DEVELOPMENT OF A SOLAR COLLECTOR/SOLAR WATER HEATING SYSTEM TEST CENTER IN IRAN

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1. Introduction

It is the aim of this paper to review the international standards for determining the thermal performance of solar thermal collectors and solar water heating systems and introduce the details of a test center which is under construction in our university.

The motivation for this research is the increasing interest and use of solar energy for domestic and industrial water heating in Iran. This made a lot of products both locally manufactured and imported without any test procedure for their performance evaluation. In this regards, a project is defined to evaluate the feasibility of a solar collector/solar water heating system test centre in the country.

The paper which originates from the above project is divided into two parts. In the first part, test procedures and standards developed or under development are described. For solar collector testing, the main standards reviewed in this paper are ISO 9806, EN 12975 and ASHRAE 93. Standards ISO 9459, EN12976/EN12977 and ASHRAE 95 are among those standards which are described for solar water heating systems. A comparison is also made among the standards in terms of their requirements and limitations.

Final part of the paper outlines the results of the review, selected standards for thermal performance tests and details of the system which is now under construction are presented.

2. Solar collectors test standards (ASHRAE 93, EN 12975-2, and ISO 9806-1) and comparisons

In this section we are going to review three solar collector test standards, namely ASHRAE 93[1], EN 12975-2[3] and 9806-1[8]. The steady state conditions and parameters have been mentioned in all these three standards. Time constant, thermal efficiency and incidence angle modifier test are three common tests that shall be done in all of the above mentioned standards. There are also some other parameters that are not common in standards. As EN 12975-2 is very similar to ISO 9806-1 in methods and parameters, the main comparison is made between these two standards and ASHRAE.

2.1 ASHRAE 93:1991:

2.1.1 Time constant test – τ:

Time constant calculation includes two steps. First, while there is radiation on the collector, the inlet fluid temperature is controlled in a way to bring it near ambient dry bulb temperature. After complying with steady state conditions mentioned in Table 2, collector surface will be shielded from the sun while the working fluid is circulating. The inlet fluid temperature (which is controlled) and the outlet fluid temperature (which is not controlled) will be recorded. The decrease in the collector outlet temperature over time provides information needed to estimate the collector's thermal time constant. The collector time constant shows the time needed for the temperature difference between outlet and inlet to decrease to 0.368 (1/e) of its initial value.

2.1.2 Thermal efficiency test – η_g:

Thermal efficiency is calculated by dividing the useful energy to solar radiance, as shown in eq. 1.

$$\eta_g = \frac{\dot{Q}_u}{A_g G_t} = \frac{A_a}{A_g}\left[F_R(\tau\alpha)_e - F_R U_L \frac{T_i - T_a}{G_t}\right] \qquad \text{(eq. 1)}$$

If thermal efficiency test is performed in normal incidence conditions which $(\tau\alpha)_e$ is constant, and F_R and U_L are constant at the test temperature too, a straight line will be produced when plotting η_g against x where

$$x = [(T_i - T_a)/G_t]$$

The measured value pair for η_g and x is called ''data point''. All of the steady-state test standards require a minimum of 16 data points at four different inlet temperatures to obtain the efficiency curve for a collector. The test conditions for performing the efficiency test are mentioned in Table 3.

2.1.3 Incidence Angle modifier - $K\theta_b(\theta)$:

Real efficiency test of a collector depends on incidence angle modifier of solar irradiance. Incidence angle modifier, $K\theta_b(\theta)$, is used to measure the dependence of the angular radiance on incidence angle. Incidence angle modifier test includes the measurement of collector efficiency in constant working fluid temperature at steady state and by different incidence angles. Different incidence angles are obtainable by changing the solar collector azimuth angle. Dependence of incidence angle modifier is approximately calculated by eq.2.

$$K\theta_b = 1 - b_0\left(\frac{1}{\cos\theta} - 1\right) \qquad \text{(eq. 2)}$$

b_0 assumed as a constant parameter and called incidence angle modifier coefficient which is usually a positive number. In ASHRAE 93 four angles of 0, 30, 45 and 60 degree are needed to perform the test.

2.1.4 Inlet temperature distribution for thermal efficiency tests

ASHRAE 93 efficiency tests are conducted for four distinctly different collector inlet temperatures. ASHRAE 93 specifies two methods to determine these temperatures. The lowest inlet temperature is equal to the ambient temperature at the test site, which can be a problem during winter in some locations. The highest inlet temperature is defined based either on the manufacturer's recommendation or on specified efficiencies achieved during the tests. In both methods the temperature may exceeds 130 °C which seems to be impractical when water is used as working fluid.

2.2 EN 12975-2:2001 and ISO 9806-1:1994:

It should be mentioned that EN 12975-2 contains some physical test procedures. These physical tests are mentioned in other ASHRAE or ISO standards like ISO 9806-2 and are not compared in this article.

2.2.1 Time constant test – τ:

The procedure in ISO and EN standards is fundamentally the same as ASHERAE. The difference is in temperature measurement where the difference between collector outlet and ambient temperatures is measured instead of the difference between outlet and inlet temperatures. Firstly, the collector is shielded from the sun until the steady state condition achieved. Then the cover is removed quickly and the measurements start till the second steady state condition is met. In this test the time constant is the time taken for the difference between collector outlet temperature and ambient temperature to rise by 63.2% of the total increase of this difference. The steady state limits are mentioned in Table 2. Performing this test is optional in EN 12975-2.

2.2.2 Thermal efficiency test – η_g:

Thermal efficiency of a collector is also calculated using data points, but the calculation method is scantly different. Thermal efficiency is calculated by dividing the useful heat to solar irradiance, as shown in eq.3.

$$\eta_g = \frac{\dot{Q}}{A_g G} \qquad \text{(eq. 3)}$$

Thermal efficiency is introduced as a function of reduced temperature difference (T^*) where reduced temperature based on the fluid inlet temperature is shown in eq. 4.

$$T_i^* = \frac{t_{in} - t_a}{G} \qquad \text{(eq. 4)}$$

Thermal efficiency can be calculated using eq. 5. Two unknown parameters a_1 and a_2 are calculated by curve fitting in first or second order fitting methods.

$$\eta = \eta_0 - a_1 T^* - a_2 G (T^*)^2 \quad \text{(eq. 5)}$$

2.2.3 Incidence Angle modifier - $K\theta_b(\theta)$:

The test should be performed at four angles of 0, 30, 45 and 60 degree in ISO 9806-1, but in EN 12975-2 only one angle 50 degree is enough for performing this test.

2.2.4 Inlet temperature distribution for thermal efficiency tests

When water is used as the working fluid, EN 12975-2 and ISO 9806-1 recommend 80 °C and 70 °C in sequence. On the other hand, quasi-dynamic test method of EN 12975-2 has categorized collectors due to their applications and specified the maximum fluid inlet temperature based on their application.

2.2.5 Quasi-dynamic test method (EN 12975-2)

The most significant difference between EN 12975-2 and two other standards is quasi-dynamic test method. In all three standards the steady state conditions shall be verified before performing tests but by using this test procedure in EN 12975-2 the test may be performed without complying with steady state conditions and is based on quasi effect. The difference between this method and steady state method is in measuring useful energy gain from the collector in small 5 to 10 minutes periods while solar radiance and ambient temperature may vary. Other remaining operation parameters are controlled to within a specified range. The conditions are shown in Table 1.

Tab. 1: Quasi-dynamic test conditions

Parameter	**Range**
Collector orientation(°)	Facing south ± 5
Tilt angle(°)	45 ± 5
Solar radiation (W/m^2)	more than 300
Wind speed (m/s)	1 – 4
Mass flow rate ($kg/s.m^2$)	1%

The data collected in this method are used in multiple linear regression (MLR) method in order to obtain final collector parameters. Recommended procedure is for 4-5 days test period, but the real time needed for this test depends on weather conditions during the test period. Day types (DT) are specified as a combination of collector plate temperature and weather conditions. In the case that the measured quantity depends on time, the data collection period is 1 to 6 seconds and averaging time is 5 to 10 minutes.

Tab. 2: Parameters comparison for steady state conditions in three standards

Variable	**maximum value or allowed variation**		
Standard	ISO 9806-1	EN 12975-2	ASHRAE 93
Minimum solar radiance for performing test (W/m^2)	800	700	790
Normal incidence variation on surface (W/m^2)	± 50	± 50	± 32
Ambient temperature variation	± 1 K	± 1 K	± 1.5 K
Flow rate variation	± 1% in successful 30 sec. period measurement	± 1% in successful 30 sec. period measurement	± 2% or ± 0.005 gpm the greater in 15 min.
Inlet fluid temperature variation	0.1 K in successful 30 sec. period measurement	0.1 K in successful 30 sec. period measurement	± 2% or 1 K the greater in 15 min.
Outlet fluid temperature variation	± 0.05 °C per minute	± 0.05 °C per minute	-

2.3 Standards comparison:

Table 2 indicates the variation of key variables for steady state conditions in the three standards. As it has mentioned before, all of the parameters shall be within the limits of this table for performing any test.

Table 3 also shows the weather conditions needed for steady state test.

Tab. 3: Required environmental conditions

Variable	**Allowed variation**		
Standard	ISO 9806-1	EN 12975-2	ASHRAE 93
Total solar irradiance normal to sun (W/m^2)	800 min.	700 min.	790 min.
Maximum diffuse fraction (%)	20%	30%	20%
Wind Speed, u (m/s)	2<u<4	2<u<4	2.2<u<4.5
Incidence angle modifier	98%<normal incidence value<102%	98%<normal incidence value<102%	98%<normal incidence value<102%

3. Solar water heater test standards (ASHRAE 95, EN 12976-2 and ISO 9459-2) and comparisons

A comparison is made in this section among ASHRAE 95[2], EN 12976-2[4] and ISO9459-2[6] which are used for testing solar water heaters. It should be mentioned that all the tables and comparisons are made for outdoor test conditions and indoor test conditions using sun radiance simulators have not been discussed.

3.1 ISO 9459:

ISO standards are known as international standard. The related standards for testing solar water heaters as issued by the Institute of Standards and Industrial Research of Iran (ISIRI) are also based on ISO standards [13]. Solar water heater test procedures are defined by ISO 9459. This standard evaluates system performance in three aspects.

3.1.1 Performance rating procedure using indoor test methods:

This test is performed based on ISO 9459-1:1993[5]. It is a one day indoor test using sun radiance simulator, which defines the yearly water heater system efficiency.

3.1.2 Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems:

This test is performed based on ISO 9459-2:1995. This test is applicable for solar-only systems and solar systems with preheater. Test reports could be directly used with daily average solar radiance, ambient temperature and fluid temperature for predicting yearly system performance prediction. Daily useful energy and environmental conditions shall be measured for more than 10 to 15 days.

3.1.3 Performance test for solar plus supplementary systems

This test is performed using ISO 9459-3:1997[7]. The performance test for solar-only systems is a “black box” procedure which produces a family of “input-output” characteristics for the system. Average daily solar radiance, ambient air and inlet fluid temperature could be used for yearly performance prediction. This test needs monitoring inlets and outlets for more that 6 to 8 weeks and there is no need to control efficiency of system components.

3.2 European standard for solar thermal systems; EN 12976-2:2001:

This standard is almost based on ISO standard and it has been edited in a form that could be verity European codes and needs. Moreover, some other tests have been added to this standard such as: Freeze resistance test, over temperature protection, pressure resistance, water contamination, lightning protection, mechanical strength of supporting frame and safety equipments.

3.3 American standard ASHRAE 95:1987:

The procedure which has been presented in this standard is helpful to determine the thermal performance of three kinds of domestic solar water heating systems as: Solar only systems, solar preheat systems, and solar plus supplementary systems. During this test, amount of energy consumed by circulation system (pumps, controllers, magnetic valves and etc) shall be measured. Supplied heat by heater collector circuit shall be measured daily and recorded after each test day. Energy consumption of accessories, pumps, fans and valves shall be separated from the energy consumption of the system components. For all systems, solar fraction or fractional energy saving shall be measured. For solar-only and solar preheat systems, the fraction of the daily system hot water load supplied by solar energy shall be calculated by eq. 6. The fractional energy savings shall be calculated by eq. 7.

$$sf = \frac{Q_S - Q_{PAR}}{Q_L} \quad \text{(eq. 6)}$$

$$e = 1 - \frac{Q_{AUX} - Q_{PAR}}{Q_{CON}} \quad \text{(eq. 7)}$$

3.4 Solar water heaters standards comparison

Table 4 shows the common parameters in three standards which have been compared to each other. As mentioned before, EN and ISO procedures were nearly the same, except some physical test procedures which have not been specified in ISO 9459 standard. As we were looking for a test procedure which is more applicable in our country, we chose ISO for performing the tests. ISO standard is also acceptable by the Institute of Standards and Industrial Research of Iran (ISIRI).

Tab. 4: Solar water heaters parameters comparison in three standards (ASHRAE 95, EN 12976-2 and ISO 9459-2)

Variable	ISO 9459-2	EN 12976-2	ASHRAE 95
Pipe length between collector and tank (when separated) (m)	15	15	15
Pyranometer	Class I	Class I	Class I
Accuracy of temperature ambient air (°C)	± 0.5	± 0.5	± 0.5
Precision of temperature ambient air (°C)	± 0.2	± 0.2	± 0.2
Temperature measurement of the water being draw-off	measured at least every 15s and average value recorded at least every time a tenth of tank volume is drawn off	measured at least every 15s and average value recorded at least every time a tenth of tank volume is drawn off	30s after withdrawal is complete
Collector angle (degree)	facing equator within ±10	facing equator within ±10	-----
Wind velocity (m/s)	3 to 5	3 to 5	----
Ambient air temperature measurement position	on shaded position, 1 m above the ground, not closer than 1.5 m and not further than 10 from collector	on shaded position, 1 m above the ground, not closer than 1.5 m and not further than 10 from collector	1.2 m from the floor and not closer than 1.5 m to the tank and system components

4. Suggested system test plan and reports

Test plan for testing collectors and systems is based on the ISO standards as it was more applicable as mentioned before. The system components specifications are mentioned in what follows. The heat pipe collector is model TZ 58/1800-20R manufactured by Sunrain [9] and flat plate collector is DAC18 manufactured by Derya[11]. A UPS 25-60 inline pump by Grundfos [12] is used for circulating the working fluid in the circuit. Reservoir tank volume was about 150 Lit. made of galvanized steel. PT-100 temperature sensors are used for measuring the inlet and outlet fluid temperatures of each collector and reservoir tank. In order to control the tank fluid temperature two no's of 2 KW electric heater and one 1 KW heater are used. The heaters were controlled by a SSR controller. Autonics model TZN4S-14S PID temperature controller was used for this purpose [10]. The pyranometer, ambient temperature probe, wind velocity sensor and data logger are all supplied by Soldata [14].

Test stand diagrams based on ISO standards mentioned before are shown in Fig. 1 and Fig. 2 for collector testing and water heater system testing, respectively.

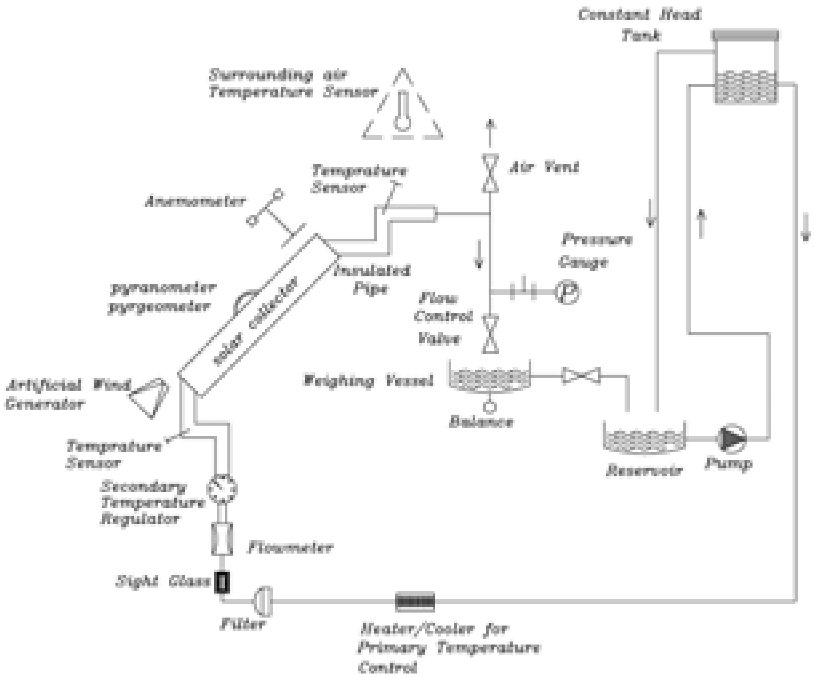

Fig. 1: Open loop test plan for testing collector based on ISO 9806-1.

Following parameters shall be calculated for completing test procedure of collector:

- Effective heat capacity
- Collector time constant
- Incidence angle modifier
- Pressure drop in collector test circuit

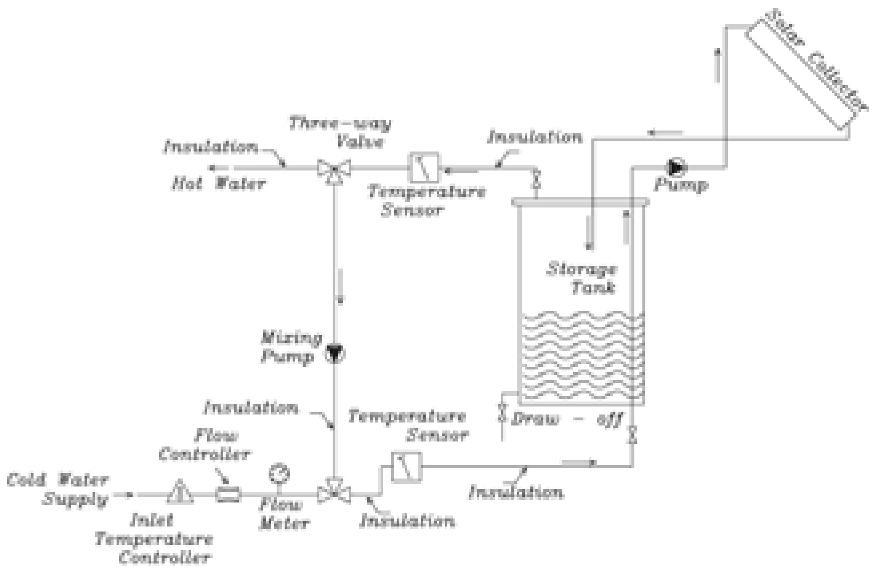

Fig. 2: Forced Open loop test plan system for testing solar water heater system based on ISO 9459.

The solar water heater test system is based on ISO 9459-2 as an open loop system. The following parameters shall be calculated after test:

- Energy available at 6 hours after solar noon
- Draw-off volume to meet minimum temperature limit
- Energy drawn off
- Energy left in tank
- Energy loss overnight
- Water volume

Fig. 3 shows a sample climate data report as logged by the data logger. Recorded parameters are ambient air temperature, global radiation, diffuse radiation and wind velocity. Fig.4 shows the weather station facilities located at test station including two pyranometers, anemometer and thermometer. Fig. 5 shows the test site designed and manufactured in Islamic Azad University for performing collector and water heating system tests.

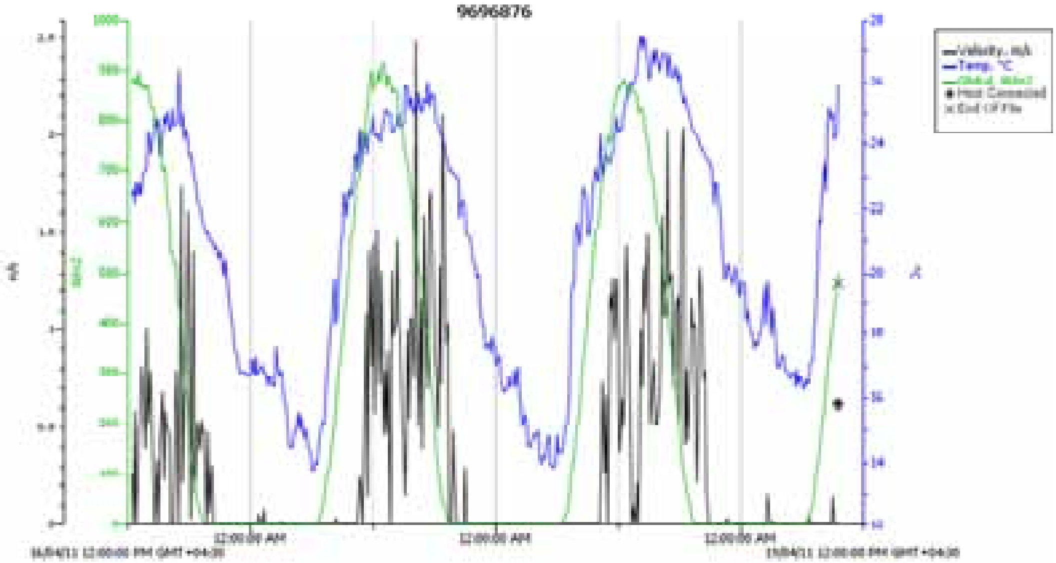

Fig. 3: Environmental conditions which have been plotted by weather station logger system

Fig. 4: Weather station including equipments for recording weather conditions at the test station

Fig. 5: collector and test facilities used for testing system and collectors

In Fig. 6 some of the test results for the evacuated collector are presented. As can be seen in the diagram on the right, theoretical efficiency is reduced by increasing the parameter T_f-T_a/I. The expected fluid outlet temperature and the measured temperature, efficiency and solar radiance are also shown in the left diagram. It should be noted that further tests are underway at the time of writing this paper and results will be presented during the conference.

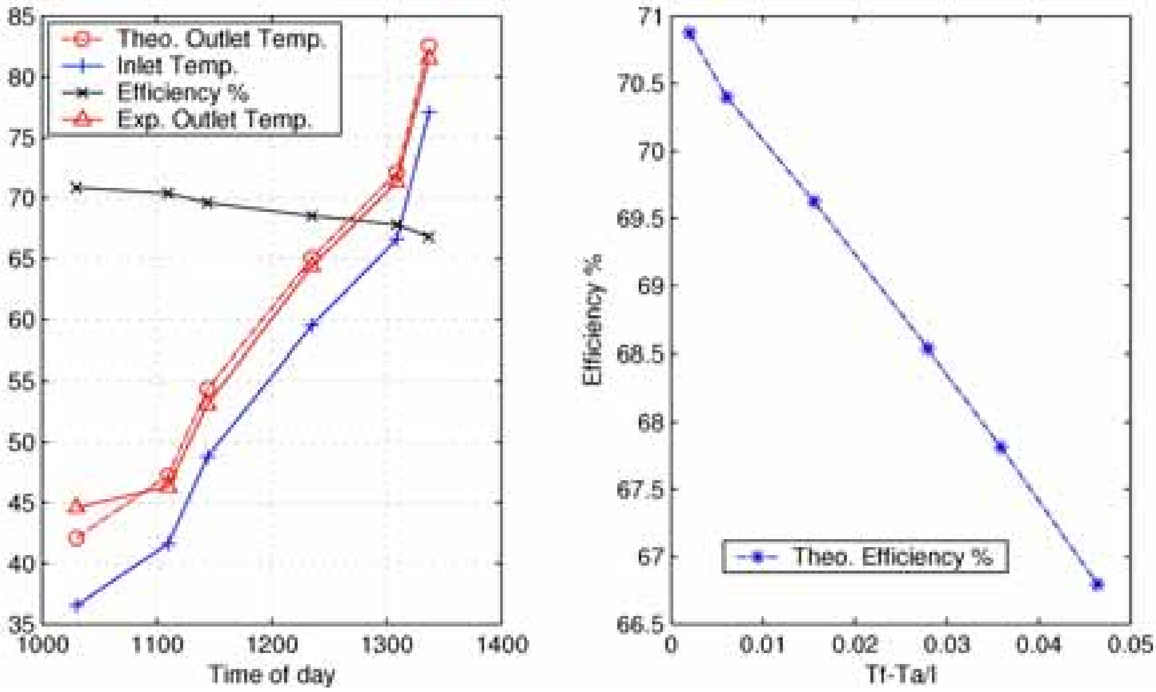

Fig. 6: Theoretical and experimental fluid outlet temperature on the left, efficiency vs. T_f-T_a/I on the right

It is planned to enter discussion with ISIRI (institute of standards and industrial research of Iran) to equip the facility at the level of a national certified testing lab for solar water heaters and solar collectors.

Among the future plans in the solar energy group of the university are installation of a grid connected PV (photovoltaic) system on the car parking lot of the university, test facility for PV panels, development of three solar cooling systems (adsorption/absorption and PV operated), manufacturing and testing a solar assisted heat pump water heater and testing a MEH solar desalination system.

5. Acknowledgment

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6. References

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