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Experimental study of a solar water treatment device with dome structure cover in winter: performance evaluation and comparative analysis

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ABSTRACT

In this paper, a dome slope single basin solar still for water treatment and desalination is presented. This new solar still device is based on installing a dome slope cover on the walls of the solar still. The main objective of such a still is to concentrate more sunrays at the still's bottom basin, through the increased area of the dome glass cover. Experiments are conducted under the climate conditions in Hangzhou city, China, for testing the operational performance of the dome slope type solar still and the fourfold slope still, so as to make a comparative analysis between them. Assessment of the dome slope still's feasibility is performed based on energy, exergy, exergoeconomic, and enviroeconomic methodologies, as well as energy payback time. Results show that the productivity of the dome slope still is 36% higher than that of the fourfold slope still, and the dome slope solar still enhances the average hourly energy efficiency by 34%. Due to the higher energy and exergy outputs of the dome slope solar still throughout its lifetime, the novel solar still proposed in this study mitigates more CO_2 compared with the fourfold slope still. Overall, incorporation of the dome slope cover with the still is found to be promising in terms of freshwater yield, cost, and energy payback time compared with the conventional one. The dome slope single basin solar still appears to be effective from exergoeconomic and exergoenvironmental parameter analysis.

Key words: dome slope, energy and exergy, exergoeconomic and environmental parameters, solar distillation, water treatment

HIGHLIGHTS

- A novel solar still with dome slope is developed and evaluated.
- Dome slope single basin solar still increases still's productivity by about 36%.
- Dome solar still enhances the average hourly energy efficiency by 34%.
- Dome still mitigates more CO_2 compared with a conventional one based on energy and exergy.
- Dome solar still's enviroeconomic and exergoenvironmental parameters are 53.74$ and 3.25$.

1. INTRODUCTION

With the development of economies and the growth of population in the world, the demand for potable water is increasing gradually. About one fifth of the world's population lives in water-deficient areas (Fang *et al.* 2019). As such, desalination of salty water has been considered to be the best method to solve the issue of shortage of freshwater in arid areas or countries. Solar energy belongs to green sustainable development energy, and the utilization of a sustainable and simple desalination method such as solar desalination is the most suitable for water supply in arid regions (Fang *et al.* 2021a, 2021b). Kabeel & El-Said (2013) review the current solar thermal desalination research activities with system production in the range of 10–150 litres/day for remote or arid regions. Then more efforts are required to further investigate more efficient, economical, and applicable solar thermal energy-driven desalination systems. Modifications of the conventional solar desalination device have been implemented by some researchers, such as Fang *et al.* (2021a, 2021b), who presented a novel small decentralized desalination device for increasing the temperature difference between brackish water and a glass cover, so as to enhance freshwater productivity. This novel solar device is based on installing a lens in front of the single slope solar still, and two

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lenses on both sides of the still, and a reflector over the back side of the solar still. The main objective of such a novel still is to concentrate sunrays at the still's bottom basin, through the refraction function of a Fresnel lens. Furthermore, this novel still makes the reflector transfer its reflected sunrays to the solar still's basin. Overall, the incorporation three lenses and one reflector with the still is found promising in terms of freshwater yield, cost, and energy payback time compared with the conventional one. Mohamed *et al.* (2019a) implemented a thermo-economic investigation to assess the enhancement of solar distillation system (solar still) performance and productivity by inclusion of a natural fine stone (black basalt) as a porous sensible absorber. The results showed that the yield of a solar still for 1, 1.5 and 2 cm stone size was about 0.901, 1.005 and 1.075 L/m^2 with enhancement of about 19.81%, 27.86% and 33.37%, respectively, compared with a conventional solar still. Kabeel *et al.* (2019) presented a novel solar still with internal reflector and composite black gravel–phase change material for thermal heat storage (THS) experimentally. The solar still water yield by utilizing the composite black gravel–phase change material is 3.27 L/m^2 with augmentation by 37.55%. Mohamed *et al.* (2019b) conducted an experimental study to investigate the influence of heat and mass transfer enhancement on solar still thermodynamic performance by using a porous absorber. The experimental results showed that the average Nusselt and Sherwood numbers inside the solar still cavity by using a porous bed with different porosities based on stone particle size were enhanced by about 115% and 51.95% respectively. Also, the exergy efficiency of the solar still with the 1, 1.5 and 2 cm fine stone particle size was enhanced by about 65%, 104.4% and 123% respectively compared with a solar still without stones.

Furthermore, many researchers modified the solar still's inner structures for improving solar–thermal conversion devices. For instance, El-Said *et al.* (2020) proposed a porous packed medium (formed from steel wire mesh screen) to augment the performance of absorbing, transferring and storing the heat in a tubular solar still. And a vibrator was attached to the wire mesh screen to generate forced vibration for destroying the surface tension and boundary layer of the salty water, which augmented the heat transfer and vaporization rate. The results showed that the modified solar still yield was enhanced by 34%. There was a study for a potential application of the adaptive neuro-fuzzy inference system (ANFIS) as a relatively new approach for predicting solar still productivity (SSP). Five variables: relative humidity (RH), solar radiation (SR), feed flow rate (MF), and total dissolved solids of feed (TDSF) and brine (TDSB), were used as input parameters (Mashaly & Alazba 2018). Jadidoleslami & Farahbod (2016) presented the experimental and theoretical analysis of the performance of a closed solar-powered still, which was joined to photovoltaic cells and a vacuum pump and equipped with nano-plate. It was observed that the increase in brackish water temperature increased the average daily production of the solar desalination still considerably. Results showed that the added nano-plate and vacuum pump could efficiently augment the evaporation rate, and the average daily production was increased by 16% compared with the conventional solar still. Jadidoleslami & Farahbod (2016) and Farahbod & Omidvar (2018) evaluated the efficiency of a solar distiller pond as a free concentration unit in a wastewater treatment process. A study of the effects of nanofluid on the productivity of a stepped solar still was conducted (Rashidi *et al.* 2018). The findings indicated that 22% enhancement in the hourly productivity was observed by increasing the nanoparticle concentration from 0% to 5%.

According to the above review, the two motivation points of the present study are: (1) maximize the solar energy storage; (2) enhance the distillated water yield. So, we will present in our research the effect of the inclined glass's shapes on solar still performance with the following targets:

1. Make a comparison between fourfold slope solar still and dome slope solar still, and point out the law of temperature variation inside the stills.
2. Estimate the distilled-water-producing performance.
3. Apply energy, exergy, exergoeconomic, and enviroeconomic parameters to evaluate the effect of dome slope on the solar still.

2. MATERIALS AND METHODS

2.1. Experimental model

Two models of FSS (fourfold slope single basin solar still) and DSS (dome slope single basin solar still) with the same design and construction were tested to assess their performance. Based on the innovative points, this research combines the solar still with multiple slope structure, proposing a new type solar still (DSS) to improve the efficiency of evaporation. Design concept of the FSS: after a four-piece inclined glass cover is installed at the top, the incident sunrays are transmitted through the glass cover with fourfold slope, and the fourfold slope's area is far bigger than that of a conventional solar still, so as to allow more sunrays

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to locate on the blackened liner. Then the steam pressure and temperature in the cavity are greater than on the outside, hence the steam is condensed on the inside surface of the fourfold slope. For this still, four water collection grooves are set on the vertical walls, so that the FSS not only receives sunrays from all sides, but also collects water from all sides to achieve the purpose of promoting freshwater production. For the DSS, the top structure of the solar still is a dome, and it can receive sunrays in the range of 0–360° and make the sunrays accumulate inside the cavity. In addition, the collection grooves are set around the vertical walls, so the condensed water can be collected in the range of 0–360° on the inner surface of the dome slope. The design scheme of the FSS and DSS is in Figure 1. Furthermore, Figure 1 also shows the actual test rig of the FSS and DSS, and the solar stills are tested in the climate conditions of Hangzhou City, China (latitude 30.3°N, longitude 120.2°E).

The basin area of the FSS is 0.5 m $\times$ 0.5 m, and the basin area of the DSS is $\pi \times 0.25$ m $\times$ 0.25 m. The thickness of the glass is 5 mm, fabricated to accommodate the water depth of 5 cm. The bottom of the still is painted black for maximum absorption of heat from the sun (see in Figure 1). The glass cover is fixed on the still's walls and properly sealed to prevent vapor leakage from the still. The produced freshwater is collected in the measuring jar (see in Figure 1). Experiments were carried out from 9:00am to 10:00pm during January 2021. The ambient, basin, vapor, water and glass temperatures, solar intensity, and freshwater yield were measured every one hour. Solar intensity was measured by a TRM-2 Thermal Performance Test System. The temperatures inside the solar still were measured using thermocouples, and then a multi-channel data acquisition device was used for reading the data from thermocouples.

In this experiment, the uncertainty of the test includes solar intensity, temperature, and distilled water production. The results of uncertainty analysis of the measurements are presented in Table 1. The uncertainty analysis is evaluated based on the method proposed by Holman (2006), and the uncertainty is calculated according to Equation (1):

$$W_R = \left[\left(\frac{\partial R}{\partial X_1}W_1\right)^2 + \left(\frac{\partial R}{\partial X_2}W_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial X_n}W_n\right)^2\right]^{1/2} \tag{1}$$

where W_R is the uncertainty in the result, W_1, W_2, W_3, … W_n are the uncertainties in the independent variables.

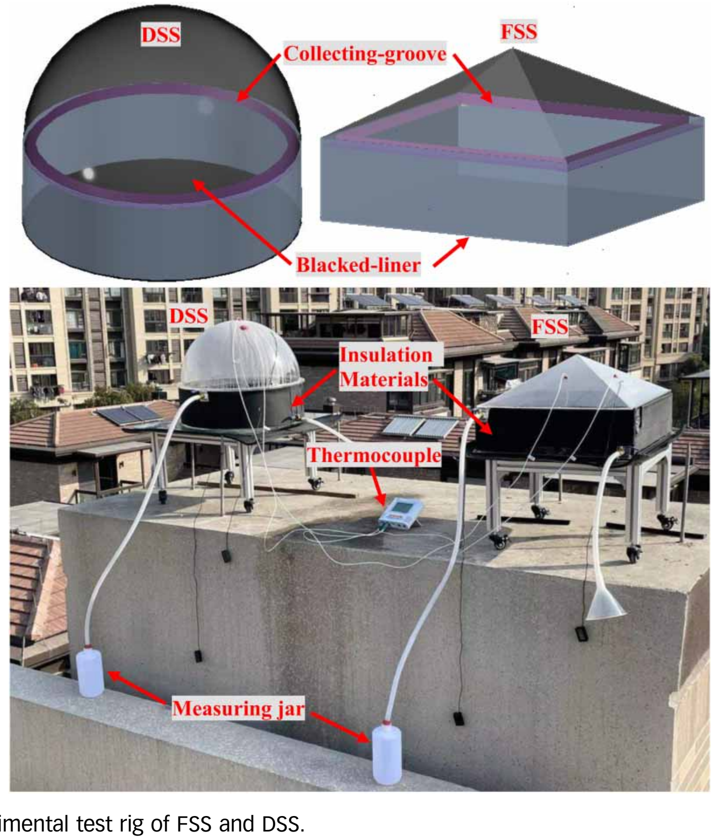

Figure 1 | Photograph of experimental test rig of FSS and DSS.

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Table 1 | Measuring instruments accuracy, range and uncertainties

Instrument	Dimension	Unit	Accuracy	Range	Uncertainty
Thermocouple	Temperature	°C	±0.1 °C	0–200 °C	1.06 °C
Pyranometer	Solar intensity	W/m^2	±20 W/m^2	0–2,000 W/m^2	5.77 W/m^2
Graduated cylinder	Distilled water	ml	±5.0 ml	0–1,000 ml	1.87 ml

2.2. Theoretical method for energy, exergy, exergoeconomic, and enviroeconomic analysis

2.2.1. Energy efficiency

Instantaneous energy efficiency of the solar still can be computed according to Equation (2) (Fang *et al.* 2021a, 2021b):

$$\eta_{th} = \frac{\sum P_d \times H_{fg}}{A_{ex\times} \sum I(t) \times 3{,}600} \tag{2}$$

where H_{fg} is the latent heat of vaporization of water (J/kg), P_d is the gathered freshwater yield (kg), A_{ex} is the exposure area of the still (m^2), and I is the solar intensity (W/m^2).

2.2.2. Exergy efficiency

The exergy efficiency of solar still is defined as the ratio of the exergy output of evaporated water $\dot{E}_{x,evap}$ to the exergy input of solar irradiance $\dot{E}_{x,sun}$, which is determined by Equation (3) (Fang *et al.* 2021a, 2021b):

$$\eta_{ex} = \frac{\dot{E}_{x,evap}}{\dot{E}_{x,sun}} \tag{3}$$

The hourly exergy output of a solar still is given by Equation (4) (Fang *et al.* 2021a, 2021b):

$$\dot{E}_{x,evap} = \frac{H_{fg}\dot{m}_{ew}}{3{,}600}\left[1 - \left(\frac{T_a + 273}{T_w + 273}\right)\right] \tag{4}$$

where T_w is the saline water temperature (°C), T_a is the ambient temperature (°C), and $\dot{m}_{ew}$ is the distilled water (kg/hr).

The exergy input of $\dot{E}_{x,sun}$ to the solar still can be determined by Equation (5) (Fang *et al.* 2021a, 2021b):

$$\dot{E}_{x,sun} = A_{ex} I(t)\left[1 - \frac{4}{3}\left(\frac{T_a + 273}{T_s}\right) + \frac{1}{3}\left(\frac{T_a + 273}{T_s}\right)^4\right] \tag{5}$$

where T_s is the sun's temperature, which is estimated as roughly 5,600 K.

2.2.3. Energy payback time

Energy payback time (EPBT) is determined by the following equations:

$$(EPBT)_{en} = \frac{E_{in}}{E_{en,out}} \tag{6}$$

$$(EPBT)_{ex} = \frac{E_{in}}{E_{ex,out}} \tag{7}$$

where E_{in} is the embodied energy, $E_{en,out}$ is the total annual energy output of the solar still, and $E_{ex,out}$ expresses the total annual exergy output of the solar still.

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2.2.4. Economic analysis

Economic analysis of a desalination device has been given by Fang *et al.* (2021a, 2021b). *CRF* (capital recovery factor), *FAC* (fixed annual cost), *SFF* (sinking fund factor), *ASV* (annual salvage value), *M* (average annual productivity and *AC* (annual cost) are the main calculation parameters used in the cost analysis of a desalination device. *AMC* (annual maintenance operational cost) of a solar still is required for regular filling of brackish water, collecting the distilled water, cleaning the glass cover, removal of salt deposited, and maintenance. As the system life moves on, the maintenance cost for it also increases. Therefore, 10% of net present cost has been considered as maintenance cost. Finally, *CPL* (cost of distilled water per litre) can be calculated by the dividing the annual cost of the system (*AC*) by the annual yield of the solar still (*M*). The above-mentioned calculation parameters can be expressed as:

$$SFF = \frac{i}{(1+i)^n - 1} \tag{8}$$

$$CRF = (SFF) \times (1+i)^n \tag{9}$$

$$FAC = P \times (CRF) \tag{10}$$

$$S = 0.2 \times P \tag{11}$$

$$ASV = (SFF) \times S \tag{12}$$

$$AMC = 0.10 \times FAC \tag{13}$$

$$AC = FAC + AMC - ASV \tag{14}$$

$$CPL = \frac{AC}{M} \tag{15}$$

where P is the present capital cost of a solar still or novel solar still; i is the interest per year, which is always assumed to be 12%; and n is the number of life years, which is assumed to be 20 years in this paper. Prices of raw materials are all according to Hangzhou materials market in this study.

2.2.5. Exergoeconomic analysis

Exergoeconomic approach is an exergy-based economic evaluation for analyzing the performance of systems. This approach targets the achievement of the overall optimal design by properly balancing the economic and exergy aspects. The ratio of exergy output per annum and annual cost has been considered and is given by Equations (16) and (17) (Fang *et al.* 2021a, 2021b):

$$R_{g,en} = \frac{E_{en,out}}{AC} \tag{16}$$

$$R_{g,ex} = \frac{E_{ex,out}}{AC} \tag{17}$$

where $R_{g,en}$ and $R_{g,ex}$ are exergoeconomic parameters.

2.2.6. Environmental analysis

The novel solar still in our research can help to control carbon emissions to the ambient environment. The average quantity of CO_2 emitted into the environment for electricity generation from the power generating plant is 980 g CO_2/kW. However, by considering 40% losses due to distribution and transmission and about 20% losses caused by inefficient domestic instruments, the total CO_2 per kWh thus comes to be about 2 kg. Therefore, the amount of CO_2 mitigated per year in tons from the solar still is set as:

$$\Phi_{en,CO_2} = \frac{E_{en,out} \times n \times 2}{1{,}000} \tag{18}$$

where Φ_{en,CO_2} is the environmental parameter, and $E_{en,out}$ is the energy output from the solar still per annum.

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The amount of CO_2 mitigated per year in tons from solar stills considering the exergy approach can be calculated by Equation (19) (Fang *et al.* 2021a, 2021b):

$$\Phi_{ex,CO_2} = \frac{E_{ex,out} \times n \times 2}{1,000} \tag{19}$$

where Φ_{ex,CO_2} is the exergoenvironmental parameter, and $E_{ex,out}$ is the total exergy output from the solar still per annum.

2.2.7. Enviroeconomic analysis

An enviroeconomic analysis is on the basis of the price of CO_2 emitted over the lifespan of the still and can be estimated as:

$$Z_{en,CO_2} = z_{CO_2} \times \Phi_{en,CO_2} \tag{20}$$

$$Z_{ex,CO_2} = z_{CO_2} \times \Phi_{ex,CO_2} \tag{21}$$

where Z_{en,CO_2} and Z_{ex,CO_2} are the enviroeconomic parameters, and z_{CO_2} is the international carbon price, which is taken to be \$14.50 per ton of CO_2.

3. RESULTS AND DISCUSSION

3.1. Solar still yield and temperature variation

The production in the daytime is expected to be quasi-steady with averaged values over an hour. Figure 2 and Figure 3 show the hourly yield values and temperature values for FSS and DSS. It is clearly shown that the yield of DSS is greater than that of FSS. The peak values of water body temperature, water vapor temperature, and glass cover temperature are 39 °C, 37.2 °C, and 27.5 °C, respectively in DSS. For the FSS, the peak temperature of the water body, water vapor and glass cover can reach 38.6 °C, 36.6 °C, and 28.9 °C, respectively. From the figures, it is found that the cumulative yield values of FSS and DSS are 225 and 240 ml respectively, and the daily yield values are 0.9 and 1.22 L/m^2 respectively. The productivity is enhanced when setting the dome slope on the solar still. The daily yield of DSS is 35.88% higher than that of FSS. This is due to the fact that more energy is absorbed from the sun's radiation and stored by the DSS, so that more distilled water can be produced.

According to the research results of Fang *et al.* (2019), it is possible to predict the water production of the solar still of FSS and DSS in Hangzhou during one year (only considering the sunny days), as shown in Figure 4. The water productivity is higher in summer (May to August) and lower in winter (November to February). Although the lower temperature in winter will lead to greater external heat transfer and condensation, the average sunshine duration in winter is less than

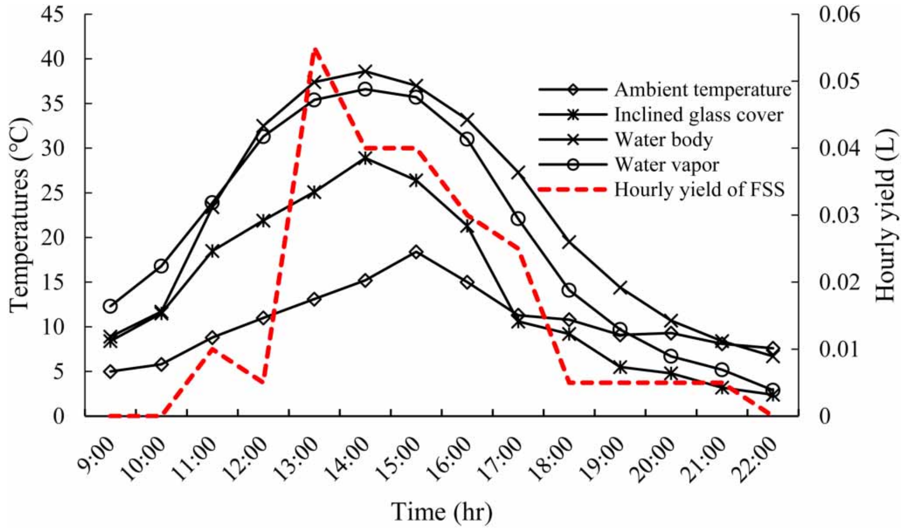

Figure 2 | Hourly yield and temperatures inside the FSS.

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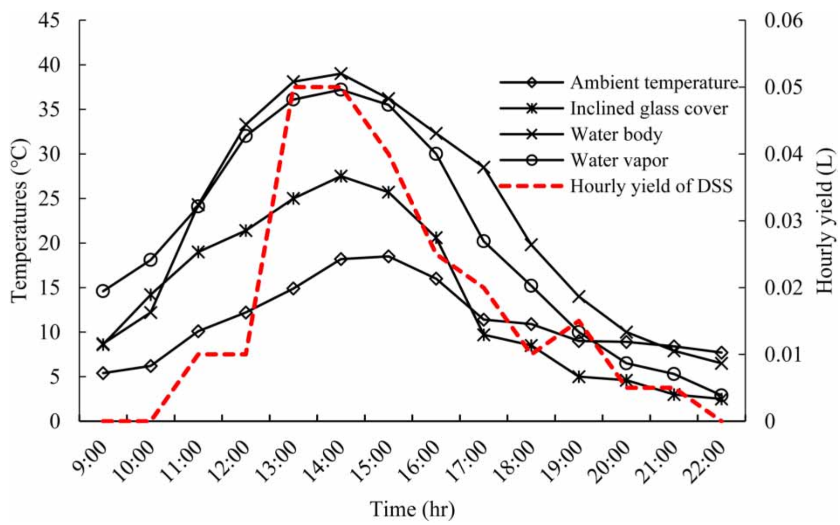

Figure 3 | Hourly yield and temperatures inside the DSS.

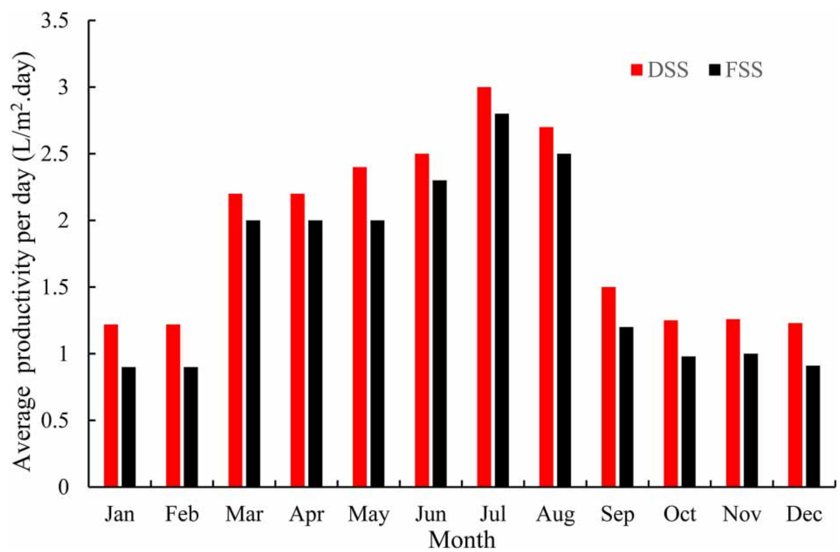

Figure 4 | Seasonal variation of water production of the solar stills.

summer. As such, the lower total solar radiation received by the still in winter causes the speed of evaporation to be slow, and there is better water production in summer.

The annual average daily productivity of the DSS is determined as 1.89 L/m^2, and the productivity of the FSS is 1.62 L/m^2. The stills are expected to operate 330 days in a year in the region of Hangzhou. As such, the annual yield of the DSS is 623.70 L, and the annual yield of the FSS is 535.98 L.

3.2. Energy and exergy efficiencies

Figure 5 illustrates the hourly evolution of instantaneous energy efficiency for the FSS and DSS. It can be observed that the energy efficiency of the DSS escalates progressively as time progresses until attaining its greatest value at approximately 9:00pm. The results indicate that the average values for the FSS and DSS are approximately 12.99% and 17.40% respectively. And the average hourly energy efficiency of the DSS is 34% higher than that of the FSS.

Figure 6 illustrates the hourly variation of the exergy output for the FSS and DSS. Exergy output for the conventional solar still increases gradually to reach its utmost value at 1:00pm and then it declines to reach nearly zero value at the end of

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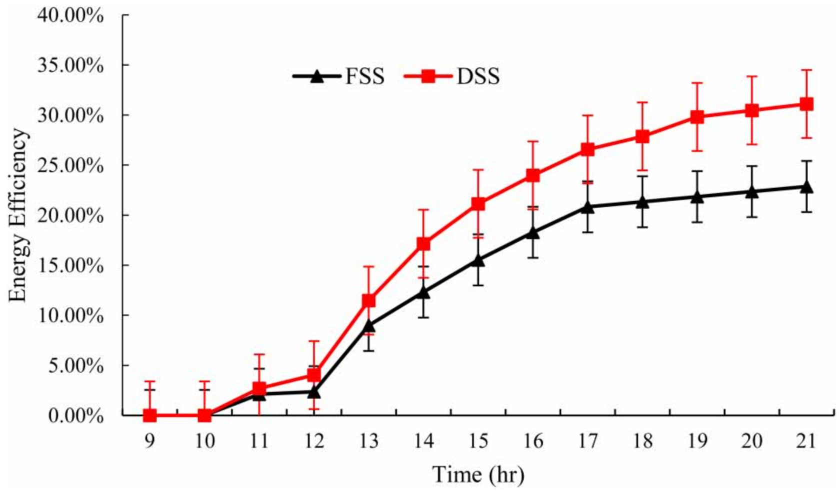

Figure 5 | Variation of the hourly energy efficiency with time for FSS and DSS.

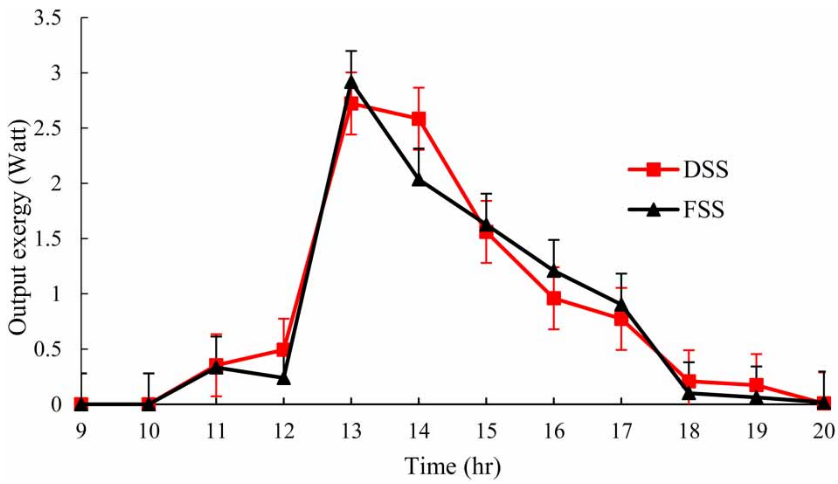

Figure 6 | Hourly variations of the output exergy for FSS and DSS.

daytime. The results show that the maximum values of exergy output are 2.72 W and 2.92 W for the DSS and FSS, respectively. In addition, the total daily exergy output values for the DSS and FSS are 9.84 W and 9.44 W respectively, and the dome slope type glass improved the total daily exergy output by 4.18% with respect to the FSS. This finding can be explained by the increase in brackish water temperatures in the DSS compared with the values in the FSS. The evaporative exergy strictly depends on the water temperature values. As the water temperature rises, the evaporation rate is augmented and thus the evaporative exergy is also enhanced.

Figure 7 shows the variation of the hourly exergy efficiency for the FSS and DSS. As shown in the figure, the hourly exergy efficiency has the same trend as the exergy output. The maximum exergy efficiencies for the FSS and DSS are approximately 2.60% and 1.65% respectively. By comparing the exergy efficiency values in this figure with those of the energy efficiency values in Figure 5, it can be perceived that the energy efficiency values are significantly greater than the corresponding values of exergy efficiency. The reason for this result is that exergy analysis signifies the degradation of energy quality and considers the irreversibility in system processes rather than the concept of conservation of energy. That is to say, the high exergy content of solar insolation from the sun (high temperature 5,600 K) is significantly degraded to the low temperature of evaporated brackish water (low energy quality).

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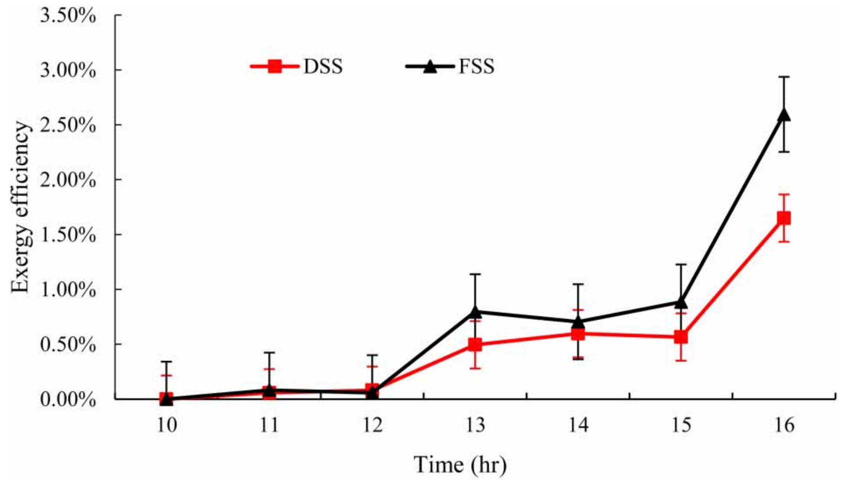

Figure 7 | Variation of the hourly exergy efficiency with time for FSS and DSS.

3.3. Energy payback time evaluation

3.3.1. Embodied energy

In order to make sure that the proposed novel solar still in this research is economically and energetically impressive, the embodied energy for FSS and DSS is quantified and compared. The embodied energy values for the materials and components of the examined solar stills are shown in Table 2. The overall embodied energies for the FSS and DSS are 323.25 kWh and 313.61 kWh, respectively. The embodied energy of the DSS is decreased by 3.07%, compared with the FSS.

3.3.2. Energy payback time

Evaluation the energy payback time (EPBT) for an energy system is necessary to validate its sustainability. Energy payback time (EPBT) on the basis of energy and exergy methodologies for all solar stills is shown in Table 3. The EPBT values for the FSS and DSS are 70.66 and 62.95 months, respectively on the basis of energy approach, whereas the corresponding values on the basis of exergy approach are 1,140.86 and 1,042.07 months, respectively. The results show that the EPBT of the FSS is higher than that of the DSS on the basis of energy approach and exergy approach.

3.4. Economic analysis evaluation

In this paper, the estimation of the cost per litre has been established for each solar still. *P* is the present capital cost of solar still or novel solar still, *i* is the interest per year, which is always assumed to be 12%, and *n* is the number of life years, which is assumed to be 20 years in this paper. Prices of raw materials are all according to Hangzhou materials market. The annual yield of the DSS is 623.70 kg, and the annual yield of the FSS is 535.98 kg. The stills are expected to operate 330 days in a year in the region of Hangzhou. The total cost of the FSS is 1,200 RMB (1 US$ = 7.08 RMB), and the total cost of the

Table 2 | Embodied energy calculations for solar stills

	Embodied energy			
Components	**MJ**	**kWh**	**FSS**	**DSS**
Basin	216	60	60	60
Fourfold slope cover	432	120	120	
Dome slope cover	405	112.5		112.5
Solar still walls of FSS	407.7	113.25	113.25	
Solar still walls of DSS	400	111.11		111.11
Basin coating	108	30	30	30
Total embodied energy (kWh)			323.25	313.61

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Table 3 | Energy payback time (EPBT) for solar stills

Parameters	FSS	DSS
Yield per month (kg)	6.75	7.35
Embodied energy (kWh)	323.25	313.61
Enout per month (kWh)	4.58	4.98
Exout per month (kWh)	0.28	0.30
EPBTen (months)	70.66	62.95
EPBTex (months)	1,140.86	1,042.07

DSS is 1,000 RMB. As shown in Table 4, the cost of distilled water for the FSS is 0.32 RMB/kg, and the cost of distilled water for the DSS is 0.23 RMB/kg. This analysis clearly shows that the cost of distilled water for the DSS is lower than that for the FSS. That is, the DSS can gather more sunrays and photo-thermal heat at the bottom of the evaporation chamber through the dome structure. Such an innovative solar still is not only cheap to manufacture, but also has significantly higher evaporation efficiency than that of a conventional solar still.

3.5. Exergoeconomic evaluation

Exergoeconomic analysis considers economic aspects in the evaluation of these two solar stills, so as to ensure the effectiveness of assessment. Results of the exergoeconomic evaluation for FSS and DSS are shown in Table 5. It can be inferred that the exergoeconomic parameter value for the DSS is greater than the corresponding value for the FSS. It can be inferred from Table 5 that the inclusion of the dome slope is attractive from the exergoeconomic evaluation.

In this research, the environmental benefits in terms of the carbon footprint for the FSS and DSS are assessed. The environmental and enviroeconomic evaluations based on energy and exergy methodologies are illustrated in Table 6. The findings reveal that the FSS and the DSS mitigated 3.404 and 3.706 tons CO_2 (environmental parameter), respectively. Then, the corresponding values on the basis of the exergoenvironmental parameter are 0.211 and 0.224 tons CO_2, respectively. It can be observed that the DSS proposed in this study mitigated more CO_2 compared with the FSS. The reason for this outcome is the higher energy and exergy outputs of the DSS throughout its lifetime. Therefore, it can be concluded that the solar still system with dome slope is environmentally feasible. Table 6 also shows that the enviroeconomic parameters for the FSS and DSS are 49.355 $ and 53.742 $, respectively, while, the corresponding values based on the exergoenvironmental parameter are 3.057 $ and 3.248 $, respectively.

4. CONCLUSIONS

Compared with the conventional still, the new still with dome slope proposed by this paper can effectively absorb a greater proportion of solar heat and raise water productivity. The main conclusions are shown as follows.

Table 4 | Cost comparison between conventional solar still and novel solar still

	P (RMB)	*SFF*	*CRF*	*FAC* (RMB)	*S* (RMB)	*ASV* (RMB)	*AMC* (RMB)	*AC* (RMB)	*M* (kg)	*CPL* (RMB/kg)
FSS	1,200	0.014	0.134	160.8	240	3.36	16.08	173.52	535.98	0.32
DSS	1,000	0.014	0.134	134	200	2.80	13.40	144.60	623.70	0.23

Table 5 | Exergoeconomic parameters for the conventional solar still and novel solar still

	Years	*i* (%)	*AC* (RMB)	Annual Enout (kWh)	Annual Exout (kWh)	Rg,en (kWh/RMB)	Rg,ex (kWh/RMB)
FSS	20	12	173.52	85.095	5.27	0.49	0.03
DSS	20	12	144.60	92.659	5.60	0.64	0.04

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Table 6 | Environmental and enviroeconomic parameters for FSS and DSS

Parameters	FSS	DSS
Lifetime (years)	20	20
Embodied energy (kWh)	323.25	313.61
Annual Enout (kWh)	85.095	92.659
Annual Exout (kWh)	5.27	5.60
Enout (kWh) for lifetime	1,701.90	1,853.18
Exout (kWh) for lifetime	105.40	112.00
Environmental parameter (tons CO_2)	3.404	3.706
Enviroeconomic parameter ($)	49.355	53.742
Exergoenvironmental parameter (tons CO_2)	0.211	0.224
Exergoenviroeconomic parameter ($)	3.057	3.248

1. The overall accumulative freshwater yield for the dome slope single basin solar still is nearly 1.22 L/m^2 in winter time, leading to an improvement of 36%, compared with the fourfold slope single basin solar still. The experimental results showed that the distilled water productivities peaked between 1:00pm and 2:00pm.
2. The dome slope single basin solar still enhanced the average hourly energy efficiency by 34%, compared with the fourfold slope single basin solar still. The EPBT values for the dome slope still and the fourfold slope still are 62.95 and 70.66 months, respectively, on the basis of energy approach.
3. The dome slope still and the fourfold slope still mitigated 3.71 tons and 3.40 tons CO_2 respectively, based on the environmental parameter. Then, the corresponding values based on the exergoenvironmental parameter are 0.224 tons and 0.211 tons CO_2, respectively. Due to the higher energy and exergy outputs of the dome slope solar still throughout its lifetime, it mitigated more CO_2 compared with the fourfold slope solar still.
4. After the cost comparison between the dome slope solar still and fourfold slope solar still, it is shown that the cost of distilled water for the fourfold slope type still is 0.32 RMB/kg, and the cost of distilled water for the dome slope type still is 0.23 RMB/kg. This analysis clearly shows that the cost of distilled water for the dome slope still is lower than that for the fourfold slope still. Then, the enviroeconomic parameters for the fourfold slope still and dome slope still are 49.355 $ (349.433 RMB) and 53.742 $ (380.493 RMB), respectively, while the corresponding values based on the exergoenvironmental parameter are 3.057 $ (21.644 RMB) and 3.248 $ (22.996 RMB), respectively. To sum, the dome slope single basin solar still appears to be effective from exergoeconomic and exergoenvironmental parameter analysis.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

El-Said, E. M. S., Elshamy, S. M. & Kabeel, A. E. 2020 Performance enhancement of a tubular solar still by utilizing wire mesh packing under harmonic motion. *Desalination* **474**, 114165.

Fang, S., Tu, W., Mu, L., Sun, Z., Hu, Q. & Yang, Y. 2019 Saline alkali water desalination project in Southern Xinjiang of China: a review of desalination planning, desalination schemes and economic analysis. *Renewable and Sustainable Energy Reviews* **113**, 109268.

Fang, S., Mu, L. & Tu, W. 2021a Application design and assessment of a novel small-decentralized solar distillation device based on energy, exergy, exergoeconomic, and enviroeconomic parameters. *Renewable Energy* **164**, 1350–1363.

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Corrected Proof

Fang, S., Mu, L. & Tu, W. 2021b Heat and mass transfer analysis in a solar water recovery device: experimental and theoretical distillate output study. *Desalination* **500**, 114881.

Farahbod, F. & Omidvar, M. 2018 Experimental evaluation of collection, thermal, and conductivity effciency of a solar distiller pond as a free concentration unit in wastewater treatment process. *Energy Science & Engineering* **6** (5), 584–594.

Holman, J. P. 2006 *Experimental Methods for Engineers*. McGraw-Hill, New York, USA.

Jadidoleslami, M. & Farahbod, F. 2016 Experimental and mathematical evaluation of solar powered still equipped by nano plate as the principle stage of zero discharge desalination process. *Advances in Energy Research* **4** (2), 147–161.

Kabeel, A. E. & El-Said, E. M. S. 2013 Technological aspects of advancement in low capacity solar thermal desalination units. *International Journal of Sustainable Energy* **32** (5), 315–332.

Kabeel, A. E., Abdelaziz, G. B. & El-Said, E. M. S. 2019 Experimental investigation of a solar still with composite material heat storage: energy, exergy and economic analysis. *Journal of Cleaner Production* **231**, 21–34.

Mashaly, A. F. & Alazba, A. A. 2018 ANFIS modeling and sensitivity analysis for estimating solar still productivity using measured operational and meteorological parameters. *Water Supply* **18** (4), 1437–1448.

Mohamed, A. F., Hegazi, A. A., Sultan, G. I. & El-Said, E. M. S. 2019a Augmented heat and mass transfer effect on performance of a solar still using porous absorber: experimental investigation and exergetic analysis. *Applied Thermal Engineering* **150**, 1206–1215.

Mohamed, A. F., Hegazi, A. A., Sultan, G. I. & El-Said, E. M. S. 2019b Enhancement of a solar still performance by inclusion the basalt stones as a porous sensible absorber: experimental study and thermo-economic analysis. *Solar Energy Materials and Solar Cells* **200**, 109958.

Rashidi, S., Bovand, M., Rahbar, N. & Esfahani, J. A. 2018 Steps optimization and productivity enhancement in a nanofluid cascade solar still. *Renewable Energy* **118**, 536–545.

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