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An experimental comparative study on different configurations of basin solar still

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ABSTRACT

A basin solar still system with four different modifications is designed and tested under actual environmental conditions of North Cyprus. The first configuration is the conventional model and the three remaining models are the ones with steps and sponges which have been developed for the aim of improving the productivity of conventional solar stills by determining the effects of additional properties in the outputs of the system. By taking advantage of steps and sponges, the modified configurations are improved in comparison with those of conventional configurations. The basin has been fabricated with galvanized iron sheets of 1 mm thicknesses which are colored in black in order to maximize the amount of heat absorption from solar radiation. The results indicated that the quantity of produced water is a function of average ambient temperature and solar radiation which have been measured accurately in the current study. Experiments are conducted during six months of the year including, September, October, November, March, April and May. The best configuration which counterparts the maximum amount of water production corresponds to the case where solar still embraces steps and sponge liner and produces 5.37 L/d m^2.

Keywords: Modified solar still; Water production; Conventional model; Basin; Sponge; Step; Desalination

1. Introduction

Earth seems to be unique among other planets due to the fact that water provides the earth with the capability of supporting life. The required fresh water of the world can be obtained from desalination systems technologies which can provide an abundant reliable fresh water supply both from seawater and brackish sources [1]. Development of desalination processes can be divided into two main categories [2]:

(1) Thermal processes
(2) Membrane processes

Distillation is a thermal desalination process which is based on the evaporation of water by employing an additional thermal energy source [3], this energy can

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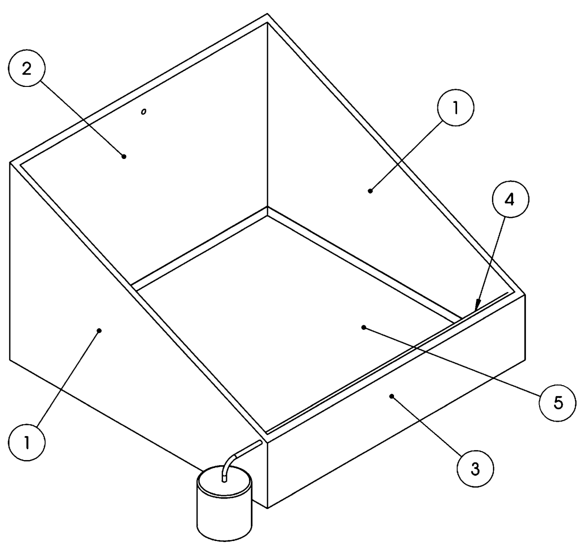
be provided by solar energy [4–7] or other additional heat sources [8–11]. The operating system of the basic solar still is explained as follows: a configuration of the closed system which includes a pan of saline water that evaporates under the effect of heating by solar radiation and condenses on the inner surface of the inclined cover. The unique property of the solar still is in the working principle of the system which results in quite pure output water due to the fact that the slow distillation process allows only pure water to evaporate from the basin and collect on the cover [12]. The performance of solar still systems depends not only on their configurations, but also on some different factors such as solar radiation on the surface, ambient temperature, water depth, and wind velocity. In this study, only the effects of solar radiation and ambient temperature were measured and considered.

Many researches and studies have been carried out by applying sponge [13–20] and steps [21–23] in order to produce more fresh water.

Kabeel et al. [21] investigated a theoretical and experimental study about the effect of depth and width of trays on the performance of a modified stepped solar still and also simultaneously a comparison was made with a conventional single slope solar still. The results indicated that the tray depth and width wereimportant factors and also a maximum productivity of about 57.3% higher than that of the conventional model was achieved. Arjunan et al. [15] presented a study about enhancing the productivity of solar stills by increasing the thermal gap between water and glass using sponge liners at the inner wall surfaces. They developed a thermal model in order to evaluate the heat transfer correlation. The results indicated that sponge liner stills work toward increasing the thermal gap between water and glass by reducing the temperature of glass.

The impact of different sizes of the sponge cubes which were placed in the basin on the productivity of the solar still system was studied experimentally by Abu-Hijleh and Rababa'h [24]. An increment of 18–273% happened in the system productivity compared to conventional systems without sponge cubes under the same conditions. Velmurugan et al. [25] presented a study about the performance of stepped solar still characteristics with two different depths of trays, fin type, sponge type, and a combination of both fin



5	PART 5	GALVANIZED IRON	1
4	PART 4	GALVANIZED IRON	1
3	PART 3	WOOD	1
2	PART 2	WOOD	1
1	PART 1	WOOD	2
ITEM NO.	PART NUMBER	MATERIAL	QTY.

Fig. 1(a). Schematic details of the solar still Type 1 (conventional model).

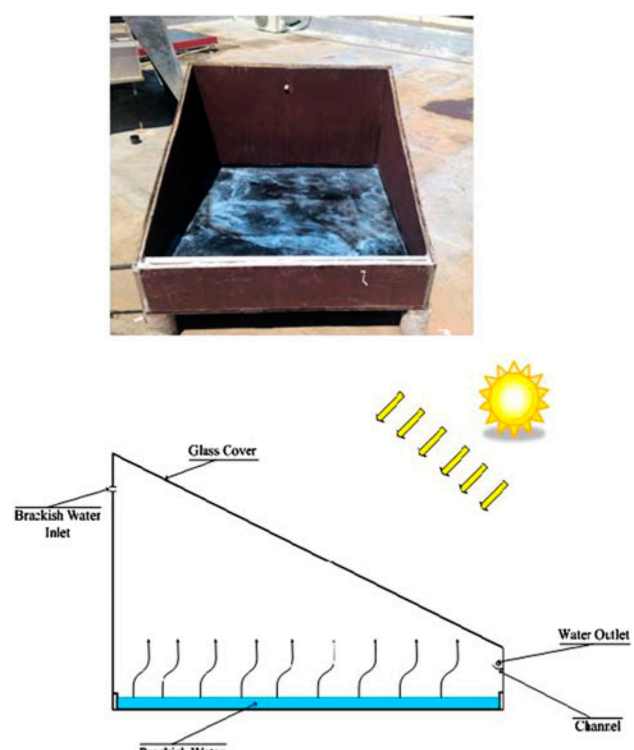
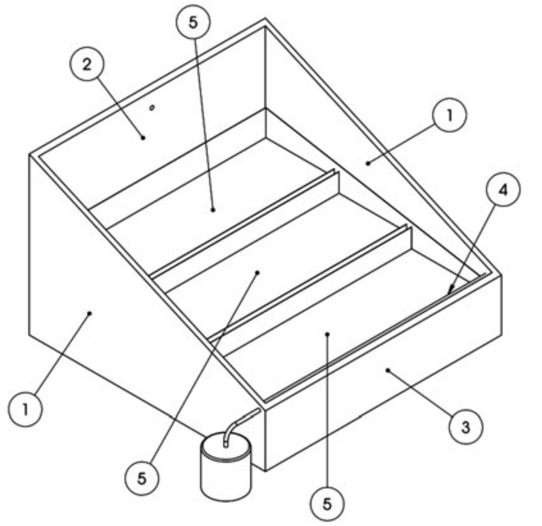


Fig. 1(b). Pictorial and schematic view of the solar still Type 1 (conventional model).



5	PART 5	GALVANIZED IRON	3
4	PART 4	GALVANIZED IRON	1
3	PART 3	WOOD	1
2	PART 2	WOOD	1
1	PART 1	WOOD	2
ITEM NO.	PART NUMBER	MATERIAL	QTY.

Fig. 2(a). Schematic details of the solar still Type 2.

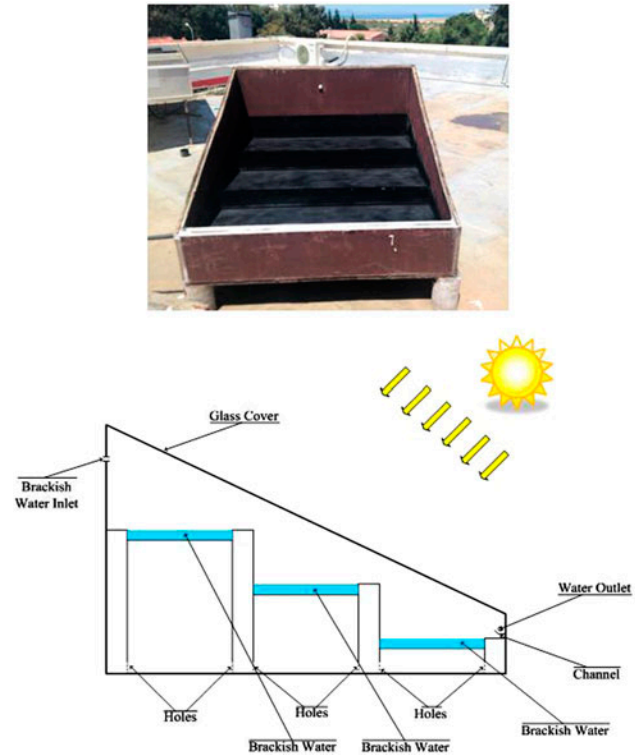


Fig. 2(b). Pictorial and schematic view of the solar still type 2.

2. Experimental work and system description

Four solar stills are designed and constructed to compare the performance of these systems. The first system as shown in Fig. 1 is the basic type (conventional model) which composed of a wooden box, channel, 5 mm thick, 24° inclined glass cover with a horizontal 1×1 m basin. The glass was inclined at 24° angle to optimally utilize the 1 m^2 surfaces (solar

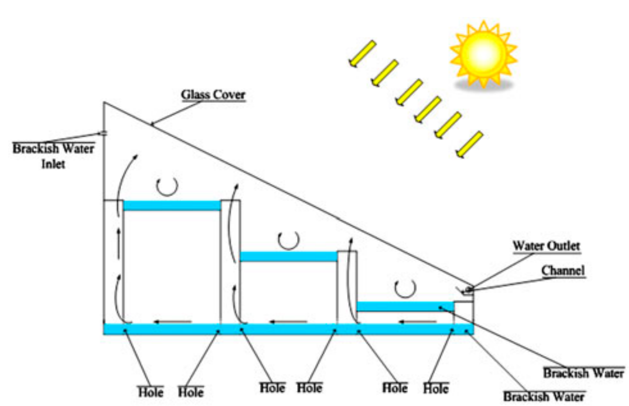


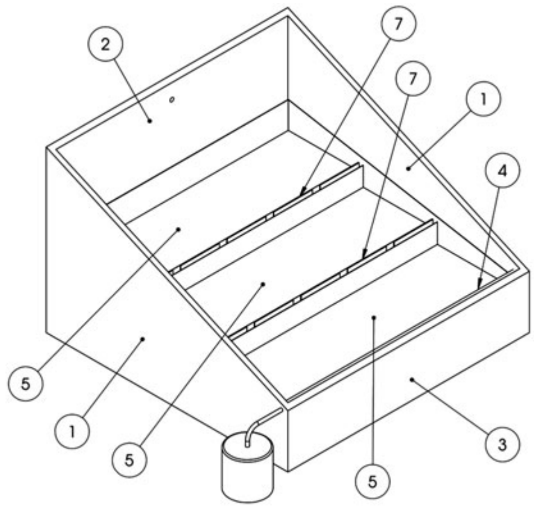
Fig. 3. Schematic view of solar still type 3.

and sponge type. The results showed 76, 60.3 and 96% productivity increment were possible by utilizing fins, sponges and combinations of both fins and sponges, respectively.

However, the effects of sponges [12,14,26] and steps [27–29] on the performance of the solar stills have been carried out individually, but the effects of both sponges and steps simultaneously on the output of basin solar stills have remained unclear.

Also, many studies and experiments have been performed in North Cyprus regarding different solar still systems except the investigation on basin solar stills. The significance of this study compared to previous studies is in investigating the effect of both sponges and steps under actual environmental conditions of Northern Cyprus.

A thorough and comprehensive experimental study has been made in order to increase the productivity of the solar still. In this study, four different configurations were built and experimentally investigated. The objective of the study is to identify the effect of some parameters on the productivity of modified solar stills such as existence of sponges and steps.



ITEM NO.	PART NUMBER	MATERIAL	QTY.
7	PART 7	SPONGE	20
6	PART 6	GALVANIZED IRON	1
5	PART 5	GALVANIZED IRON	3
4	PART 4	GALVANIZED IRON	1
3	PART 3	WOOD	1
2	PART 2	WOOD	1
1	PART 1	WOOD	2

Fig. 4(a). Schematic details of the solar still type 4.

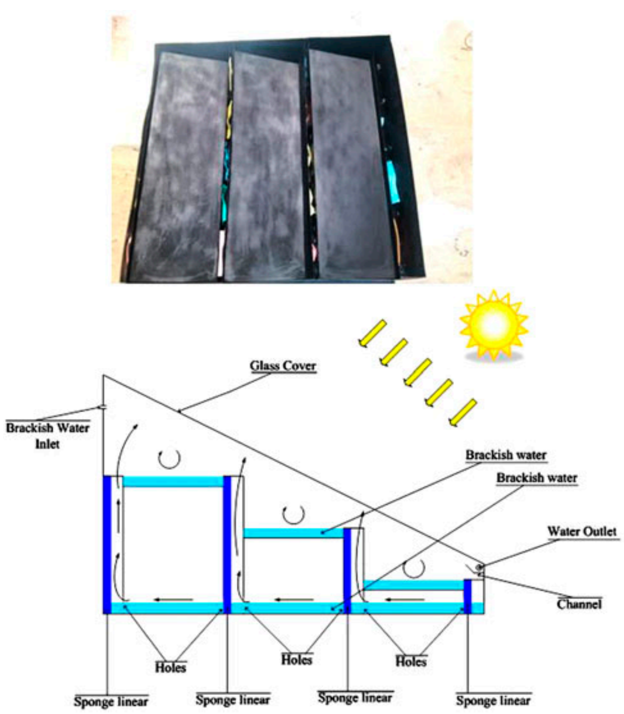


Fig. 4(b). Pictorial and schematic view of the solar still type 4.

radiation incidence) of the plate and to allow water flow through the whole length and width of the surface. The basin has been covered with galvanized iron sheets of 1 mm thickness which was painted black in order to maximize the radiation heat absorption from the solar radiation. It should be noted that all the holes and the sides of the basin are sealed with silicon to prevent the flow of warm air to the outside of the system. A galvanized channel has been designed and placed under the lower side of the glass to collect the condensed water; the water only exists in the basin of this system. The source of water used in the experiments was brackish water. Also, the basin pan for all configurations was insulated completely in order to prevent heat loss from the pan to the environment. Fig. 1(a) shows the schematic details of conventional solar still and Fig. 1(b) shows the pictorial and schematic view of the system.

Based on Fig. 2(a), the second type consists of the conventional model and three additional steps which are exactly similar to each other. As Fig. 2(b) illustrates, only the three steps contained the brackish water.

The configuration of type three (Fig. 3) is exactly the same as type 2 with only difference being the existence of water in both basin and steps. Also, at the bottom of the steps there are some semi-circular holes which create a chimney effect and enable the hot air in the solar still to move and rise through the holes at the bottom of the steps. It results in more water production compared to type 2 due to the combination of the humid air and evaporated water of the steps and results in more water production compared to type 2.

As demonstrated in Figs. 4(a) and 4(b), it can be seen that type 4 has four additional sponge liners with a uniform thickness of 2.5 mm in the gaps between the steps in order to increase the evaporation and water production of the system.

Table 1 shows the major parts of each setup:

The solar radiation on the cover (surface) of the solar still was measured by using an Eppley radiometer Pyranometer which was coupled to a solar radiation meter in a digital HHM1A model with a

Table 1
Consistence parts of each configuration

Types/Parts	Wooden box	Glass cover	Steps	Sponge	Channel
Type 1	✓	✓	–	–	✓
Type 2	✓	✓	✓	–	✓
Type 3	✓	✓	✓	–	✓
Type 4	✓	✓	✓	✓	✓

Table 2
Hourly average radiation and ambient air temperature for different months

Hourly average radiation and ambient air temperature from Sep 2012 to May 2013

	Months September		October		November		March		April		May	
Time	E_e (W/m^2)	T_o (°C)	E_e (W/m^2)	T_o (°C)	E_e (W/m^2)	T_o (°C)	E_e (W/m^2)	T_o (°C)	E_e (W/m^2)	T_o (°C)	E_e (W/m^2)	T_o (°C)
08:00	–	–	–	–	563.5	21.13	485.5	18.9	–	–	–	–
09:00	569	26.45	596.8	25.28	638.1	22.1	574.9	20.48	515.66	25.88	521	25.6
10:00	661.9	27.98	726.2	26.8	754	23.8	685	22.45	634.6	27.03	650.2	26.58
11:00	750	29.08	841.2	28.1	850.1	25.07	790	23.5	733.2	28.15	766.4	28.1
12:00	847.5	30.28	871.4	29.53	827.7	26.6	865.6	24.85	828.4	29.45	867.2	29.8
13:00	883.3	31.28	879.3	30.25	744.5	26.05	828.9	24.33	875.3	30.1	909.9	31.5
14:00	866.7	32.9	836.5	29.08	648.4	25.05	733.5	23.35	830	30.25	873.4	30.68
15:00	795.3	31.38	691.3	27.88	560.4	24.15	620.1	22.33	740.9	29.15	791.1	29.38
16:00	697.6	29.9	604.8	27.23	446	23.33	505.5	20.88	638.5	27.7	664.2	28.5
17:00	590.5	28.45	518.3	26	–	–	–	–	543.1	26.6	533.6	27.13

Note: T_o is the ambient temperature and the E_e is the radiant intensity.

Table 3
The amount of remaining fresh water during different months

	September (17–9) (L/m^2)	October (17–9) (L/m^2)	November (16–8) (L/m^2)	March (16–8) (L/m^2)	April (17–9) (L/m^2)	May (17–9) (L/m^2)
Type 1	0.39	0.17	0.13	0.12	0.28	0.34
Type 2	0.56	0.26	0.16	0.15	0.55	0.58
Type 3	0.65	0.37	0.27	0.26	0.56	0.68
Type 4	0.7	0.47	0.28	0.23	0.65	0.67

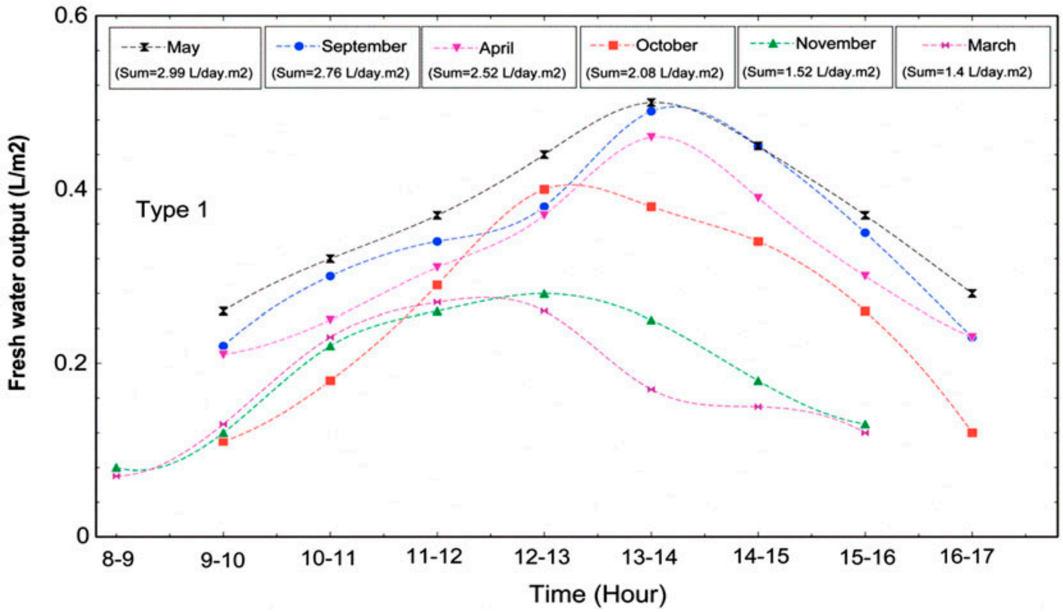


Fig. 5. Water production of Type 1 during different hours and months.

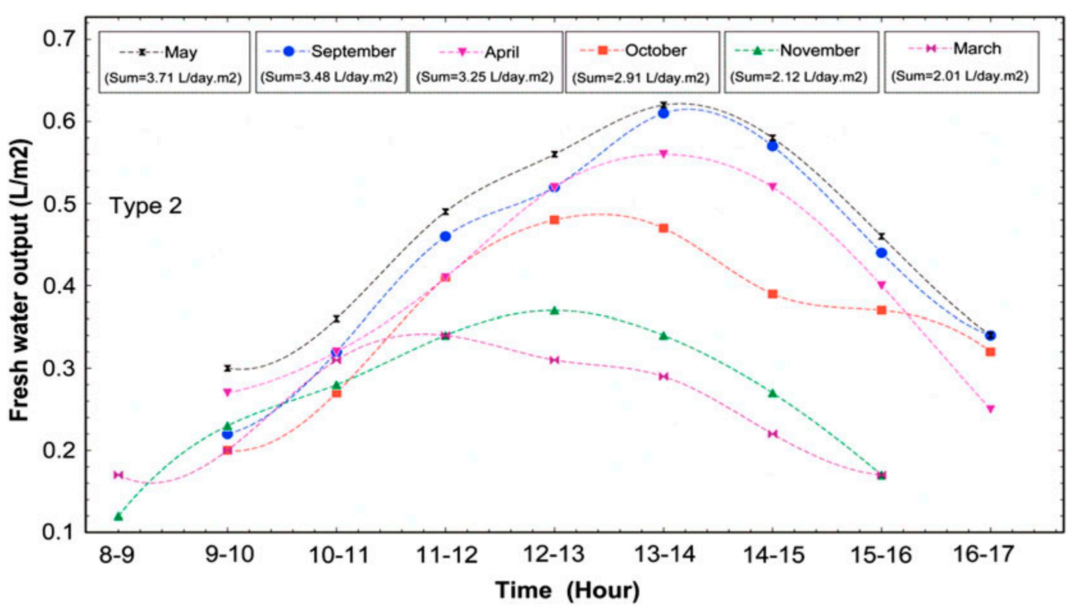


Fig. 6. Water production of Type 2 during different hours and months.

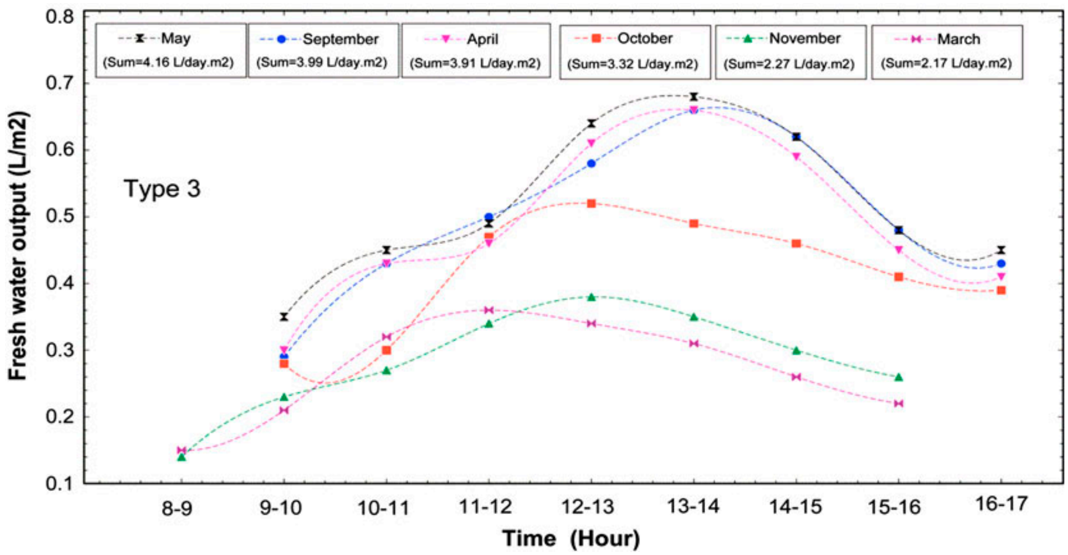


Fig. 7. Water production of Type 3 during different hours and months.

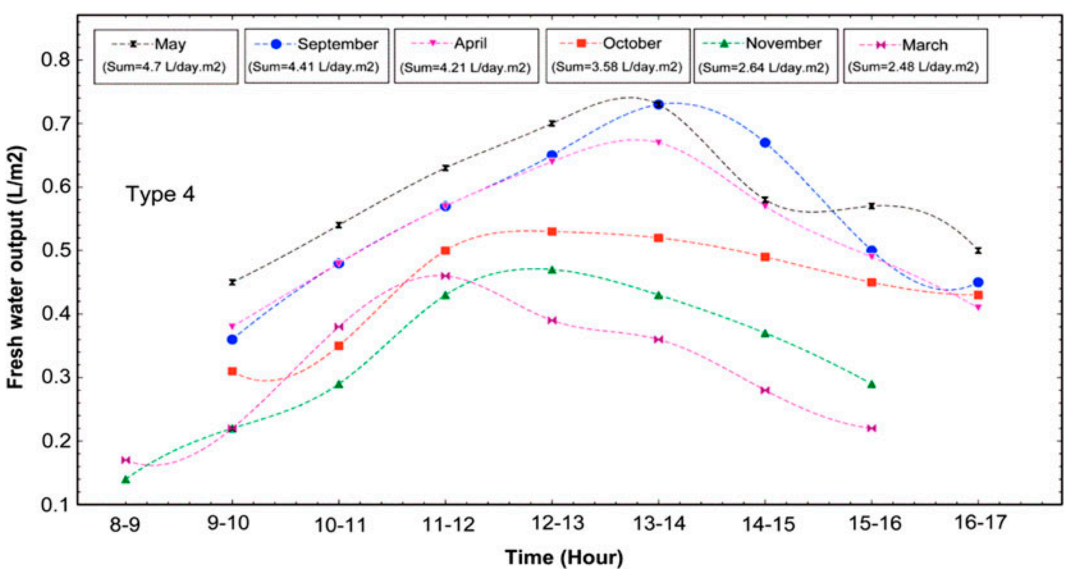


Fig. 8. Water production of Type 4 during different hours and months.

resolution of ±0.5% from 0 to 2,800 W/m^2. Also, the experiment was carried out under the climate condition of Famagusta (35.125˚N and 33.95˚E longitude) which is placed in North Cyprus. This experiment was performed during six months of the year; in November and March, the experiments were performed from 8:00 am to 4:00 pm. daily, while in September, October, April, and May, the experiments were carried out from 9:00 am to 5:00 pm. daily. In this study, the mentioned months were chosen in order to find out the performance of the different solar stills in various times of the year.

3. Result and discussion

Table 2 reports hourly average radiation and ambient air temperature for different months and it is explicit that the solar radiation increases to reach the maximum value at mid-day, then decreases again. Solar radiation was measured on the horizontal

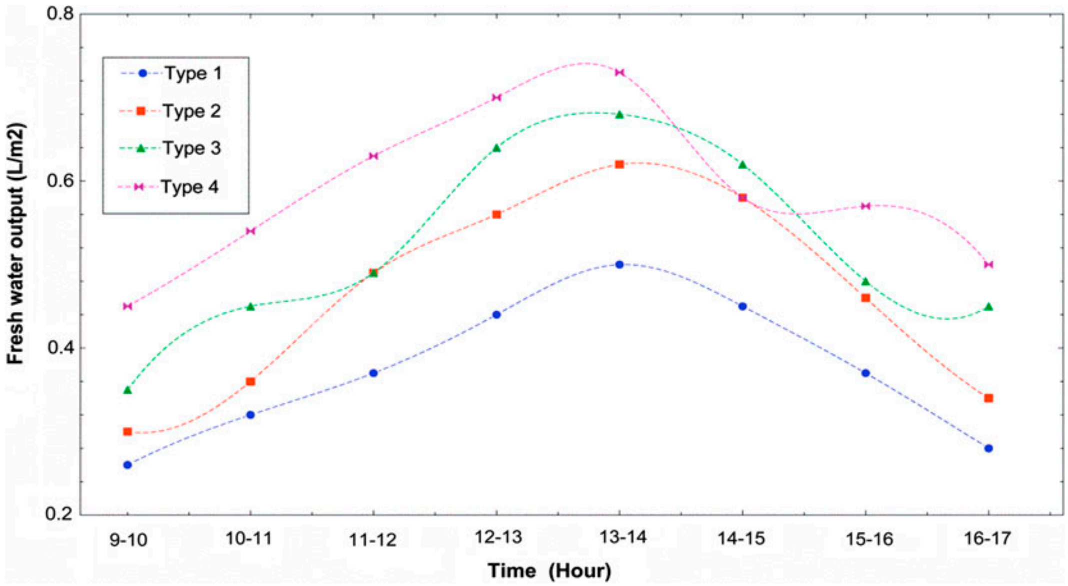


Fig. 9. Water production of different types in May.

surface of the system. The maximum solar radiation and ambient temperature achieved were 909.9 W/m^2 and 31.5°C, respectively.

The quantity of fresh water will be divided into two parts; fresh water output during the experiment hours (main fresh water) and fresh water output collected after experiment hours until the next day of experiment (remaining fresh water). Total fresh water collected will be the summation of the main fresh water and the remaining fresh water output. Actually, the experiment was conducted during 8–17 h for all the months but for some months, the first hour and the last hour outputs were considered as remaining fresh water due to their low amounts.

Table 3 shows the amount of remaining fresh water for different types in different months and Figs. 5–8 show the amount of fresh water during the experiment hours.

Fig. 5 shows the hourly rate of water production during different months. The solar radiation intensity and ambient temperature affect the water production rate. Consequently, the rate of water production varies during each experiment due to the different radiation intensities and ambient temperatures throughout the day. Based on Fig. 5, the water production rate increases until its maximum value around 14:00 pm. Afterwards, the productivity decreases with decrease in solar intensity and ambient temperature.

The maximum and minimum amount of daily water production achieved by type 1 is related to May and March, which are 3.33 and 1.56 L/d m^2, respectively.

The water production of type 2 during different months is presented in Fig. 6. According to Fig. 6, the maximum water production was obtained in May at 14:00 pm. The obtained fresh water is close to the result of September at the same time in the afternoon, due to the similar weather condition of these two months.

In addition, maximum and minimum amounts of daily water production in May and March are: 4.29 and 2.16 L/d m^2, respectively.

According to Fig. 7, similar to type 2, the maximum amount of obtained water is related to May at 14:00 pm. Furthermore, the maximum and minimum amount of daily water production is achieved in May and March, which are 4.84 and 2.43 L/d m^2, respectively.

Fig. 8 indicates the water production of type 4 which has the maximum output fresh water amongst all models. It can be seen in Figs. 5–8 that the fresh water productivity is increasing in each configuration compared to its last one and highest fresh water yielded by the type 4 among all the types which is related to May (5.37 L/d m^2).

Fig. 9 shows the amount of fresh water output in May which has the highest output among the other months for different types. There is an agreement between the different types with regard to the highest amount of fresh water output in mid-day and lowest amount of fresh water output in the first and last hour of the day.

As presented in Figs. 5–9, it can be seen that the water production increases in each type

Table 4
Average measured values of September for all types

Time	Radiation (W/m^2) (Type 1)	T_{amb} (℃) (Type 1)	Water production (L/m^2) (Type 1)	Radiation (W/m^2) (Type 2)	T_{amb} (℃) (Type 2)	Water production (L/m^2) (Type 2)	Radiation (W/m^2) (Type 3)	T_{amb} (℃) (Type 3)	Water production (L/m^2) (Type 3)	Radiation (W/m^2) (Type 4)	T_{amb} (℃) (Type 4)	Water production (L/m^2) (Type 4)
9:00	580.9	26.5	–	552.3	25.6	–	542.8	27.3	–	600	26.4	–
10:00	647.6	27.5	0.22	695.2	27.7	0.22	657.1	28.5	0.29	647.6	28.2	0.36
11:00	771.4	28.3	0.3	790.5	28.9	0.32	742.9	29.6	0.43	695.2	29.5	0.48
12:00	885.7	29.9	0.34	857.1	29.6	0.46	809.5	30.9	0.5	838.1	30.7	0.57
13:00	923.8	31.2	0.38	895.2	30.2	0.52	847.6	32.5	0.58	866.6	31.2	0.65
14:00	857.1	32.6	0.49	790.4	31.3	0.61	914.3	34.5	0.66	904.7	33.2	0.73
15:00	790.4	30.1	0.45	752.4	30.7	0.57	790.5	32.6	0.62	847.6	32.1	0.67
16:00	723.8	28.7	0.35	647.6	29.8	0.44	704.7	31.3	0.48	714.3	29.8	0.5
17:00	600	27.6	0.23	552.4	27.8	0.34	600	29.7	0.43	609.5	28.7	0.45
17:00–9:00	–	–	0.39	–	–	0.56	–	–	0.65	–	–	0.7
Ave	753.4	29.15	–	725.9	29.06	–	734.4	30.76	–	447.06	29.97	–
			Tot = 3.15 L/m^2 d			Tot = 3.15 L/m^2 d			Tot = 3.15 L/m^2 d			Tot = 5.11 L/m^2 d

Table 5
Average measured values of October for all types

Time	Radiation (W/m^2) (Type 1)	T_{amb} (°C) (Type 1)	Water production (L/m^2) (Type 1)	Radiation (W/m^2) (Type 2)	T_{amb} (°C) (Type 2)	Water production (L/m^2) (Type 2)	Radiation (W/m^2) (Type 2)	T_{amb} (°C) (Type 3)	Water production (L/m^2) (Type 3)	Radiation (W/m^2) (Type 4)	T_{amb} (°C) (Type 4)	Water production (L/m^2) (Type 4)
9:00	590.5	25.7	–	609.5	26.3	–	555.5	24.8	–	631.7	24.3	–
10:00	787.3	27.5	0.11	730.1	27.8	0.2	679.3	26.4	0.28	707.9	25.5	0.31
11:00	879.3	28.8	0.18	847.5	28.8	0.27	796.8	28.1	0.3	841.2	26.7	0.35
12:00	892	29.3	0.29	869.8	30.3	0.41	850.7	29.5	0.47	873	29	0.5
13:00	920.5	30.8	0.4	885.6	30.8	0.48	863.4	29.9	0.52	847.5	29.5	0.53
14:00	828.5	28.8	0.38	853.9	29.8	0.47	838.1	28.9	0.49	825.3	28.8	0.52
15:00	584.1	27.8	0.34	752.3	28.8	0.39	736.5	27.6	0.46	692.1	27.3	0.49
16:00	495.2	27.4	0.26	673	28.2	0.37	647.6	26.8	0.41	603.1	26.5	0.45
17:00	460.3	26.1	0.12	555.5	27.2	0.32	571.4	25.5	0.39	485.7	25.2	0.43
17:00–9:00	–	–	0.17	–	–	0.26	–	–	0.37	–	–	0.47
Ave	715.3	28.02	–	753.02	28.66	–	726.58	27.5	–	723.05	26.97	–
			Tot = 2.25 L/m^2 d			Tot = 3.17 L/m^2 d			Tot = 3.69 L/m^2 d			Tot = 4.05 L/m^2 d

Table 6
Average measured values of November for all types

Time	Radiation (W/m^2) (Type 1)	T_{amb} (°C) (Type 1)	Water production (L/m^2) (Type 1)	Radiation (W/m^2) (Type 2)	T_{amb} (°C) (Type 2)	Water production (L/m^2) (Type 2)	Radiation (W/m^2) (Type 3)	T_{amb} (°C) (Type 3)	Water production (L/m^2) (Type 3)	Radiation (W/m^2) (Type 4)	T_{amb} (°C) (Type 4)	Water production (L/m^2) (Type 4)
8:00	590.4	22	–	542.8	21.2	–	536.5	20.8	–	584.1	20.5	–
9:00	641.2	23.4	0.08	609.5	22	0.12	606.3	21	0.14	695.3	22	0.14
10:00	746	25.5	0.12	784.1	23.1	0.23	692.1	23	0.23	793.6	23.6	0.22
11:00	860.3	26.7	0.22	844.4	25.2	0.28	857.1	24.1	0.27	841.2	24.3	0.29
12:00	882.5	27.6	0.26	793.6	26.5	0.34	796.5	26.1	0.34	838	26.2	0.43
13:00	825.3	26.8	0.28	717.5	26.2	0.37	692.4	26.2	0.38	742.8	25	0.47
14:00	720.6	25.8	0.25	698.4	25.3	0.34	520.6	25	0.35	654	24.1	0.43
15:00	654	24.6	0.18	587.3	24.3	0.27	473	24.1	0.3	527	23.6	0.37
16:00	476.1	24.1	0.13	450.7	23.5	0.17	409.5	22.8	0.26	447.5	22.9	0.29
16:00–8:00	–	–	0.13	–	–	0.16	–	–	0.27	–	–	0.28
Ave	710.71	25.16	–	669.81	24.14	–	620.44	23.67	–	680.38	23.57	–
			Tot = 1.65 L/m^2 d			Tot = 2.28 L/m^2 d			Tot = 2.54 L/m^2 d			Tot = 2.92 L/m^2 d

Table 7
Average measured values of March for all types

Time	Radiation (W/m^2) (Type 1)	T_{amb} (°C) (Type 1)	Water production (L/m^2) (Type 1)	Radiation (W/m^2) (Type 2)	T_{amb} (°C) (Type 2)	Water production (L/m^2) (Type 2)	Radiation (W/m^2) (Type 3)	T_{amb} (°C) (Type 3)	Water production (L/m^2) (Type 3)	Radiation (W/m^2) (Type 4)	T_{amb} (°C) (Type 4)	Water production (L/m^2) (Type 4)
8:00	487.3	19.2	–	498.3	18.5	–	497.3	19	–	459.3	18.9	–
9:00	506.8	20.2	0.07	614.7	19.8	0.17	585.4	21	0.15	592.5	20.9	0.17
10:00	622.2	22.5	0.13	725.2	22.1	0.2	697.5	23.1	0.21	694.6	22.1	0.22
11:00	744.9	23.5	0.23	783.4	23.1	0.31	839.2	24.2	0.32	792.5	23.2	0.38
12:00	850.7	25.2	0.27	868.3	24.3	0.34	885.9	25.1	0.36	851.3	24.8	0.46
13:00	812.5	24.7	0.26	850.3	24.1	0.31	840.2	24.4	0.34	812.4	24.1	0.39
14:00	755.5	23.8	0.17	754.6	23.2	0.29	724.9	23.2	0.31	698.7	23.2	0.36
15:00	625.3	22.6	0.15	621.4	22.1	0.22	650.1	22.1	0.26	583.4	22.5	0.28
16:00	506.8	21.5	0.12	488.6	20.2	0.17	548.3	21	0.22	478.3	20.8	0.22
16:00–8:00	–	–	0.16	–	–	0.15	–	–	0.26	–	–	0.23
Ave	656.88	22.57	–	689.42	21.93	–	696.53	22.56	–	662.55	22.27	–
			Tot = 2.80 L/m^2 d			Tot = 3.8 L/m^2 d			Tot = 4.47 L/m^2 d			Tot = 4.86 L/m^2 d

Table 8
Average measured values of April for all types

Time	Radiation (W/m^2) (Type 1)	T_{amb} (°C) (Type 1)	Water production (L/m^2) (Type 1)	Radiation (W/m^2) (Type 2)	T_{amb} (°C) (Type 2)	Water production (L/m^2) (Type 2)	Radiation (W/m^2) (Type 3)	T_{amb} (°C) (Type 3)	Water production (L/m^2) (Type 3)	Radiation (W/m^2) (Type 4)	T_{amb} (°C) (Type 4)	Water production (L/m^2) (Type 4)
8:00	487.3	19.2	–	498.3	18.5	–	497.3	19	–	459.3	18.9	–
9:00	506.8	20.2	0.07	614.7	19.8	0.17	585.4	21	0.15	592.5	20.9	0.17
10:00	622.2	22.5	0.13	725.2	22.1	0.2	697.5	23.1	0.21	694.6	22.1	0.22
11:00	744.9	23.5	0.23	783.4	23.1	0.31	839.2	24.2	0.32	792.5	23.2	0.38
12:00	850.7	25.2	0.27	868.3	24.3	0.34	885.9	25.1	0.36	851.3	24.8	0.46
13:00	812.5	24.7	0.26	850.3	24.1	0.31	840.2	24.4	0.34	812.4	24.1	0.39
14:00	755.5	23.8	0.17	754.6	23.2	0.29	724.9	23.2	0.31	698.7	23.2	0.36
15:00	625.3	22.6	0.15	621.4	22.1	0.22	650.1	22.1	0.26	583.4	22.5	0.28
16:00	506.8	21.5	0.12	488.6	20.2	0.17	548.3	21	0.22	478.3	20.8	0.22
16:00–8:00	–	–	0.16	–	–	0.15	–	–	0.26	–	–	0.23
Ave	656.88	22.57	–	689.42	21.93	–	696.53	22.56	–	662.55	22.27	–
			Tot = 1.56 L/m^2 d			Tot = 2.16 L/m^2 d			Tot = 2.43 L/m^2 d			Tot = 2.71 L/m^2 d

Table 9
Average measured values of May for all types

Time	Radiation (W/m^2) (Type 1)	T_{amb} (°C) (Type 1)	Water production (L/m^2) (Type 1)	Radiation (W/m^2) (Type 2)	T_{amb} (°C) (Type 2)	Water production (L/m^2) (Type 2)	Radiation (W/m^2) (Type 3)	T_{amb} (°C) (Type 3)	Water production (L/m^2) (Type 3)	Radiation (W/m^2) (Type 4)	T_{amb} (°C) (Type 4)	Water production (L/m^2) (Type 4)
8:00	514.3	25.4	–	524.9	25.2	–	508.4	26.5	–	535.7	25.3	–
9:00	581	26.2	0.26	595.3	26.3	0.3	708.2	27.3	0.35	716.3	26.5	0.45
10:00	752.4	27.3	0.32	698.4	27.8	0.36	821.3	28.9	0.45	793.5	28.4	0.54
11:00	885.7	29.4	0.37	840.2	29.8	0.49	879.3	30.3	0.49	863.5	29.7	0.63
12:00	914.3	31.3	0.44	885.7	31.2	0.56	931.4	32.3	0.64	908.2	31.2	0.7
13:00	885.7	30.2	0.5	847.7	31	0.62	868.5	31.2	0.68	891.6	30.1	0.73
14:00	780.9	29.2	0.45	764.8	29.3	0.58	793.2	29.8	0.62	825.4	29.2	0.58
15:00	619	28.3	0.37	592.5	28.6	0.46	725.8	28.7	0.48	719.3	28.3	0.57
16:00	504.7	27.3	0.28	487.6	26.9	0.34	582.3	27.4	0.45	559.8	26.9	0.5
16:00–8:00	–	–	0.34	–	–	0.58	–	–	0.68	–	–	0.67
Ave	715.33	28.28	–	693.01	28.45	–	757.6	29.15	–	757.03	28.4	–
			Tot = 3.33 L/m^2 d			Tot = 4.29 L/m^2 d			Tot = 4.84 L/m^2 d			Tot = 5.37 L/m^2 d

Table 10
Ascending percentage in water production of each type compared with Type 1 in different months

Months	Type 2 (%)	Type 3 (%)	Type 4 (%)
September	28.26	47.31	62.23
October	40.89	64	80
November	38.19	53.94	76.97
March	38.47	55.77	73.72
April	35.72	59.65	73.58
May	28.83	45.35	61.27
Average	41	54.33	71.29

(Type4 > Type 3 > Type 2 > Type 1) and also the effect of daytime on the system output. The results demonstrated that the maximum water output occurred in type 4 in May which has the highest ambient temperature and radiation intensity. As it is expected, in type 4, the sponge liners and steps affect the productivity of the system.

The average hourly radiation, ambient air temperature, and water production rate for each type are presented in detail in tabular format in Tables 4–9 for different months.

It can be concluded that the modified solar stills show better performance in different times of the year especially when the solar intensity is low, compared to conventional model.

Also, the highest achieved fresh water output occurred in May due to the effect of solar radiation intensity and ambient temperature on the fresh water productivity. Table 10 presented the percentage of increased fresh water output for each system in different months compared to the conventional model (Type1) and it can be seen that an increment occurred in each type due to the existence of each added property. The average increased percentage values of type 4, type 3, and type 2 are 71.29, 54.33, and 41%, respectively.

4. Conclusion

Based on the results obtained from the comparisons between the three modified stills and a conventional type, the following can be concluded:

(1) Fresh water productivity increased as a result of radiation intensity and ambient temperature growth.
(2) The water productions of the three modified systems were higher compared to the conventional type.
(3) The maximum fresh water output of the modified solar still type 4 (5.37 L/d m^2) which occurred in May is greater than the other types(Type4 > Type 3 > Type 2 > Type 1).
(4) The increased percentage values in water production of each type compared to the conventional model are 71.29, 54.33, and 41% for the type 4, type 3, and type 2, respectively.
(5) Modified solar stills showed better performance in the times of the year when the solar intensity is low, compared to conventional model.

From the previous conclusions, the results show that the three modifications improved the performance of the conventional solar still system. The maximum amount of water production for all types occurred in May which shows the effect of the radiation intensity and ambient temperature on the output. Also, the existence of steps and sponge liners has great effect on the output of each system.

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