتوية على حوائط تخزين حرارى من الطوب النى والأحمر على الترتيب مقارنة بالصوبة الغير محتوية على حائط تخزين.
- الوزن الجاف للنباتات في نهاية الموسم وجدت أكبر داخل الصوب الملحق بها حوائط التخزين مقارنة بالصوبة الغير محتوية على حوائط تخزين حرارى.
- استخدام حوائط التخزين الحرارى داخل الصوب أدى إلى خفض تكلفة إنتاج الكيلوجرام من محصول الكوسة مقارنة بالصوبة الغير محتوية على حوائط تخزين حرارى.