Desalination and Water Treatment
www.deswater.com

12 (2009) 382–388

doi: 10.5004/dwt.2009.970

Desalination of seawater using a humidification–dehumidification seawater greenhouse

T. Tahri[a], S.A. Abdul-Wahab[b], A. Bettahar[a], M. Douani[a], H. Al-Hinai[b], Y. Al-Mulla[c]

[a]*Faculty of Sciences and Engineering Sciences, Hassiba Ben Bouali University, P.O. Box 151, Chlef 02000, Algeria*
Tel. +213 551591304; Fax +213 721794; email: ntahritoufik@yahoo.fr
[b]*College of Engineering, P.O. Box 33, Sultan Qaboos University, Al-Khod 123, Sultanate of Oman*
[c]*College of Agricultural and Marine Sciences, P.O. Box 34,Sultan Qaboos University, Al-Khod 123, Muscat, Sultanate of Oman*

Received 28 September 2008; Accepted in revised form 11 October 2009

ABSTRACT

Agriculture is the sector that consumes over 70% of all freshwater in the world. Taking into account the dominant phenomena of evaporation in arid regions, there is an overconsumption that is reflected by a very pressing need. To this end, the desalination process exploiting solar energy is a promising alternative with strong analysis of the feasibility has been a series of studies in various research laboratories. The feasibility analysis focused on the influence of operating parameters: the temperature of the seawater, the temperature of moist air, its relative humidity, speed of movement and intensity of solar radiation and for the prototype located in Al-Hail, Muscat, Oman. During the period spanning from 30 April 2005 to 3 May 2005, the results of experimental studies demonstrate the positive impact of solar radiation on the flow of condensate to reach a speed of about 65 l/h for a current of around 800 Wt/m^2 and that it reaches its minimum value, almost zero, at dusk. In addition, similar behavior emerges for the influence of temperature and relative humidity of air. Although the impact of the temperature of cooling water (seawater) is tested, we note that the trend confirms the negative and shallow this parameter on the flow. For efficient operation of fans in terms of production cost, control conditions in the greenhouse showed that the maximum throughput for a speed of around 7 m/s.

Keywords: Desalination; Greenhouse; Solar radiation; Relative humidity; Temperature; Seawater; Air velocity

1. Introduction

Agriculture currently represents about 70% of all human use of water. In arid countries, the rate may exceed 90%. Lack of water is very harmful to agriculture, it is expected that the growth of the world's population aggravates the situation [1]. In the context of desalination, it is therefore appropriate to consider technologies that facilitate more efficient use of water in agriculture.

The seawater greenhouse (Fig. 1), provides an environment where sweat loss is minimized, at the same time producing enough freshwater for a household with a solar distillation process [3]. Goosen et al. [4] have recently reviewed a number of approaches to solar distillation, focusing on those involving the humidification and dehumidification of air. According to the authors, processes exist for a long time, but their combination with the culture in greenhouses is relatively new. Indeed, solar distillation projects have been installed in several places in the world [5,6]; in some cases, these projects have been

* Corresponding author.

Fig. 1. Seawater greenhouse at Al-Hail, Muscat, Oman [2].

deemed uneconomic to maintain. There are a number of ways in which the integration of a solar distillery with a greenhouse could minimize costs and make it economically more favorable. For example, some components of the greenhouse, condenser, evaporator and pipes are manufactured by the cheapest materials (polyethylene, PVC, paper). The seawater greenhouse is designed to provide a relatively cool and moist culture of a variety of crop species thus avoiding the stress due to heat or lack of water. At the same time it must deliver the hot fluid in step distillation process. The design carefully avoids the conflict that may arise between these conditions. In this article we focus on studying the impact of parameters: the temperature of moist air, the temperature of sea water, relative humidity, air velocity and solar radiation in the greenhouse on the operation of the seawater greenhouse of Muscat during the period from 30 April 2005 to 3 May 2005. The data were taken every half hour.

2. Seawater greenhouse process description

Based on solar radiation energy, sea water is used for the production of fresh water from humid air on the one hand and environmental conditions favorable to the growth of crops in the greenhouse on the other hand according to the method illustrated in Fig. 2.

The idea depends on creating the natural water cycle in a controlled environment. To do this, and after filtration through layers of soil made of sand, sea water is pumped to be sent to a storage cold seawater tank (Fig. 3a). Following a closed loop, cold seawater passes through the condenser (Fig. 3b), exiting from condenser hot seawater passes through the first evaporator (Fig. 3c), respectively, to contribute to a consistent humidification of the air introduced into the greenhouse. It should be noted that the evaporator is a compact heat exchanger, it consist of a cardboard honey-comb lattice (Fig. 3d), placed perpendicular to the flow of air drawn in by fan (Fig. 3e). From an exchange of mass and heat, during his run through the structure of the first evaporator, seawater is cooled by air humidification. Aspired by fan, air relatively cold and humid through the entire greenhouse to undergo a second humidifier at the second evaporator (Fig. 3f),

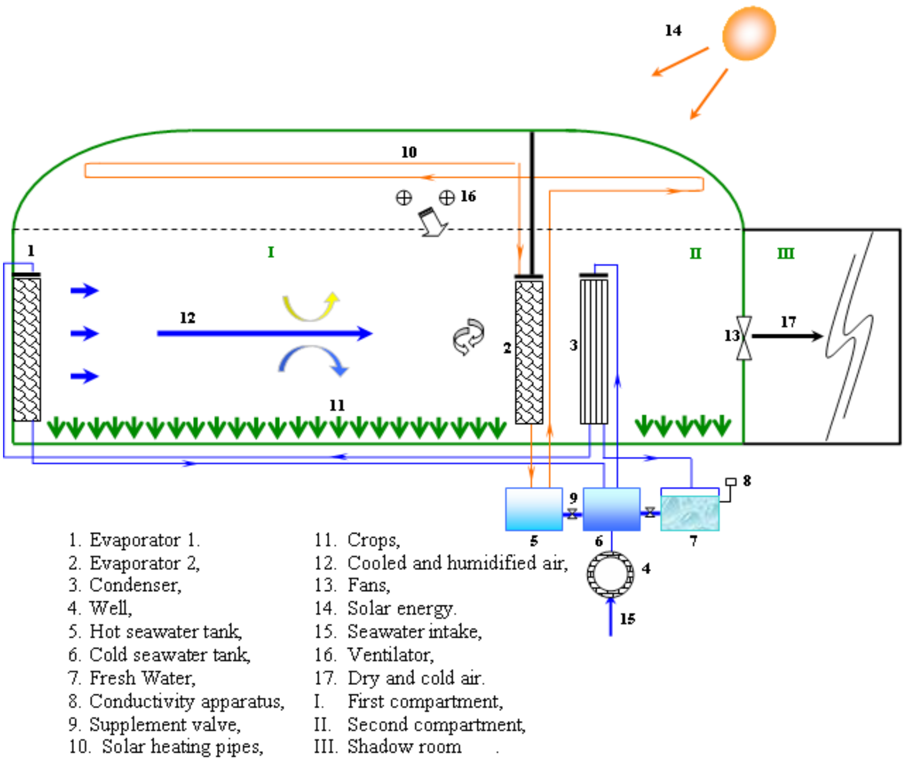

Fig. 2. Seawater greenhouse process schematic [7].

Fig. 3a. Cold seawater tank [8].

Fig. 3b. Condenser [8].

Fig. 3c. Front evaporator [8].

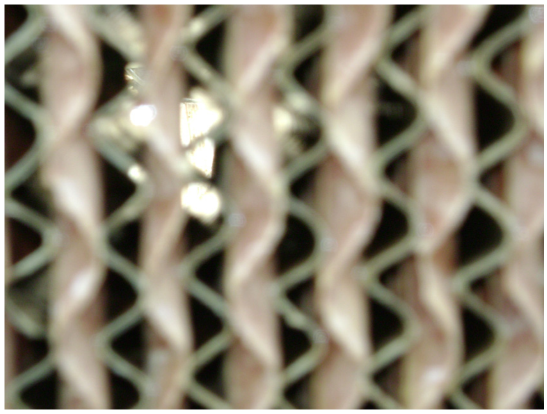

Fig. 3d. Cardboard honey-comb lattice [8].

Fig. 3e. Fans [8].

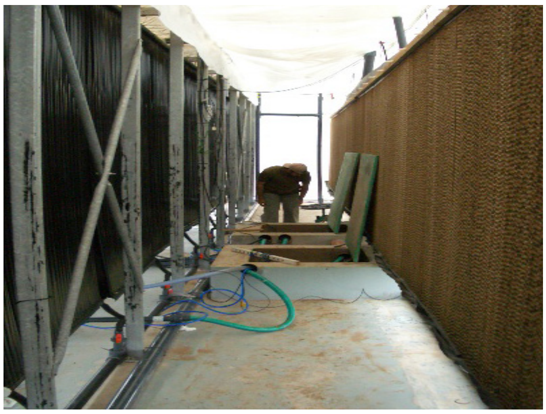

Fig. 3f. Back evaporator [8].

which is supplied with hot seawater and whose operation is identical to that of the first evaporator. The cold air from the second evaporator is at its saturation point. To provide a homogenous mixture of humid air, the greenhouse is equipped with two ventilators (Fig. 3g) whose size depends on the geometric characteristics of the greenhouse. The greenhouse is designed in such away that seawater leaving the hot seawater tank is heated by solar energy when it is conveyed inside the pipes (Fig. 3h) placed on the roof of the greenhouse. This hot sea water will be the feed that will enter the second evaporator.

It was noted that only a small fraction of solar radiation involved in photosynthesis, because the roof selectively filter solar radiation incident. Such technology aims

Fig. 3g. Ventilator [8].

Fig. 3h. Solar heating pipes [8].

Fig. 3i. Fresh water tank [8]

maintaining appropriate conditions for the development of plants namely a relatively fresh and fairly light.

The cold saturated humid air from the second evaporator passes through the condenser where cold seawater flows inside its tubes. Part of the humid air condenses on the walls of vertical tubes of the condenser. The resulting condensate is collected to be routed to the storage reservoir (Fig. 3i) for use in irrigation of crops. Table 1 illustrates the principal parameters of the design of the seawater greenhouse in the Sultanate of Oman.

However, in normal greenhouse, the remaining sunlight translates into hot growing conditions and large watering requirements [9].

Table 1
Design parameters of the seawater greenhouse [9]

Width, m	16
Length, m	45
Maximum height, m	4.8
Maximum speed of the air, m/s	7.1
Dimensions of first evaporator, m	15.6 × 2 × 0.2
Dimensions of second evaporator, m	15.6 × 2 × 0.2
Dimensions of the condenser, m	15 × 1.9 × 0.8

In order to analyze how it works in real time, the greenhouse is equipped with thermocouples and hygrometers arranged in different places to measure the dry bulb temperature and relative humidity. Moreover, the intensity of solar flux inside and outside the greenhouse is determined as well by a sensor. The temperature dry bulb, relative humidity, seawater temperature, air velocity and solar radiation values were collected from 30 April 2005 to 3 May 2005. The data were taken every half hour.

3. Results and discussion

The results of the experiment, illustrate the impact of operating parameters on the production of freshwater and performance of the greenhouse are represented in Figs. 4–8.

The intensity of solar radiation inside the greenhouse desalination of sea water is a weather factor, which changes depending on the location and seasonal fluctuations. It directly affects the amount of heat received by water in the tubes placed on the roof, thereby contributing to the increase in its heat sensitive. This energy supply is reflected in the intensification of humidifying the air by evaporation of water from evaporator 2. This enrichment, even the vapor is to operate by the circulation of seawater increasingly cold in the condenser to make the installation. The flow of condensate with the power of sunlight received (Fig. 4) are in perfect agreement. It can be seen clearly that the solar radiation went hand-in-hand with the amount of freshwater product [10]. It follows that the flow of fresh water (condensate) reached its peak during the interval from 08:00 to 18:00 pm and it is almost zero at night.

The seasonal variation in temperature of moist air inside the greenhouse is strongly linked to environmental conditions on the one hand and the actual performance of the two evaporators on the other. For increasing temperatures, there is a temperature increase of saturation, setting key conditioning condensation. The profile of the varying flow of condensate with a temperature of moist

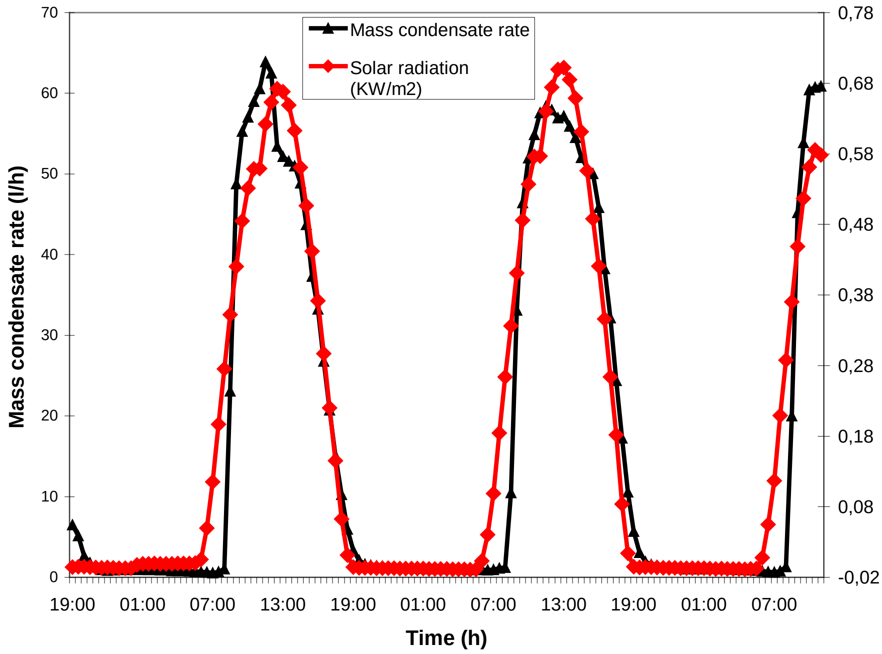

Fig. 4. Comparison of the measured average mass condensate rate of the condenser and solar radiation inside the seawater greenhouse Muscat (30 April–3 May 2005).

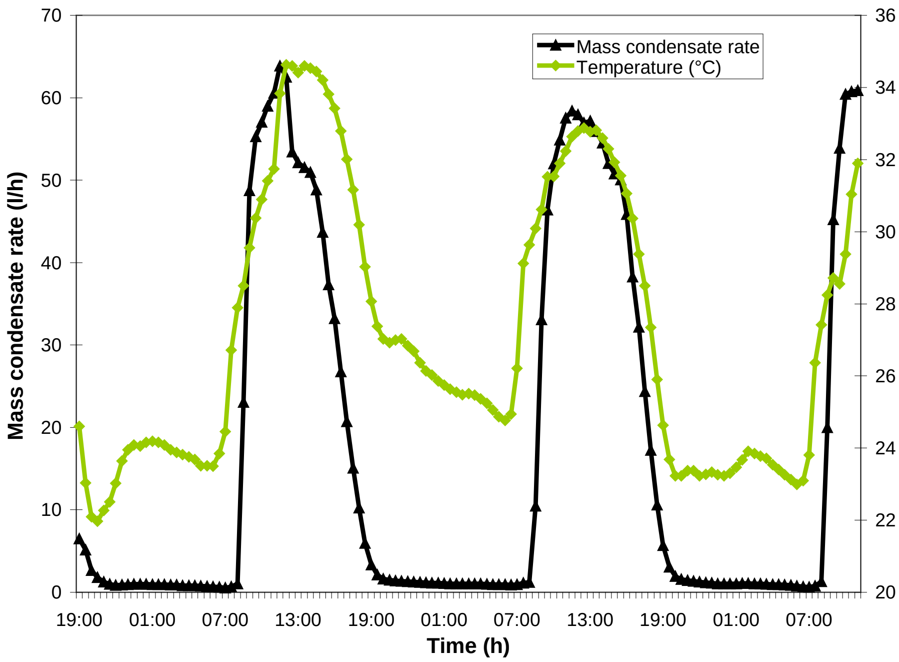

Fig. 5. Comparison of the measured average mass condensate rate of the condenser and inlet dry bulb temperature in the condenser in the seawater greenhouse Muscat (30 April – 3 May 2005).

air is introduced through Fig. 5. We notice that the temperature of moist air contributes positively to the flow of condensate and that it reaches its maximum when the temperature of moist air reaches its peak during the interval from 08:00 to 18:00.h.

The absorption of solar energy led to a consequent increase in tension of water vapor necessary for humidifying the air through the evaporator 2. The second wall of evaporator pads met its construction objective by increasing the relative humidity to 100% most of the time

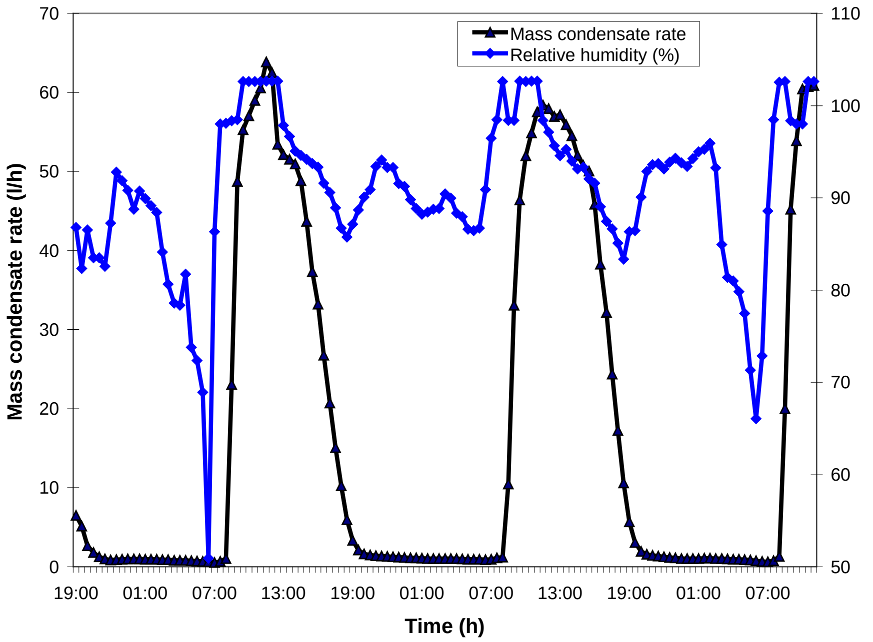

Fig. 6. Comparison of the measured average mass condensate rate of the condenser and relative humidity in the seawater greenhouse Muscat (30 April – 3 May 2005).

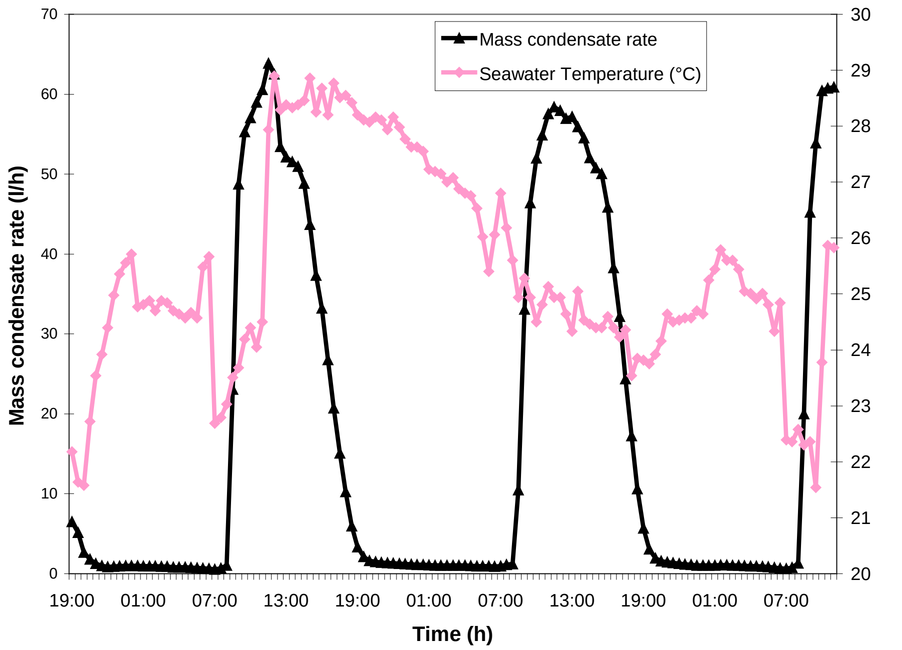

Fig. 7. Comparison of the measured average mass condensate rate of the condenser and temperature of seawater in the seawater greenhouse Muscat (30 April – 3 May 2005).

[11]. It follows that the relative humidity is a function of the diurnal variation of the intensity of solar radiation, which reached its peak almost simultaneously in the interval from 08:00 to 18:00 pm (Fig. 6). Indeed, a strong value relative humidity is high value flow condensate. It follows that the flow of fresh water (condensate) reaches its maximum when the relative humidity reaches its peak during the interval from 08:00 to 18:00 pm and it is almost zero at night despite the importance of relative humidity. Obviously, a reduction in the relative humidity is reflected by an increase in the amount of non-condensable gas (air), which, by its presence, is a barrier on the wall of the tube

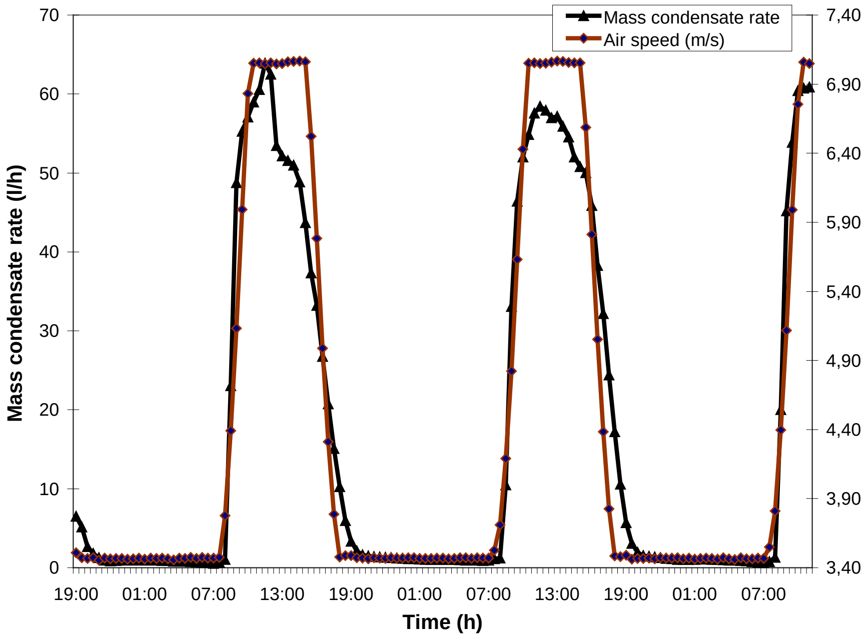

Fig. 8. Comparison of the measured average mass condensate rate of the condenser and air speed in the seawater greenhouse Muscat (30 April – 3 May 2005).

condenser, disabling the phenomenon of condensation. This explains the gradual reduction of the flow of condensate during the night.

Comparing the change in temperature of seawater at the entrance to the condenser to the flow of condensate is presented in Fig. 7. It follows that the condensation of steam in the condenser carried out in the interval from 08:00 to 18:00 pm with an average temperature of cold fluid (seawater) exceeding 23°C.

To ventilate the greenhouse, speed training of air varies according to a daily appearance presented in Fig. 8. Condenser design and airflow velocity appears to be the bottle neck of the dehumidification process [11]. It notes that it reaches its peak during the interval from 08:00 to 18:00 pm with a speed equal to 7.02 m/s. Profiles of condensate flow measured are in perfect agreement with those of air velocity inside the greenhouse. Specifically, this speed is independent of ambient conditions.

4. Conclusions

In light of these results, we note that the optimal operation of the greenhouse must take into account the relative orientation of the surface of the latter in relation to the equator. It must also take into account the disposal tube installed in the ceiling, because sunlight plays a crucial role in condensation, is directly linked to air temperature and relative humidity in the greenhouse. These three parameters directly affect the flow of condensate which reached its peak during the interval from 08:00 to 18:00 pm. So we propose the installation of finned tubes to support the intensive trapping condensation of moisture in the air. The approach, combining the desalination of seawater and the greenhouse effect while exploiting the phenomenon of condensation of water vapor in the air, seems to respond favorably water needs, expressed for the agriculture. It is interesting to note that a solution to the lack of water in the world is not to produce more water, but use less water in irrigation in agriculture.

References

[1] C.J. Vörösmarty, P. Green, J. Salisbury and R.B. Lammers, Science, 289 (2000) 284–288.
[2] T. Tahri, S.A. Abdul-Wahab, A. Bettahar, M. Douani, H. Al-Hinai and Y. Al-mulla, J. Therm. Anal. Cal., 96 (2009) 43–47.
[3] P.A. Davies and C. Paton, Desalination, 173 (2005) 103–111.
[4] M.F.A. Goosen, S.S. Sablani, W.H. Shayya, C. Paton and H. Al-Hinal, Desalination, 129 (2000) 63–89.
[5] E. Delyannis and V. Belessiotis, Adv. Solar Energy, 14 (2001) 287–330.
[6] E. Delyannis, Solar Energy, 75 (2003) 357–366.
[7] C. Paton and A. Davis, The seawater greenhouse for arid lands, Proc. Mediterranean Conf. on Renewable Energy Sources for Water Production, Santorini, 10–12 June 1996.
[8] www.seawatergreenhouse.com.
[9] T. Tahri, S.A. Abdul-Wahab, A. Bettahar, M. Douani, H. Al-Hinai and Y. Al-mulla, J. Therm. Anal. Cal., 96 (2009) 35–42.
[10] H. Mahmoudi, S.A. Abdul-Wahab, M.F.A. Goosen, S.S.Sablani, J. Perret, A. Ouagued and N. Spahis, Weather data and analysis of hybrid photovoltaic–wind power generation systems adapted to a seawater greenhouse desalination unit designed for arid coastal countries, Desalination, 222 (2008) 119–127.
[11] J.S. Perret, A.M. Al-Ismaili and S.S. Sablani, Development of a humidification–dehumidification system in a Quonset greenhouse for sustainable crop production in arid regions, Biosystems Eng., 91(3) (2005) 349–359.