THERMAL PERFORMANCE OF GREENHOUSE WITH BUILT-IN SOLAR DISTILLATION SYSTEM: EXPERIMENTAL STUDY

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ABSTRACT

This paper presents an experimental investigation of the thermal performance of agriculture greenhouse (GH) with built-in solar distillation system. A set of solar basins, with saline water, is placed on the greenhouse roof to reduce the GH cooling load and to produce the required fresh irrigating water by solar distillation. The ventilation air enters the GH through an evaporative cooler for cooling in summer (and hot days), and is partially re-circulated for heating in winter (and cold days).

The experimental work was carried out for the GH constructed at the King Abdul Aziz University (KAAU), the city of Jeddah, Saudi Arabia. The system transient performance (temperatures, relative humidity, and water productivity) are presented for the summer of Jeddah-KSA (July 2004). Measures to improve GH performance are also highlighted.

Key Words: Solar Desalination, Agriculture Greenhouses

INTRODUCTION

Fresh water is the essence of life and is a basic human requirement for domestic, industrial and agriculture purposes. The international rapid developments and population explosion all over the world have resulted in a large escalation of demand for fresh water. On the other hand, the surface water (rivers and lakes) pollution caused by industrial, agricultural and domestic wastes, limits the suitability of fresh water availability in many regions. By the beginning of this century, fresh water shortages and quality became an international problem confronting human groups and countries. The problem is more apparent in most of the Arab countries due to its limited natural resources. It is, therefore necessary that sincere effort be made to face the looming water crisis and conserve shrinking water supply amid the rising demand.

Saudi Arabia (KSA) is the largest country in the Middle East with an area of about 2,252,500 km2, and has a population of about 23 millions. KSA is an arid desert country with limited ground supplies and dependable surface sources. No perennial rivers, streams or permanent fresh-water lakes. The rain fall is both scarce and infrequent and associated with high evaporation and sandy land dissipation rates. The available ground water supplies are deeply buried and do not replenish themselves. KSA per capita water availability is expected to sharply decline from 300 m^3/day in 2000 to 113 m^3/day in 2025, while the per capita proposed by UN is about 1000 m^3/day, Radwan and Fath [1]. The shortage of water in KSA has been exacerbated by a number of factors, including; (i) increasing population, (ii) substantial growth in the standard of living, and (iii) increasing in agriculture and industrial development. These and other conditions, such as the limited resources and the difficulty of polluted water treatment, led to the decision of Saudi government to use desalination as one of the strategic alternatives and main source of potable water for all major metropolitan areas in the kingdom. Although it seems more expensive in area of surface or ground water availability, it is not so in areas 300 – 500 km far from surface fresh water availability or of deep ground fresh water. KSA produces more than 5 million m^3/day of desalinated water from more than 2000 desalination plants of different technologies; mainly MSF & RO. This represents more than 21% of the desalinated water world production, Fath [2]. Desalted water is transported (after blending with brackish water) to most of the cities for domestic and potable use.

Considering the fact that areas of very small communities, largely exposed to the water scarcity, and at the same time, are characterized by high levels of solar radiation, an appropriate consideration needs to be given to the opportunity of using solar energy. No doubt a bit costly but having optimal features for its coupling with desalination processes. This is true, especially in isolated and far remote areas that; (i) having no access to electrical grid and fuel supply and (ii) of very limited technical capabilities. Many researchers have investigated and developed solar distillation systems in order to increase the still efficiency & yield, see for example Malik et al. [3], Fath et al. [4, 5], and Nafey et al. [6, 7].

SOLAR DISTILLATION AND GREENHOUSES

In hot and sunny desert regions, it is difficult to grow plant in the open field due to the harshness of land and climates. To overcome these difficulties, the use of greenhouses can provide a proper environment to plant growth. In hot climates, however, the greenhouse inside temperature can reach so high value that prevents its utilization or, otherwise, a costly mechanical air conditioning system should be used. Fath [8] proposed a system to decrease the greenhouse cooling load and utilize the surplus solar energy during the day for natural ventilation of the greenhouse. Fath [9, 10] proposed placing a group of solar stills on the top of the greenhouse roof. The combined GH - solar distillation system utilizes the abundant solar energy in hot climates (above that required for plants photosynthetic process) to partially produce the required irrigating water by solar distillation.

The suitability of such systems for remote areas in KSA arises from the fact that solar distillation can, in most cases, provide the rather modest demand of the greenhouse for fresh water (about 10 % of water requirement for irrigation in an open field). Thus, in remote areas where fresh water for irrigation is not available or costly to obtain, the GH – distillation system can support local agriculture activities. No water transport or storage is required since distillate can be fed directly into the greenhouse (after adjusting its properties).

Water is required for plants as it is the medium of absorbing the plants nutrition. The absorbed water is ultimately transferred by transpiration to the surrounding through plants leafs. In addition, the successful operation of greenhouses depends on maintaining its inside climatic conditions within specified desired range. Control of greenhouse interior is, therefore, important for effective plants growth. This could be carried out through ventilation, heating, cooling and control of inlet solar energy and heat transfer to & from the greenhouse.

GH cooling systems provide ventilation air. Even when the evaporative cooling pads are not being used, the fans can be used to bring outside air into the greenhouse. Ventilation is used to control humidity, especially during winter months. The importance of humidity control is to avoid plant water stress in low humidity (high plants water vapor transpiration) and pest and diseases growth in high humidity conditions. Another important aspect of greenhouse ventilation is the need to ensure adequate supply of CO2. Ventilation is rated by the amount of 2.5 to 3.5 m^3 / min / m^2. This will provide the desired of 0.8 – 1.0 GH volume air exchange per minute in a greenhouse with an average height of 3.0 m. Air change in green houses could, however, be as low as 0.1 air change per minute. Air velocity in the range of 5-15 m/min suits plants leafs and CO2 absorption. Higher velocity of 30 m/min reduces plants chances for CO2 absorption which stops at 60 m/min.

Table (1) Main Crops Requirement inside Greenhouse

Crop	T (C)	R.H. (%)	Water (L/m2)
Tomato	15-25	60 - 65	3
Cucumber	20	60 – 65	3
Pepper	20	60	3
Lettuce	25 - 25	60	3
Flower	15 - 25	60 - 70	8

Most economic plants requires temperature in the range of 10 - 30°C. High temperature increases the evaporation by transpiration and affect the water stress in the plants. Cooling in summer and hot days as well as heating in winter and cold days are therefore important for GH temperature control. Moreover, plant requires light in the range of 390 – 700 Nanometer for photosynthetic growth. Ultra Violate in the range 290 – 390 Nanometer is dangerous for the plants. Carbon dioxide CO2 is required for plants photo synthetic process. Table (1) shows the general water & environment requirements for some crops.

EXPERIMENTAL SYSTEM DESCRIPTION

(i) System Construction

The design criterion for the constructed GH with built-in solar distillation system is to be partially self sufficient of energy and irrigating water. This could be achieved through; a- reduce the cooling load and provide sufficient cooling in summer, b- provide sufficient heating in winter and c- utilize the abundant solar energy in hot climates (above that required for plants photosynthetic process) to partially produce the required irrigating water by solar distillation. A set of solar basins, partially filled with saline water, is placed on the GH roof to implement this function. The overall conceptual configuration of the constructed system is shown in Figure (1). West side view and GH photo are shown in Figure (2).

The main components of the system are; Greenhouse cavity (plant growth zone), Transparent south side channel, Evaporative cooler with Forced air blower (for GH cooling and ventilation), Transparent (Triangular) cover, transparent roof water basins, Product Water (Distillate) collection trays (Trough), Product water, Brine Collection and Feed water tanks.

GH constructed cross section has a rectangular configuration with triangular roof. GH is 9 m long, 5 m wide and 3.0 m high. The triangle roof angle is about 30 degrees from horizontal. GH is built of steel frame structure made of 10 cm square tubes (2.0 mm thick). The tubes are welded and painted green. Tempered glass sheets 6.0 mm thick are then fixed all over the greenhouse boundary and roof in order to maximize the amount of transmitted solar energy. Square tubes of 5.0 cm (1.5 mm thick) are used to form the roof ceiling structure and to frame the ceiling glass sheets.

The evaporative coolers are placed in the north side of the greenhouse. Four windows of 2.2 m wide and 1.25 m high are fixed on the GH north wall, Figure (2). These windows are filled with Celdek cooling pads, made of a specially formulated cellulose paper, impregnated with insoluble anti-rot salts, stiffening saturates and wetting agents. Evaporative Pads have a cross fluted configuration that provides maximum cooling when warm air passes through the wet evaporative pad material. Each two windows (sections) are connected to a general air duct ends with a high pressure industrial blower as shown in Figure (2). Air passing through the pad is provided by two blowers (blower rating is 3520 rpm, 6 kW, 7.1 kPa, 60 Hz). One blower is used for two cooling pad sections and each blower is connected with T-Shaped 6-in. diameter pipe. This pipe is connected to the air ducts by flange couplings. Ambient air is forced to flow through the wetted pads, where it is partially humidified and cooled before entering the GH cavity. There are four outlet air openings (2.2m x 60 cm each), located on the south side at the top of GH cavity.

Water for evaporative coolers pads are drawn from the feed water tank by the feed pump to a perforated pipe located on the top of the pads. Triangular channels of large number of holes (drilled with 5 cm spacing) are located on the top of cooling pads are used for uniform water dripping. The triangular channel is covered by zinc galvanized rectangular top cover to prevent dust accumulation and water contamination. Water is dripped over the pads to keep them wet during the system operation. Every cooling pad has rectangular tray in the bottom for water collection. There are two water pumps for water supply (Pump rating is 3450 rpm, 0.5 HP, 60 Hz, max. head 21 m, 1 phase). One pump is used to supply water to each of the two cooling pad sections. The water is drained from the bottom trays of the pad section through PVC pipe and returned to the tank for recycling.

Roof solar basins are constructed 0f 1.0 m x 1.0 m transparent square base of a box type basin with 10.0 cm side height. Twenty Four basins are placed on the greenhouse roof of 5 m x 9 m roof area, Figure (3). Each basin has a feed water hole in its side and a brine drain hole in its centre. The basins are framed with 2.0 cm L-shaped aluminium angle. PVC piping systems are connected to all basins for saline feed water and brine rejection. Feed water is pumped from the feed water tank and distributed to all basins through four main headers. By the end of the day, a drain valve is opened to drain the brine from all basins to the brine tank. Distilled water troughs are fixed at the bottom of all roof glass walls. These troughs are interconnected and have one outlet to the distilled water tank located with other tanks at the greenhouse east side.

(ii) System Operation

For ventilation and air cooling requirements, in summer and hot days, ambient air enters the GH cavity, through the evaporative coolers by switching on both air blowers and dripping water pumps. The inlet air is partially cooled (and humidified) and, therefore, cools the air inside the GH cavity. Ventilation air gains some of the cavity heat (inlet solar energy & other energies from plants, soil and lighting) and moisture (from wet soil and plants transpiration) and leaves the cavity to a vertical side channel. Air is then flown out of the GH through south vertical channel and outlet openings. The transparent triangle roof is fully isolated from the GH cavity by closing the north and south ceiling openings. In the triangle roof, the solar basins absorb the excess solar energy (above that required for plants photosynthetic process) and heat the basins and saline water. Hot vapour evaporated from the basins is carried out upwards, naturally, to the colder roof glass surfaces. The vapour is condensed on the roof surfaces, to form the distillate (product water), and is then collected in the product water collection trays (troughs) in the bottom of the roof surfaces. Product water is first collected in a scaled container to measure its rate of production, then passed to the PW tank.

In winter and cold days (and nights) and based on the plant solar energy requirements, evaporative cooler is shut down and ambient ventilation air enters the GH without cooling. Ventilation air partially exits the GH through the outlet south openings and partially recirculation to the triangular roof through the ceiling openings. Re circulated air is heated from the roof basins, mixed with the incoming ventilation fresh air, and re-enters the GH cavity through the north roof openings and heats the GH cavity. On the other hand, the vapour carried out by the hot re circulated air is condensed on the colder cavity walls and adds its condensation heat to GH cavity.

(iii) System Measurements

The climatic environmental conditions inside the GH cavity, mainly temperature and humidity, were measured and recorded at two vertical planes in the GH cavity, Figure (4). The distance between the planes was 4 m and the distance of each plane from the GH sides is 2.5 m Six different points at each plane are selected to measure the temperature at different heights and locations as shown. In the top roof zone, the inclined glass temperature was recorded at four points, two points on each side, and then the average temperature of the four readings was computed. There are 24 basins (1m x 1m) with initial water level of 3 cm. The basin water temperature was measured by four thermocouples fixed at the bottom of the basins. The air temperature inside the top roof zone is measured by placing four thermocouples at a 1.5 m high and equally spaced along the GH. Then the average temperature of the four readings is obtained. Temperature in all points is measured using copper and constantan thermocouples, of type “T”. All thermocouples were connected to the input module at channels of Fluke Data Logger connected to a computer.

A Hygro-thermometer Model 4465CF is used to measure the humidity in the two places one is inside the green house and other one is outside the greenhouse. The data were recorded by connecting the Hygro–thermometer to the Fluke Data logger and then connected to the computer. The solar intensity was measured by solar Pyronometer at three locations. The first is in the centre of lower portion of GH cavity, (Point 15), the second is in upper triangle roof, (Point 13), and third one is outside the GH, (Point 14). All three instruments were also connected to fluke data logger and to the computer. Ventilation air velocity was measured by Portable PMV Data Logger, Model PVL-500, in both planes inside the greenhouse. The recorded data is transferred from the Portable PMV Data Logger to the computer for processing and calculations.

(iv) Data Collection

The data was recorded every 15 minutes from 6:00 AM to 8:00 PM for 10 days, for each point as follows:

1- The dry bulb temperature (^{o}C) for the six points for the two measurement planes, points (T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12), see Figure (4).
2- The solar radiation at 3 locations. One is in the centre of GH cavity (Ic, point 15) recorded as (VDC). 2nd one in upper portion of the green house (Ia, point 13) recorded as (VDC) and 3rd one is outside the green house (Ib, point 14) (VDC).

After recording the data and saving it in excel format, the following parameters were calculated:

1- Wet bulb temperature at inlet of evaporative cooler (TW1) using EES – Program by inserting the recorded relative humidity and dry bulb temperature at inlet of evaporative cooler (T1)

2- The cooling efficiency of the evaporative cooler, defined as :

$$\text{Efficiency} = [(T_1-T_2)/(T_1-T_{W1})]*100 \qquad (1)$$

Where:
T_1 is the inlet dry bulb temperature to the evaporative cooler,
T_2 is the outlet dry bulb temperature from the evaporative cooler,
T_{W1} is the inlet Wet bulb temperature inlet to the evaporative cooler.

3- Solar Intensity is calculated by dividing the data taken from data logger by the conversion factor ($8.67*10^{-6}$) given by the Fluke manufacturer to get the Solar Intensity in (W/m^2).

RESULTS AND DISCUSSION

The results of the main parameters influencing the GH performance will be presented and discussed below.

i- Solar Intensity Measurements

Figure (5) illustrates a sample of the measured solar intensity in the GH site at the three different locations; i- inside the top roof zone (Ia), ii-out side the GH (Ib), and, iii- inside the GH cavity (Ic). The solar intensity trend follows, in general, the sinusoidal shape where its peak reaches about 880 W/m^2 at almost mid day (hour 13). The sinusoidal trend is lost in some periods of the day where the sky was cloudy during the recording moments. The transmisivity of the top triangular glass cover could be obtained by dividing the solar intensity in the roof zone, Ia, by the solar intensity outside the GH, Ib. Similarly, the combined transmisivity of the solar water basins and the roof glass ceiling could also be obtained by dividing the solar intensity in the GH cavit, Ic, by that at the roof zone, Ia. These ratios were found to be almost constant during the day. The average transmisivity of the top triangular glass cover (Ia/Ib) is in the range of 0.7- 0.8 which is reasonably accepted with thin dust layer and moisture formed on the outside glass surface (this layer could not be avoided even with the roof glass washing). The combined transmisivity of the solar water basins and the roof glass ceiling (Ic/Ia) is in the range of 0.3 – 0.6 depending on the amount of water and scale deposits in the basins. The percentage of solar intensity transmitted to the plants zone (Ic/Ib) is in the range of 0.2 to 0.4 which is good enough to provide the sun light required for the plants photo-synthetic process. The results for other days show similar trend with some expected discrepancies due to climatic changes from day to day.

ii- Air Temperature

Typical temperature changes with time are shown in Figures (6) for one plane of measuring thermocouples. The general trend is that all air temperatures follow the solar intensity sinusoidal trend. The lowest inside air temperature is at Points #2 and #8 where the thermocouples are facing the evaporative cooler (at 5 cm from the evaporative cooler and 1.5 m high from the ground). The value of this temperature reaches its maximum of about 34 C at midday (almost 8-10 degrees below the ambient temperatures of Points #1 & #7). Air temperature starts to increase as it moves through the GH cavity to reach its maximum value at the outlet openings (points # 6 & # 12). The outlet air temperature is still 3-6 degrees below the ambient temperature. Temperature at the points (9/3, 10/4 and 11/5) are some where in-between the lowest temperature at Points (8 & 2) and the highest temperature at Points (12 & 6). Each point differs in temperature depending on its height from the ground and the distance between such point and the evaporative cooler. Thus, Points (9 & 3) are the nearest in temperature value to Points (8 & 2) relative to the other points (which is 2.5 m from the evaporative cooler and 0.5 m high from the ground). As to the temperature at Points (10 & 4) which are also 2.5 m from the evaporative cooler but at 1.565 m high from the ground, they were found to be higher than the temperature at Points (9 & 3), as they are near the hot roof. Points (11 & 5) are at the same level as Points (9 & 3) but further from the evaporative cooler, therefore are at higher temperature than Points (9 & 3) due to the additional gained energy.

iii- Relative Humidity

Figure (7) shows the air relative humidity before (ambient condition) and after the evaporative cooler. The relative humidity follows also the sinusoidal trend and reaches its minimum value at midday. The outside RH at midday was found to be in the range of 10-30 % and increased to about 45-70 % after the evaporative cooler. Fortunately, lower RH at mid day helps the evaporative cooler to reduce the midday high ambient air temperature. The air relative humidity, after evaporative cooler, increases by about 20 % to 35 % above that of the ambient. Relative humidity inside the GH cavity is, therefore, within the acceptable values (comfort zone) for plants growth.

iv- Air Velocity

Air velocity was measured at fixed locations (points 2 & 8) in front of the evaporative coolers pads. Some oscillations in velocity values were observed, mainly due to the water blocking the evaporative cooler pads from one point to another where the air velocity meter was located. The average values were found to be between 0.27 to 0.4 m/s. Considering the inlet air flow area of 1x8 m^2, the air change rate is almost one volume change/min as designed.

v- Evaporative Cooler Efficiency

The evaporative cooler efficiency, defined by Equation (1) is shown, for five days, in Figure (8). The evaporative cooler efficiency follows the sinusoidal trend similar to the ambient RH, with minimum value occurred at midday. The daily average efficiency varies between 47 - 64 %.

vi- Roof Distillation System

When the evaporative cooler was in shut down position, the measured temperature of the solar water basins, roof humid air and glass temperatures were found to follow the sinusoidal trend. However, due to the small energy absorbed by the water, the water temperature did not increase so much. The relatively thin dusty layer on the triangle glass roof absorbs more heat than expected which causes relatively high glass temperature. This creates small driving force between the water (source) and glass roof (sink) and causes relatively small amount of evaporated vapour collected as distillate. The collected amount of distillate ranges from 1.7 to 2.5 litres/day. Another problem was observed during system operation, which is the fall of distilled water droplets from the glass roof back to the basins or the GH ceiling was observed during operation. In order to overcome this problem additional troughs are installed at the middle of the inclined glass of the roof zone in such a way that the falling drops fall into these troughs. The increase in collected distillate improved slightly.

On the other hand, the large ceiling surface causes a leak of air from GH cavity to the roof (The GH cavity air is at relatively low temperature and higher pressure caused by the forced draft fan). This influences the roof air conditions and distillate rate. Figure (9) shows a typical sample of the roof distillation system temperatures. Future experimental work will, therefore, consider the measures that must be taken into consideration in order to improve distillation system productivity, including: (i) each water basin will be covered to form conventional solar stills. This will minimize vapour leaks, (ii) the basins should be insulated (using transparent air sheet gap) to minimize base losses, (iii) the basins water may contain black dies (balls) to increase the water absorbitivity (within the acceptable range of transmitted sun light required for plants growth (the treated polyethylene sheets used as conventional GH cover.

CONCLUSION

1- Experimental investigation of the thermal performance of agriculture greenhouse (GH) with built-in solar distillation system has been carried out and presented. The combined GH - solar distillation system utilizes the abundant solar energy in hot climates (above that required for plants photosynthetic process) to partially reduce the GH cooling load in summer, and to partially produce the required irrigating water by solar distillation. The experimental work was carried out for a GH constructed at the King Abdul Aziz University (KAAU), in the city of Jeddah, Saudi Arabia.

2- The system transient performance (temperatures & humidity inside the plants growth zone, and water productivity) were presented. Within the summer climatic conditions of the city of Jeddah, the results indicated the GH inside temperatures could be 8-10 °C (at GH inlet) and 3-6 °C (at GH outlet) below ambient temperature. The GH inside relative humidity was found to vary from 20 % to 35 % above ambient conditions and within the comfort zone of plants growth.

3- Some measures to improve GH solar distillation system productivity were highlighted.

ACKNOWLEDGMENT

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REFERENCES

1- Radwan A. M. and Hassan E. S. Fath, "Design and Construction of Greenhouse Self Sufficient of Energy and Irrigating Water", Final Report, Project No 108/1423, KAAU, Jeddah, Saudi Arabia (2004).

2- Hassan E. S. Fath, *Desalination Technology*, Book (In Arabic), Al-Dar Al-Jameiah, Alex., Egypt (2001).

3- Malik, M.A.S, Tiwari G.N., Kumar A., and Sodha M.S, *Solar Distillation*, Pergamon Press (1982).

4- Hassan E S. Fath, S. Elsherbiny, and A. Ghazy, "A Naturally Circulated Humidifying/Dehumidifying Solar Still with a Built-in Passive Condenser**",** *Desalination*, Vol. 169/2, pp. 129-149 (2004).

5- Hassan E. S. Fath, M. El-Sammanoudy, K. Fahmy, and A. Hassabou "Thermal-Economic Analysis and Comparison between Pyramid-Shaped and Single-Slopped Solar Still Configurations", *Desalination*, Vol. 159, pp. 69-79 (2003).

6- Nafey A. S., Hassan E. S. Fath, S. O. El-Hlaby, and Soliman A. M., "Solar Desalination Using Humidification-Dehumidification Processes (I) A Numerical Investigation", *Energy Conversion & Management*, Vol. 45, pp. 1241-1261 (2004).

7- Nafey A. S., Hassan E. S. Fath, S. O. El-Hlaby, and Soliman A. M., "Solar Desalination Using Humidification-Dehumidification Processes (II) An Experimental Investigation", *Energy Conversion & Management*, Vol. 45, pp. 1263-1277 (2004).

8- Hassan E. S. Fath, "Development of a New Passive Solar Fan for Ventilation of Greenhouse in Hot Climate", *Int. J. of Solar Energy*, Vol. 13, No. 4 (1993).

9- Hassan E.S. Fath, "Transient Analysis of Naturally Ventilated Greenhouse with Built-in Solar Still and Waste Heat & Mass Recovery System", *Energy Conversion & Management*, Vol. 35, No. 11, pp. 955-965 (1994).

10- Hassan E. S. Fath "An Integrated Agriculture System: A Self Sufficient System For Energy & Irrigating Water" Proceedings of The *Third Gulf Water Conference*, Oman, Vol. 3, pp. 797-806, 8-13 March (1997). Also the *sixth Arab Int. Solar Energy Conference*, Oman, March 29 (1998).

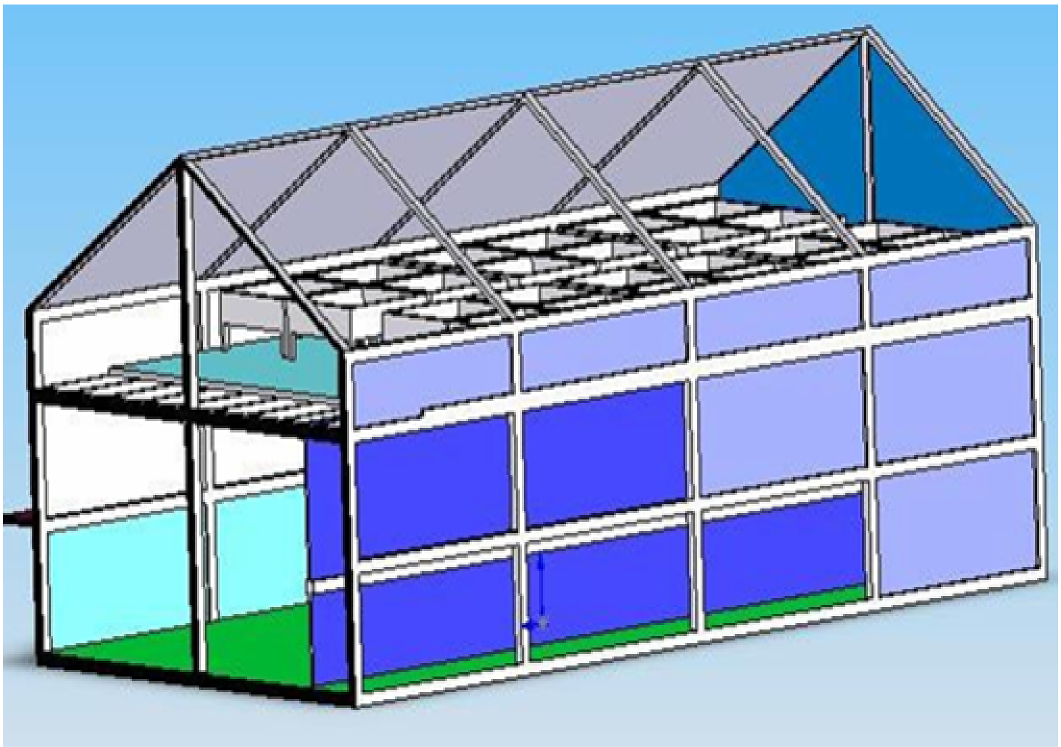

Figure (1) Overall System Schematic Configuration

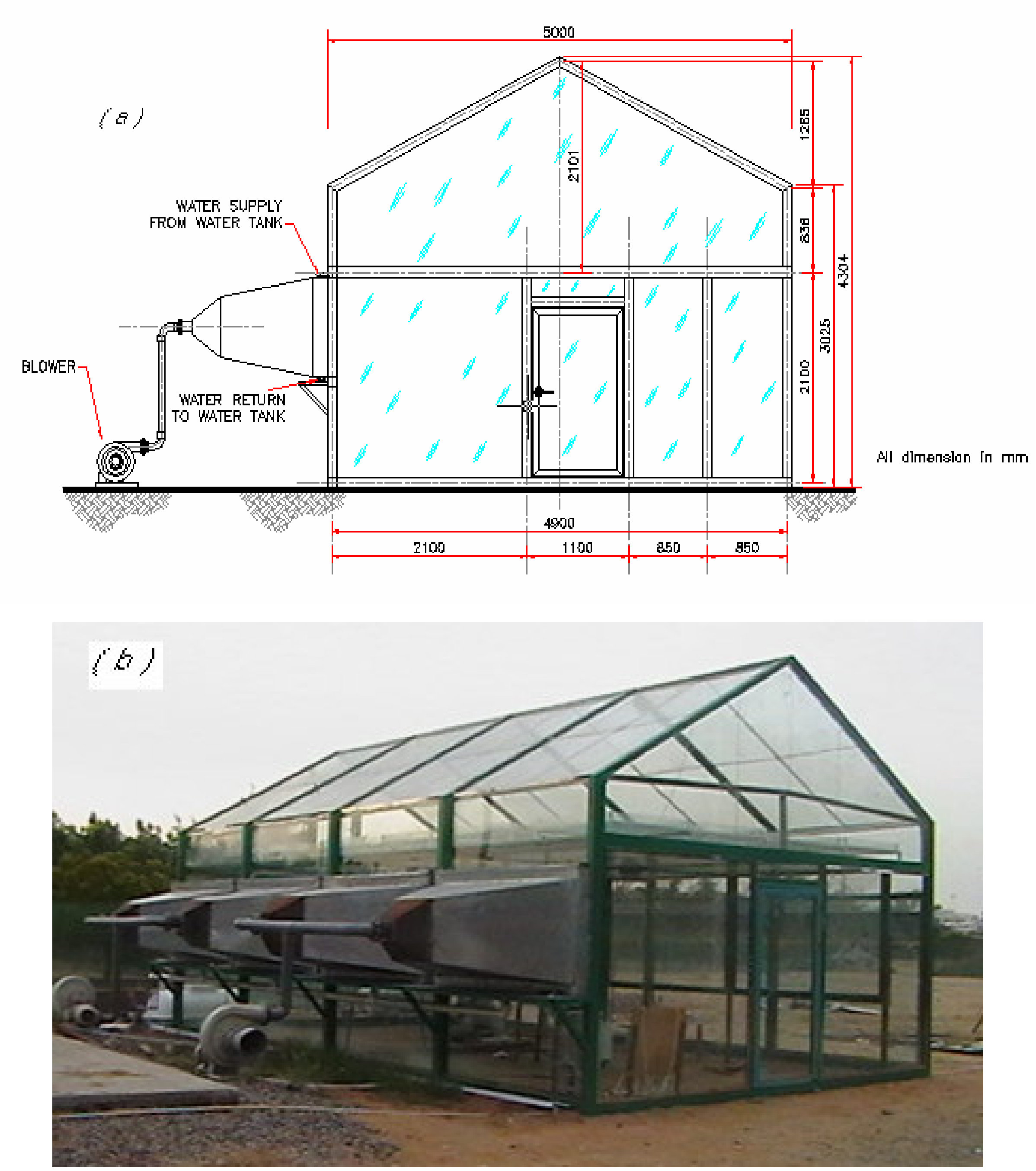

Figure (2) As Built System Configuration

(a) Construction Drawing of the West side View, (b) System Photo

Figure (3) Roof Solar Water Basins in the Triangular Zone

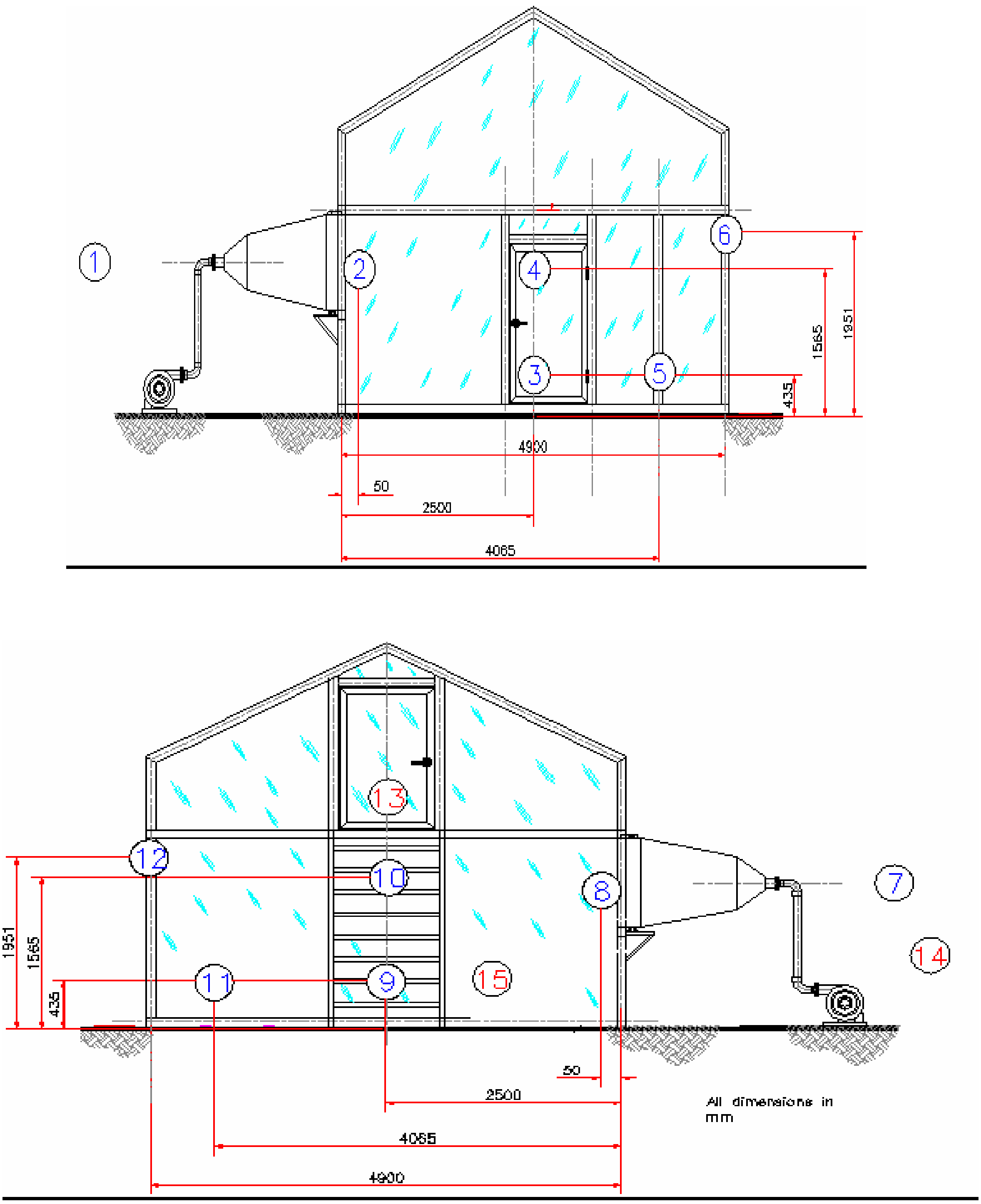

Figure (4) Selected Measurements Location

(a) West Side, (b) East Side

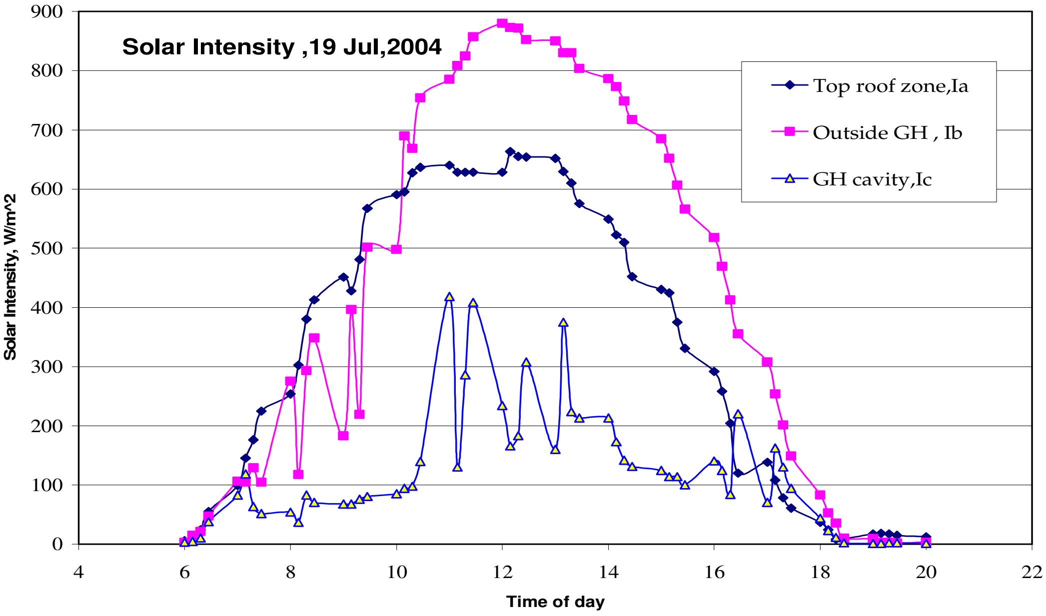

Figure (5) Solar Intensity Variation during the Day

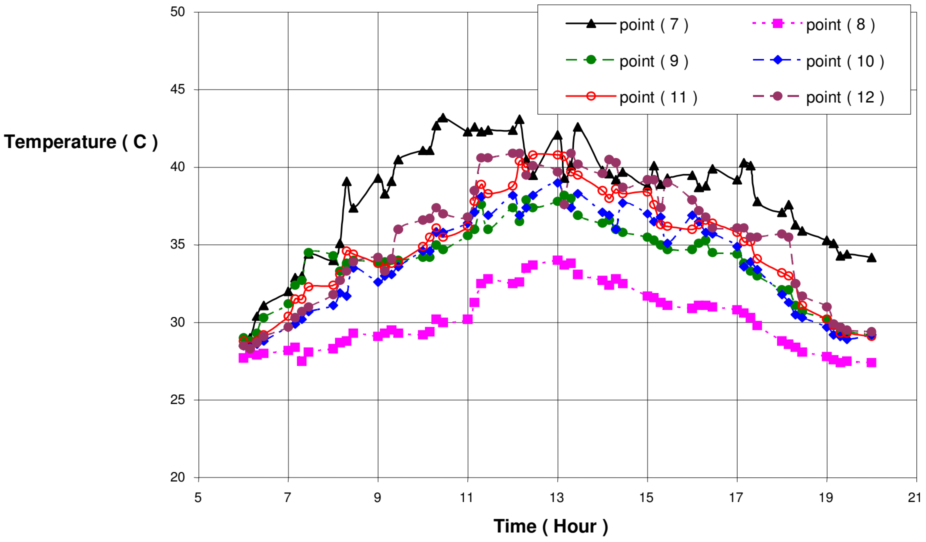

Figure (6) Second Plan Temperature Variation

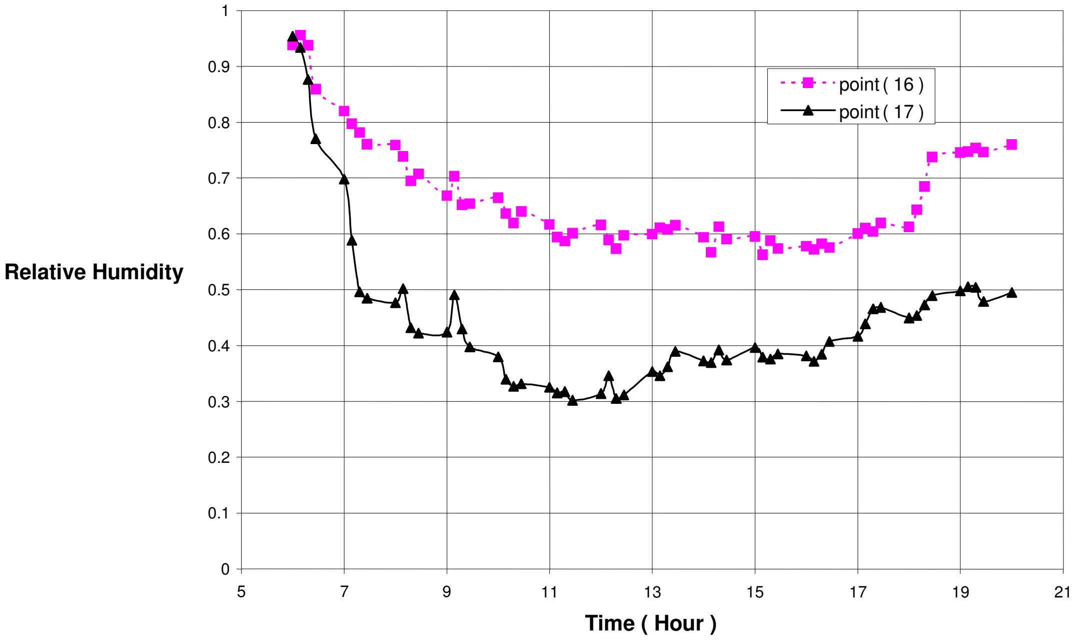

Figure (7) Relative Humidity Variation

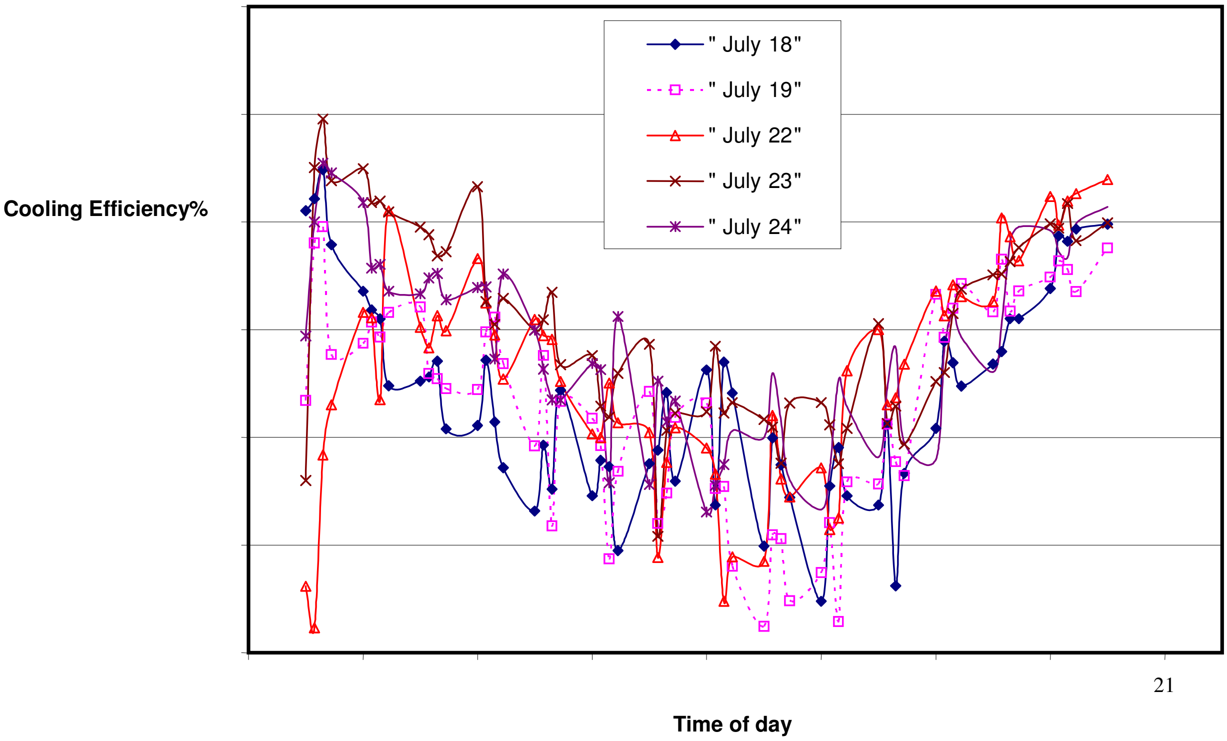

Figure (8) Evaporative Cooler Efficiency

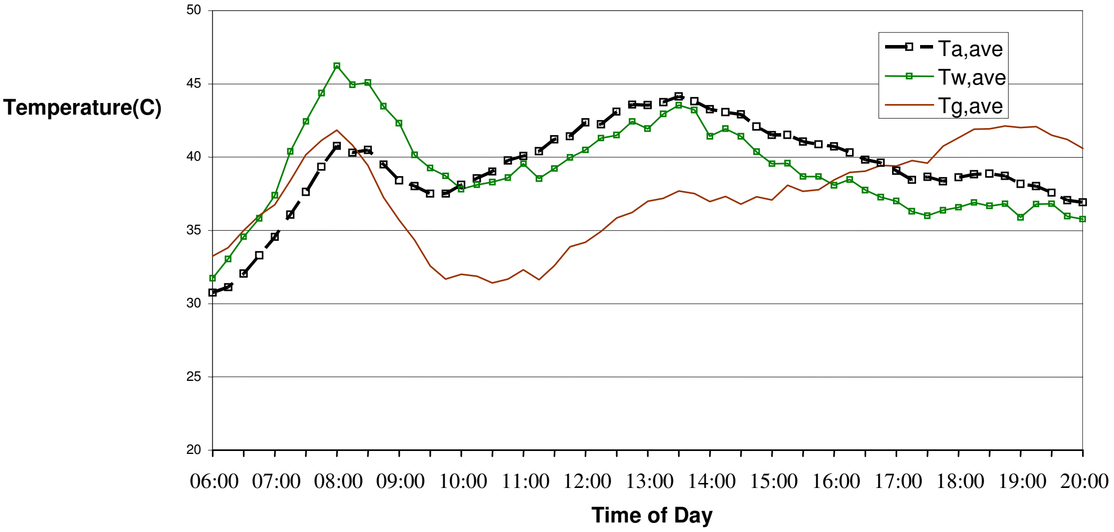

Figure (9) Temperatures of the Roof Distillation System