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To cite this article: A H Omar *et al* 2025 *J. Phys.: Conf. Ser.* **3051** 012010

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Leveraging thermoelectric coolers for solar distillation: A review of design and distillate yield.

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Abstract. Solar desalination techniques were developed to cater to the exponentially growing need for fresh water. The main limitation of solar desalination, suboptimal distillate yield, led researchers to explore and propose multiple solutions including leveraging Thermoelectric coolers (TECs). Thermoelectric coolers induce a cooling and a heating effect that can boost condensation and evaporation rates respectively in solar distillers. This paper examines the existing body of knowledge on the integration of TECs and categorized use cases into three main categories, heating side only, cooling side only and combined integration of heating and cooling sides. For each of the use cases, the design, experimental procedure, distillate yield and Localized Cost of Water (LCOW) are explored. Depending on the environmental and design conditions, it was shown that the daily productivity of TEC-equipped solar stills could range from 1.3 to 8.14 liters per square meter while the LCOW ranged between 0.013 and 0.291\$.

Keywords: Solar Still, TEC, Desalination, Active Distillation, Solar Energy, Thin Film Cooling, Distillate.

1. Introduction

Earth is covered with around 1.38 bn km³ of water, 97.5% of such water volume has a high salt content while the other 2.5% is Fresh water. The consumption of fresh water multiplied 7 folds from 671.3 bn m³ to 3.99 tn m³ from the year 1900 to 2014 [1]. Consequently, freshwater scarcity indices were developed to predict the impacts of the ever-increasing consumption. The indices predict that by 2030 2.4-3.4 bn people will be experiencing water scarcity in contrast with 3-4.4 bn people by 2050 [2].

Multiple solutions were proposed and trailed to help improve the freshwater deficiency, including desalination. Desalination aims to remove the TDS (total amount of dissolved solids) or reduce it to safe levels depending on the application. Desalination has garnered research and industrial attention; the combined capacity of commercial desalination plants has almost multiplied 60-fold since 1960. Furthermore, the total daily productivity of 95.7 mn m³ has been made possible through 15,906 operational desalination plants [3]. Desalination is mainly divided into categories, thermal techniques that rely on evaporation and subsequent condensation and membrane-based techniques that rely on a membrane to provide filtration of TDS.



Solar distillation is a sub-branch of thermal techniques, it requires no energy input other than incoming radiation that is transmitted through a typically sloped transparent cover. Solar stills were rumored to be used by Aristotle in the 3rd century B.C. in a basic way to desalinate sea water despite the absence of physical model documentation. Almost 1800 years later, Arab alchemists utilized solar distillation for the purpose of obtaining distilled water to be used in their experiments. Two centuries later, European scientist Nicole Ghezzi utilized lenses in a developed form of solar distillation [4]. It wasn't until the year 1872 that solar distillation was first utilized commercially for the large-scale production of water in Las Salinas Chile.

Solar Still Components and operational principles are portrayed in Figure 1 [5], the transmitted radiation from the sloped surface impinges upon a dark colored/coated basin that absorbs the radiation and experiences an increase in temperature. Water is then evaporated from the basin and subsequently condensed on the sloped surface, only to be collected as freshwater distillate.

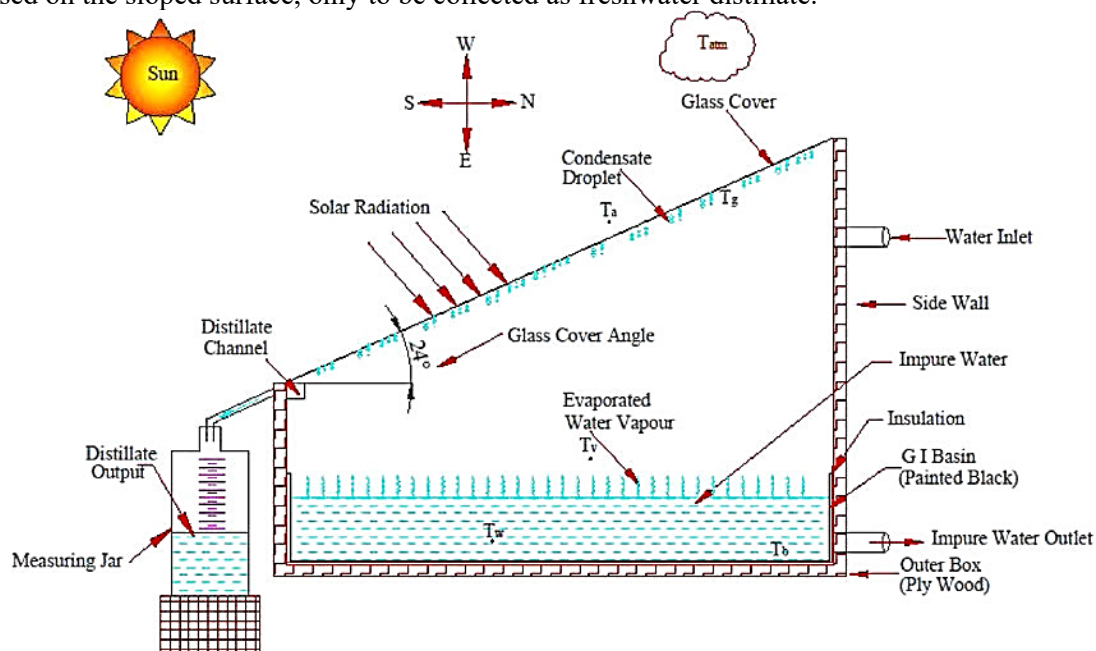


Figure 1 Solar Still Operational Diagram [5].

Solar stills provide multiple advantages, including reliance only on the impending solar radiation which offers flexibility of deployment in any location. Moreover, solar stills provide independence from water grids, enabling the decentralization of water resources. Additionally, due to the simplicity of building components, deployment in lower-income countries and disaster-struck zones is made possible. Despite all these advantages, the main drawback is the limited water production. Solar distillers can produce only up to 2-5 liters per meter squared per day [6]. Consequently, the cost per cubic meter of solar distilled water ranges from 31 to 230 \$ [7].

Extensive studies have targeted the identification of the parameters influencing the productivity of solar distillers with the aim of improving distillate yield. Such parameters have been grouped into 2 main categories, namely Design factors and Environmental factors. Design factors are related to the physical construction elements of the solar still such as basin material [8], cover material [9], cover inclination [10], thickness [10] and geometry [11]. Conversely, environmental can be broken down into radiation [10], temperature, wind speed [12] and humidity [13].

In addition to the studies, multiple modifications have been introduced into solar stills. These modifications can be grouped into active and passive modifications. Active modifications typically require an external energy source while passive modifications require don't rely on external energy. Passive modifications include the addition of dyes [14], wicks [15] and reflectors [16] into the solar still. On the other hand, active modifications include integration with solar collectors [17], integration with

PV modules [18]. integration with heat pipes [19] and finally integration with Thermoelectric Coolers otherwise known as TEC [20].

Thermoelectric modules are heat transmitting devices that produce a temperature difference between both sides when experiencing an electrical potential difference. The modules are based around multiple semiconductor junctions made of P and N type elements. Junctions are encased by a copper plate to enhance heat conduction properties followed by a ceramic casing as depicted in Figure 2 [21].

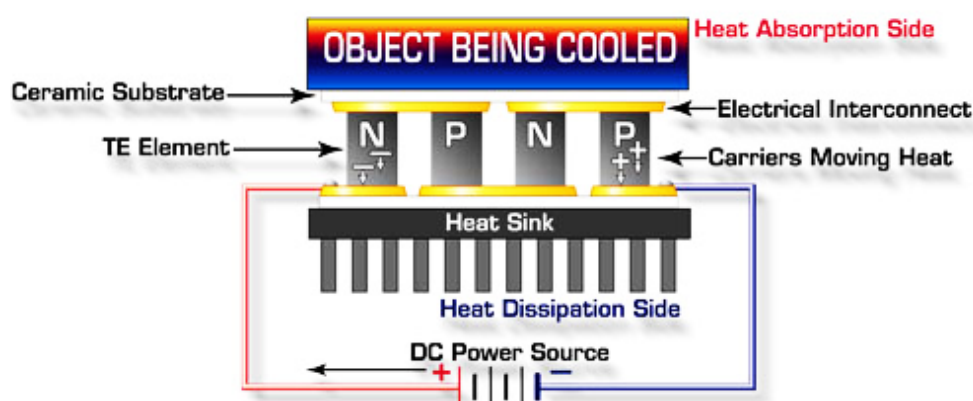


Figure 2 TEC operational principle [21].

The thermoelectric effect is made up of three smaller effects, discovered in 1821, 1835 and 1851 by Thomas Seebeck, John Peltier and William Thomson respectively. The Seebeck effect occurs when a dissimilar metal joint experiences a difference in temperature resulting in an electrical potential difference. On the other hand, the Peltier effect suggests a relationship between the electrical potential difference and relocation of heat energy across the P N semi-conductor junction based on the polarity. Finally, the Thomson effect relates the relocated heating energy from the Peltier effect to the magnitude of the applied electrical potential difference [22].

Based on the previewed literature, there are three main ways to integrate TEC modules into the solar still, either through hot side integration only, cold side integration only, hot and cold side integration of TEC modules. The upcoming sections will be divided based on the methods of TEC module integration.

2. Hot Side Only Integration of TEC Module

In this section, the main method of integrating a TEC module into a solar still is through the adhesion of the hot side of the TEC module towards the basin while attaching a heat dissipation mechanism onto the cold side.

2.1. Direction Adhesion of TEC to Basin

A detailed experimental investigation of TEC assisted solar stills in addition to an analytic, economic, and environmental analysis was conducted[23]. Four solar stills were fabricated for the study, two of them utilizing the heat from the TEC module and solar radiation as depicted in Figure 3 and two relying solely on solar radiation. The solar stills were tested at 1200m and 4000m elevation in Tehran and Tochal mountain respectively. An analytical model was additionally developed based on heat transfer correlations to forecast the yield of the solar still.

Based on the experimental data, TEC integrated solar stills offer an annual productivity of 916, 2971, 717, 2123 l/m² which correspond to an improvement of 225% and 195% in Tehran and Tochal Mountain respectively when comparing active and passive stills. The LCOW for TEC integrated Tehran and Tochal distillers compared with passive ones is 0.0174-0.0243 \$/l compared to 0.01-0.0128 \$/l at 20 years lifetime and 12% interest rate.

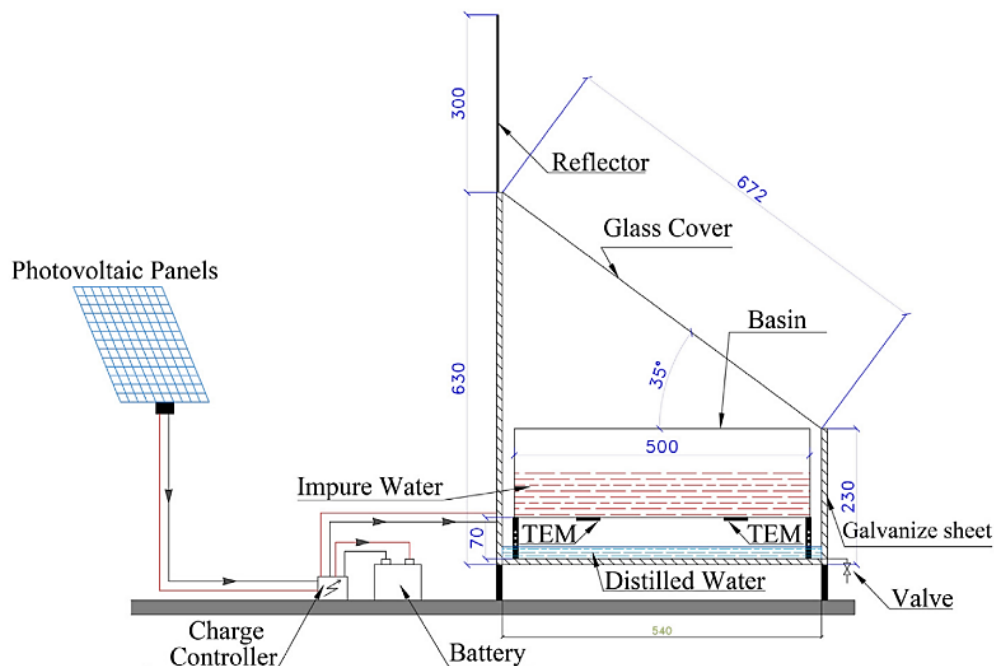


Figure 3 Experimental Setup of Single Slope TEC-Equipped Solar Still [23].

In a similar method of integrating the TEC module into the solar still while opting for a different frame geometry, A two-story Plexi-glass doubled sloped TEC assisted solar still was developed and further studied economically [24]. The solar still depicted in Figure 4 is divided into an evaporation-condensation partition and a heat absorption partition. The upper vapor-tight partition houses a black plexiglass basin that absorbs solar radiation. The hot sides of four 12708 thermoelectric modules are attached to an aluminum plate that contacts the bottom of the basin. Conversely, Cold sides of the modules are attached to heat sinks which experience an air stream created by four circulation fans.



Figure 4 TEC Assisted Double-Slope Double-Story Solar Still [24].

The annual water production for day and night was found to be 912 and 547 l/m². Furthermore, The LCOW was found to be 0.1422 and 0.237 \$ for day and night operation modes.

Aside from integrating the heating side of the TEC, A TEC-augmented solar still was used to generate electricity by reversing the mode of operation during daytime to charge a battery [25]. The experimental apparatus depicted in Figure 5 is made up of a wooden housing, a stainless steel basin and a glass cover. The hot side of a single 12706 TEC was adhered to the bottom of the basin while the cold side setup wasn't specified. The TEC was operated as a generator from 09:00 to 16:00 and switched to heating mode from 16:00 to 18:00.

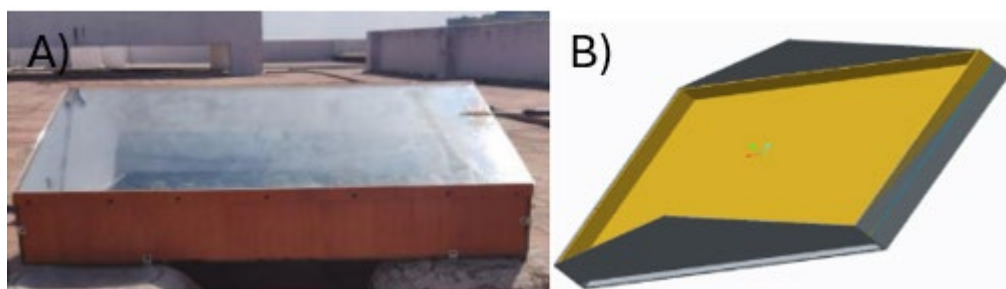


Figure 5 a) Battery Equipped TEC Assisted Solar Still b) 3D Model of Battery Equipped TEC assisted Solar Still [25].

The results demonstrate that the TEC module was able to generate around 3-5V without specifying the generated current. It was also demonstrated that the integration of a TEC module increased productivity by 11 and 8% based on a basin height of 1 and 0.5CM. The annual production was calculated to be 1460 l/m² based on the estimate of 365 operational days.

3. Cold Side Only Integration of TEC Module

3.1. Direct Adhesion of TEC Setup to Cover or Frame

In this section, the main method of integrating a TEC module into a solar still is through the adhesion of the cold side of the TEC module towards the frame or cover material while attaching a heat dissipation mechanism onto the hot side. A novel portable solar still equipped with a thermoelectric cooler and an external parabolic trough collector (PTC) was designed, manufactured and tested [26]. The solar still depicted in Figure 6 is made of a Plexi glass housing and is divided into condensation and evaporation regions. Water is circulated from the evaporation to the PTC to be further heated before being sprinkled towards the TEC package in a semi-misted form using a DC pump. The TEC setup consists of heat sinks on both sides of the 12706 TEC module and an extra heat dissipation fan on the hot side.

Additionally, a fan circulates the humid air through the plastic duct located right below the top to improve condensation rates. The annual productivity of the solar was calculated to be 438 l/m² based on the estimation of 365 days of operation. Additionally, the LCOW was found to be 0.13\$/l when using an interest rate of 12%.

In another study by the authors, A dual condensation zone Plexi glass solar still, equipped with a TEC module and heat pipes heat exchanger was also designed, manufactured and tested as depicted in Figure 7 [27]. The first zone utilizes natural convection on the sloped glass surface to achieve condensation while the second utilizes the cold side of a 12708 TEC module. The hot side of the TEC module is coupled with a commercial CPU cooling heat pipe to enhance the cooling performance of the module.

The average Annual productivity and LCOW were calculated to be 182 l/m² and 0.18 \$/l based on the estimate of 365 operational days. It should be noted that the daily productivity is significantly low even when compared to the average productivity of passive solar stills.

In a continuation of the authors' exploration of studying the productivity increase resulting from adding the cold side of TEC, a TEC-enabled Plexi glass solar still was designed and tested [28]. The experimental apparatus depicted in Figure 8 shows the cold side of three 12708 TEC modules attached to an aluminum plate to serve as a condensing region in addition to the sloped surface. The solar still contains two water collection compartments to compare the productivities of the different condensing regions.

The daily productivity was found to be 1.3-3 l/m² depending on solar radiation. Moreover, Condensate at the TEC region was found to be 3.2 times larger than sloped surface condensate while being 2.8 times smaller in area. Finally, LCOW wasn't mentioned in the paper.

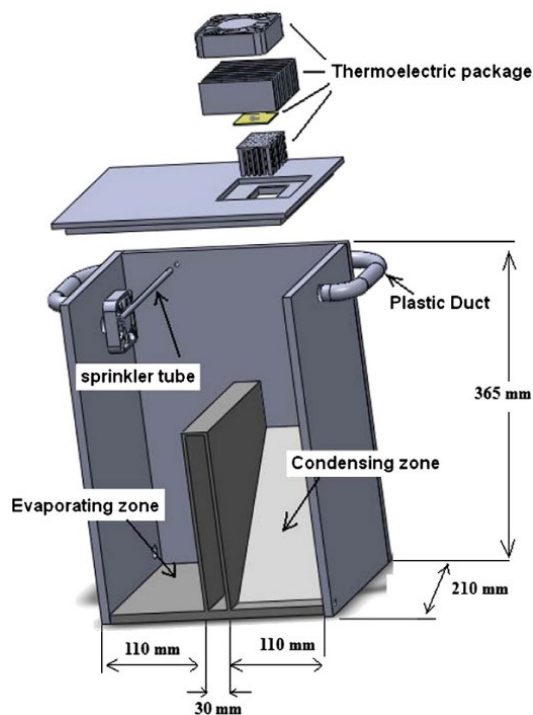


Figure 6 Novel TEC & PTC Assisted Solar Still [26].

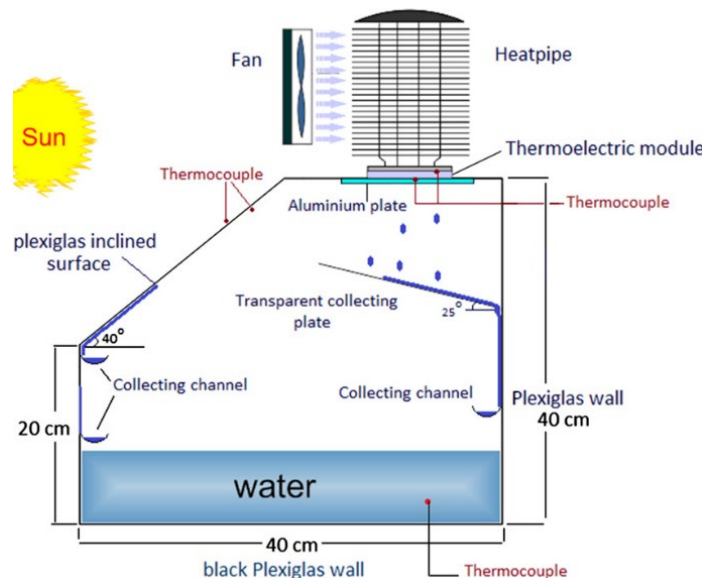


Figure 7 Heat Pipe Equipped TEC Assisted Solar Still [27]



Figure 8 Double Condensing Region TEC-Assisted Solar Still [28].

On the other hand, the productivity for a multi-sloped still that incorporated cold side integration of a TEC module in addition to a magnetic stirrer was investigated [29]. The productivity was compared against a double-sloped solar still which was used as a baseline. Figure (9, a) highlights the doubled solar still (base still) while Figure (9, b) highlights the modified solar still. The base still relies on solar insolation only to produce water while for the modified solar still, the cooling side of the TEC assembly is directly attached to the glass to decrease its temperature, thus increasing condensation rates. A multi-speed magnetic stirrer is attached to the bottom of the novel still's basin, thus boosting evaporation rates.



Figure 9
(a) Double-Sloped Solar Still
(b) Multi-Sloped Modified Solar Still
[29]

The authors ran 6 different scenarios over 12 days, investigating the effect of magnetic stirrer speeds, the effect of number of active TEC modules and the combined effect of magnetic stirrers and TEC modules. Compared to the base solar still, TEC modifications alone were found to boost productivity by 65 to 185% depending on the number of active modules. The annual productivity of the modified and base solar stills was found to be 565 and 282 l/m² while the LCOW was found to be 0.081 and 0.072 \$/l respectively.

3.2. Integration of TEC Setup into Cooling Channel/External Condenser

In this section, the TEC is integrated with a cooling channel instead of being directly installed into either the glass or a cooling cover. The first example is the device designed, manufactured, and tested as depicted in Figure 10 [30]. has an added duct at the back where the cold side of four 12706 TEC modules are attached while their hot sides are attached to heat dissipation heatsinks. Two fans push air from the internally finned duct towards the galvanized iron solar still to cool the inside of the sloped condensing surface. The solar still was further enhanced with two mirrors glued to the sides to increase the attenuated radiation. Additionally, copper oxide nanofluid was employed in the basin at concentrations of 0%, 0.04% and 0.08% instead of brackish/saline water. A second identical solar still was also designed and manufactured for simultaneous comparison.

The authors ran three different test cases in outdoor conditions, the first being without nanofluid, the second having 0.04% nanofluid and the third having 0.08% nanofluid. Productivity enhancements of 41.8, 65 and 81% over the conventional still correspond to an annual production of 1404, 1557 and 1689 l/m² while the LCOW was calculated to be 0.0218, 0.0235 & 0.0252 \$/l based on the percentage of nanofluids.

Another study looked at a different design of the condenser in addition to the development of an analytical MATLAB model for the prediction of the still's performance [31]. The experimental apparatus depicted in Figure 11 was augmented by including a circulation fan to push humid air to an external condenser. The condenser was made of an aluminum coil that spirals into a cold-water bath of unknown temperature.

Six different cases were tested during the experimental period. Cases 1 to 4 contained no nanoparticles but had varied rates of the circulation fan from 0-180 RPM at increments of 60 RPM. Moreover, cases 5 and 6 were studied with 0.04 and 0.08% copper oxide concentration and a constant RPM of 180.

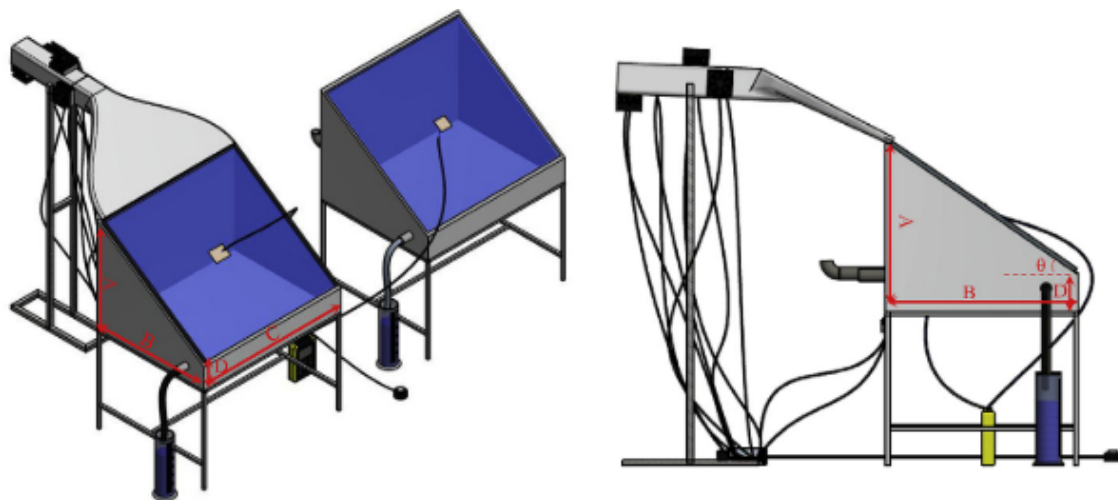


Figure 10 Cooling channel TEC & nanofluid assisted solar still [30].

- 1-Thermoelectric condensation channel
- 2-TEC modules
- 3-Solar still basin
- 4-Solar still stand
- 5-Digital thermometer
- 6-Power Supply
- 7- Cold water bath
- 8-Graded container

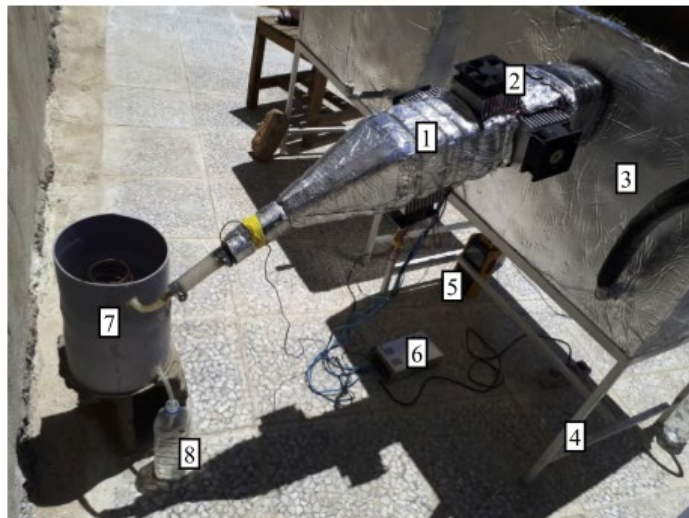


Figure 11 Cooling Channel TEC, nanofluid & external condenser assisted solar still [31]

Daily water productivity was found to increase in the range of 31.8% to 38.5% in cases 1 to 4 which demonstrates the non-significance of varying fan speed. On the other hand, productivity was found to increase by 65.4% and 82.4% in cases 5 to 6 which reflects the significant effect of including nanoparticles in the basin. The annual productivity was found to range from 1280 to 1338 l/m² in cases 1 to 4 while ranging from 1707 to 1860 l/m² in cases 5 & 6. The LCOW ranged from 0.025 to 0.021 \$/l without accounting for the cost of electricity. Finally, the analytical model developed was found to experience less than 5 and 10% deviation from the empirical values in the cases of conventional and modified device productivity and efficiency.

A more recent study has looked at the integration of TEC into solar still through the usage of a condensation channel under lab conditions without comparison against a baseline solar still [32]. The device portrayed in Figure 12 consists of a traditional solar still that is equipped with 4 fans that force air onto the glass cover, thus increasing heat rejection to the environment and subsequently condensation. Additionally, the device is also equipped with a secondary condensation chamber that is made of a plexiglass channel where the cold side of the TEC module is connected to a heat exchanger. Humid air transfer towards the secondary condensation chamber is enhanced through the usage of a transfer fan.

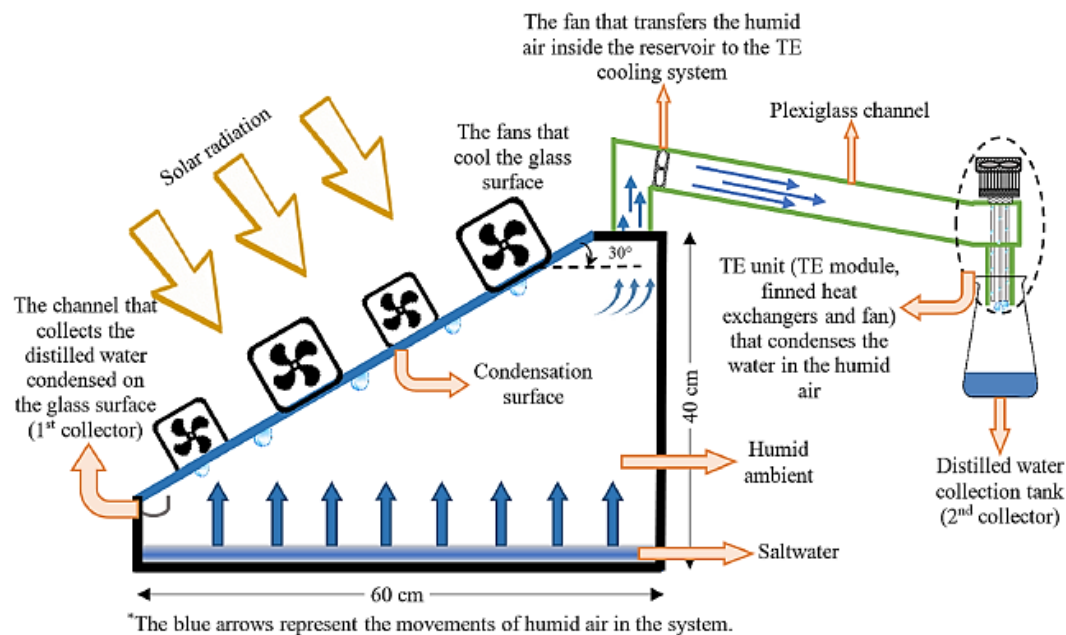


Figure 12 Solar Still equipped with Fans and External Cooling Channel [32]

Twelve test cases were conducted by the authors, the parameters included altering the water quantity in the solar distiller, altering the flow rate of cover cooling fans, altering the thermoelectric power input and finally altering the transfer fan's speed. One of the test cases was used as a baseline for the device's performance after optimizing the water level.

The authors concluded that the usage of the cover cooling fans solely can result in a production increase of 17%. The authors further demonstrated that while both transfer and tec assemblies are utilized, the usage of a cooling fan can impede water distillate production by approximately 18%. Finally, the authors determined the productivity increase due to operating the TEC assembly and transfer fan while turning off the cooling fans to be around 34% which corresponds to 251 l/m² annually and a LCOW of 0.187 \$/l. On the other hand, the base case annual productivity was determined to be 187 l/m² while LCOW was calculated to be 0.197 \$/l.

In another study, the usage of the cold side of the TEC module to increase water productivity through the usage of a cooling air channel while comparing the productivity against a base solar still was investigated [33]. Both the modified solar still (left) and base solar still (right) are portrayed in Figure (13, a) below. The modified solar still is equipped with two TEC assemblies that inject cold air in between the double-glazed glass channel, thus increasing the condensation as demonstrated in Figure (13, b). The heat from the hot side of the TEC is then rejected into the atmosphere.

The authors conducted experiments for 3 days in outdoor conditions to study the effect of the air speed in the cooling channel on productivity. The authors additionally included numerical simulations through the usage of Solidworks software. The authors noted a proportional relationship between the air speed and the water productivity. The maximum production of water was noted to be around 289 and 201 l/m² for the modified and base solar still. On the other hand, the LCOW was found to range between 0.1033 and 0.0972 \$/l for the modified and base solar still.

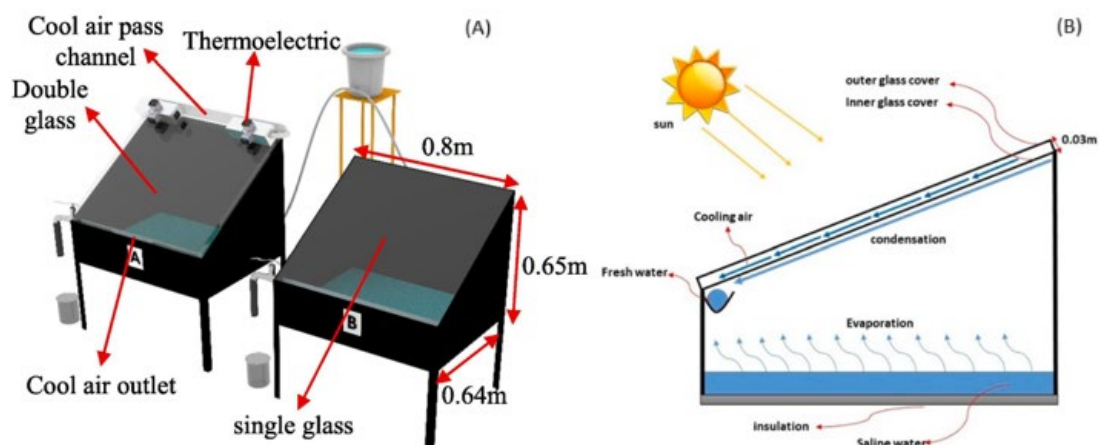


Figure 13 (a) Modified and Base solar stills b) TEC Modified Solar still with double glazed glass channel [33]

3.3. Thin-Film Cooling

In this section, Thin-Film Cooling is utilized to cool the transparent cover through inducing water flow. An investigation of the impact of utilizing a special cover glass coating in addition to thin film cooling on the productivity of a solar still while comparing the performance to a reference solar still was conducted [34]. Two devices portrayed in Figure 14, were designed, built and tested by the authors. One of the devices is a traditional solar still while the other is augmented with a coating to increase wettability in addition to thin film cooling. The thin film cooling setup is created through the usage of the cold side of the TEC module to cool the water, and a DC pump that recycles water at the rate of 2 liters per hour.

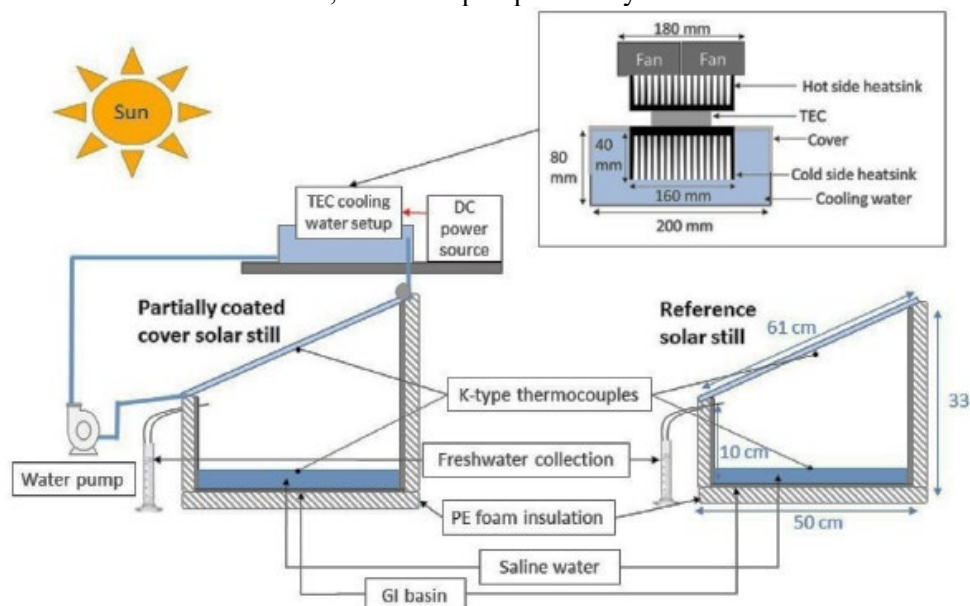


Figure 14 Partially Coated Solar Still with Thin Film Cooling [34]

The authors operated the devices for 2 days in outdoor conditions while altering the TEC assembly input power from 12w to 36w. The authors concluded that the implementation of the TEC alongside the coating resulted in a freshwater output increase of 49% and 126% depending on the TEC wattage. The annual production was noted to be 384, 292 and 195 l/m² for the 36-watt, 12-watt TEC-equipped solar still and the reference solar still. Similarly, the LCOW was noted to be 0.036, 0.047 and 0.044 \$/l/m².

Another paper has studied the performance benefits of integrating the cold side of TEC modules with different covered solar stills simultaneously while comparing the productivity against a reference solar still [35]. The authors have built four different solar stills as indicated in Figure 15 below. The cover materials of choice were Plexi glass, Polycarbonate and glass for 2 solar stills. The first three solar stills are equipped with a TEC assembly that employs thin film cooling using cold water. The cold side of the TEC cools the water while the hot side rejects its heat to the atmosphere. The last solar still doesn't employ any TEC assemblies and is used as a reference for performance comparison.

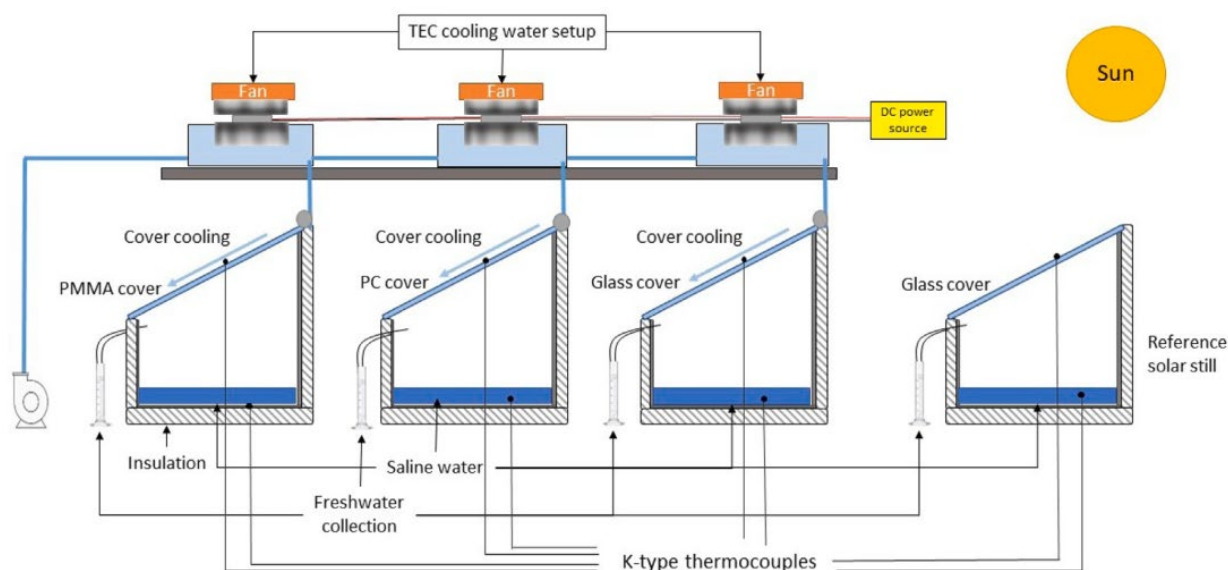


Figure 15 Solar Stills with Different Cover Materials & Thin Film Cooling [35]

The authors conducted 3 different experiments in outdoor conditions to study the effect of varying TEC currents on water yield. The water flow rate over the cover was held stable at 2 liters per hour. The authors concluded for glass cover material, there is a direct proportionality between the current supplied to the TEC and the water produced. However, for both PC and Plexi-glass covers, the authors concluded that increasing the current beyond a certain threshold leads to a significant decrease in water productivity. It is also worth noting that both PC and Plexi-glass equipped solar stills have performed up to 85% worse than the reference solar still with the glass cover, thus raising the validity of using such cover materials with TEC cooling. The performance difference between TEC stills equipped with Glass, Poly Carbonate & Plexi Glass solar stills with comparison to the reference still based on the median value of TEC current was noted to be 55, -76, -49% translating to an annual production of 593, 90, 197 l/m². The LCOW was determined to be 0.0476, 0.291, 0.1321 \$ respectively and 0.0473 \$ for the reference solar still.

4. Hot and Cold Side Integration of TEC

4.1. Simultaneous usage of hot and cold sides of same TEC module

The earliest documented attempt at simultaneous usage of both sides of the same module has focused on the development of a thermoelectric distiller that functions independently of solar radiation [36]. The system portrayed in Figure 16 is made up of two main blocks, a Plexi glass housing, and a TEC assembly. A pump circulates water from the basin to the top heat exchanger. The water heat exchanger is connected through a copper plate to the heating side of the TEC assembly subsequently heating the water. The cooling side of the TEC module is connected to a hydrophobic aluminum heat sink to boost condensation rates. Subsequently, condensed water is collected through collector channels on the vertical walls and below the condenser.

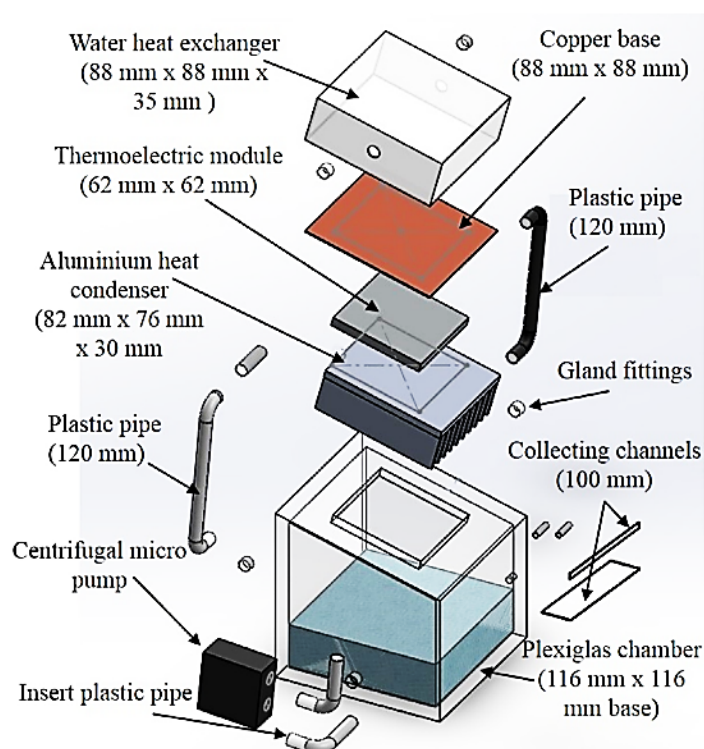


Figure 16 Pioneering TEC Distiller System Components [36]

The water productivity was measured to be 28.5 ml and annual productivity was calculated to be equivalent to 247.47 l/m². The electrical energy intensity was calculated to be 1.1368 kwh/liter; however, LCOW wasn't discussed in the paper.

Several years later, the first TEC equipped desalination device that utilizes both solar irradiation and both sides of the TEC while using a non-modified solar still as a baseline was introduced [37]. The novel design portrayed in Figure 17 is made up of two main assemblies, the solar still frame and the TEC assembly. The TEC assembly is comprised of multiple 12706 TEC modules adhered to aluminum plates to facilitate heat transfer. The aluminum plates are then integrated into cold and hot water tanks and further insulated to prevent heat loss. The cold-water tank is then connected using a pump to a distribution pipe on the top of the solar still to allow water to trickle on the sloped surface thereby cooling it. On the other hand, the hot-water tank is also connected to a pump to circulate the hot water in the basin.

The annual production capability of the modified and the base still were stated to be 1033 and 449 l/m² Furthermore, The LCOW at 10% interest rate was calculated to be 0.1055 and 0.1763 \$/l for the modified and conventional solar stills respectively.

In their subsequent work, the authors have performed further investigation on the benefits of including nanoparticles in their novel solar still using the same thermoelectric solar still from the previous study, portrayed in Figure 17 [38]. Four different nanoparticles were used, Carbon Wall Nano Tubes (CWNT), copper oxide, aluminum oxide and titanium oxide. The nano solution was placed inside both the heating and cooling tanks, to be later pumped inside the heating coil and in the form of a water film on the cover respectively. Additionally, based on the first law of thermodynamics, an analytical model was created.

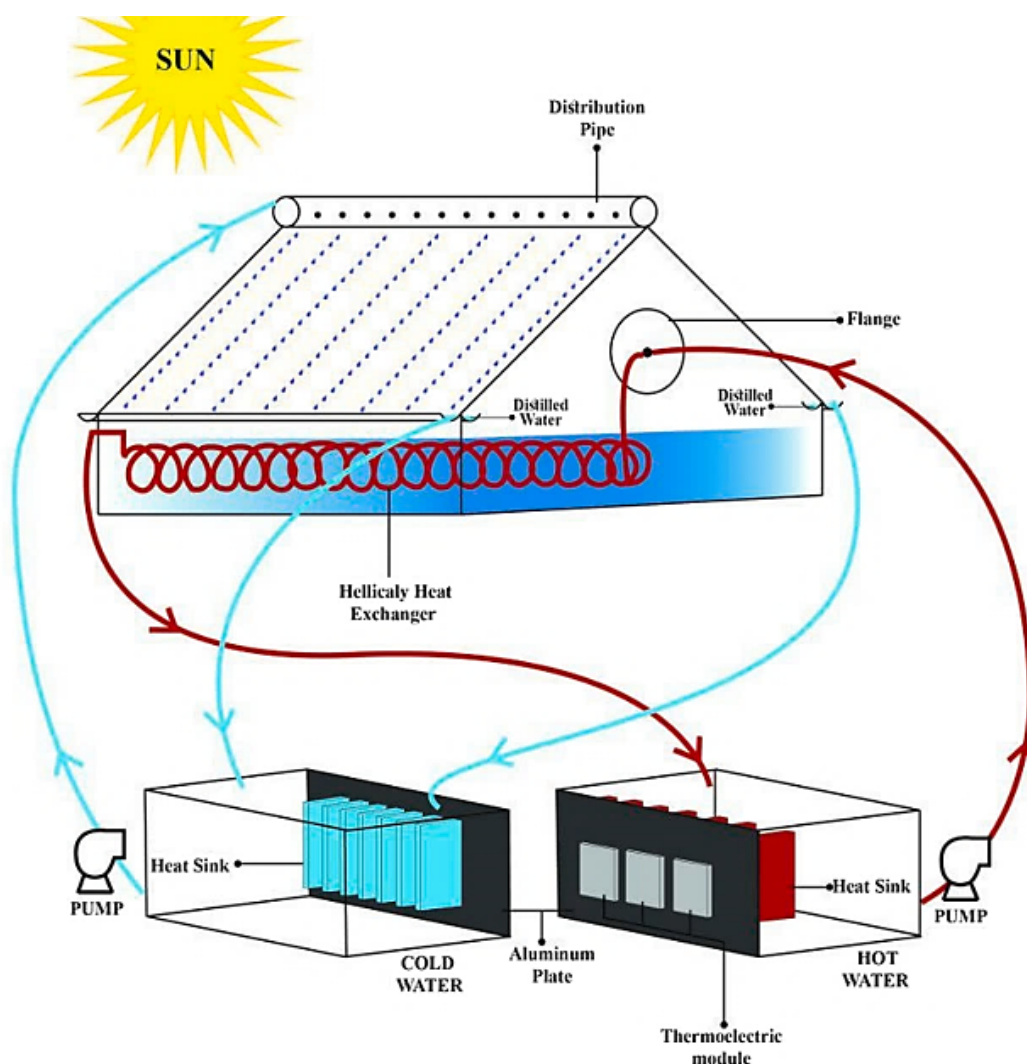


Figure 17 TEC-Equipped Solar Still with Simultaneous Hot and Cold Side Usage [37]

The analytical model was found to have an accuracy ranging between 1.33% and 14.45 in predicting the hourly yield which was deemed satisfactory by the authors. A daily yield improvement of 23.2, 19.1, 18.1 & 16.2 % resulted from the usage of CWNT, copper oxide, aluminum oxide and titanium oxides respectively. Higher nanofluid concentrations resulted in higher daily productivity as well as increased power consumption for the TEC modules. Accordingly, the annual productivity ranged between 814.2 and 895.9 l/m². Finally, The LCOW excluding the cost of electricity was found to range between 0.0986 and 0.1652 \$/l.

On the other hand, a different method of integration of both sides of a TEC module into a solar still was evaluated and compared it against a baseline solar still as demonstrated in Figure 18 [39]. The modified solar still includes a TEC assembly inside the basin where the hot side is connected through a heat sink to the basin for heating purposes to increase the evaporation rates. The cold side is connected to a copper plate that serves as a condensation surface.

The authors have performed a single experiment to investigate the added benefits of the TEC setup that took place in outdoor conditions. There was a 41.2% increase in productivity in contrast to the base solar still which translated to an annual water production of 699 and 494 l/m² respectively. Finally, the LCOW of fresh water was calculated at 0.037 and 0.039 for the base and TEC equipped solar still respectively.

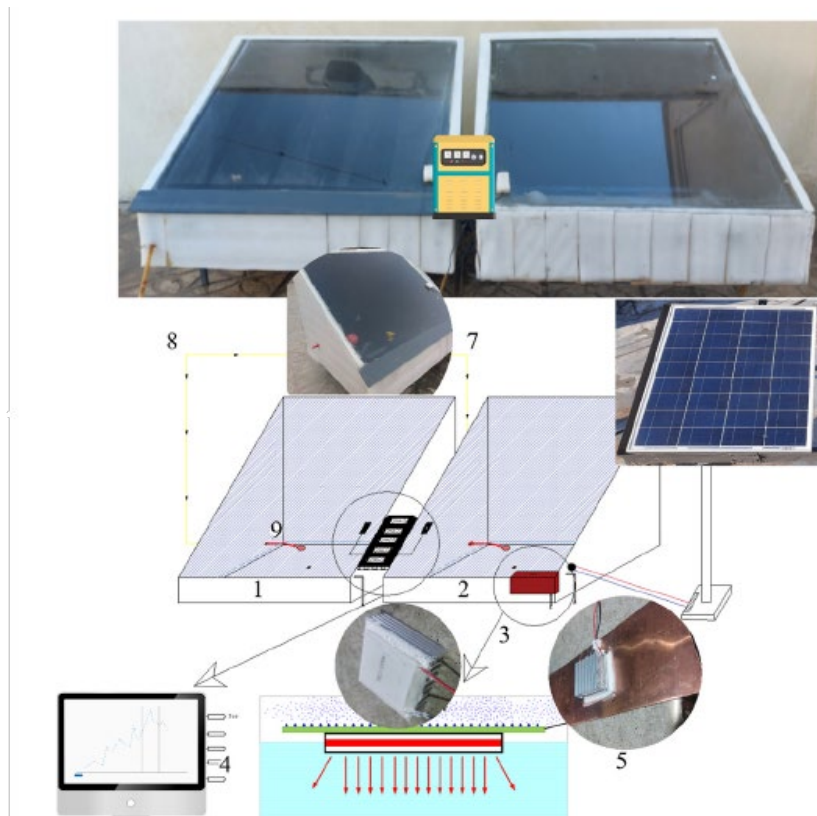


Figure 18 TEC-Equipped Solar Still with Simultaneous Hot and Cold Side Usage [39]

A more recent study has looked at heating the basin in combination with a cooling channel while comparing distillate yield against a base solar still [40]. The modified solar still (left) and base solar still (right) are portrayed in Figure (19, a) below. The modified solar still has 6 TEC modules that are directly attached to the basin to aid with improving the evaporation rates. The modified solar still is also equipped with a cooling channel that is powered through the cooling side using fins. The channel is then equipped with fans that circulate cold air onto a double-glazed glass channel, thus cooling the cover and increasing the condensation rates.

The authors conducted experiments on two consecutive days without altering any of the design/operational parameters under outdoor conditions. The yearly water production for the modified and base devices was calculated to be 586 and 141 l/m² which represents a 570% performance increase. The LCOW was noted to be 0.0326 and 0.0739 \$/l for the modified and base solar stills respectively.

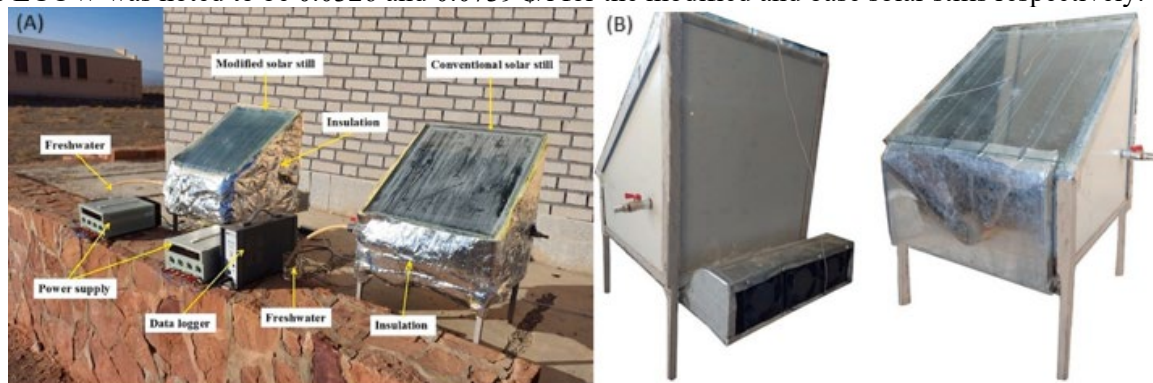


Figure 19 (a) Overall View of Based and Modified Solar Still (b) TEC Equipped Solar Still Side and Back View with Simultaneous Cold and Hot Side Integration of TEC Module [40]

4.2. Utilizing Hot and Cold Sides of Different TEC Modules

In this section, instead of using both sides of the same module, two different modules are used. This setup is less favourable due to doubling the power requirements for the system. Using such a setup, an study of a silver nanoparticle augmented solar still with the addition of an external condenser was performed [41]. The experimental apparatus depicted in Figure 20 and 21, is made up of two identical galvanized iron solar stills with two 12708 TECs used in heating mode. Both solar stills are equipped with an external reflector while only one is equipped with an external condenser. The external condenser depicted in Figure 21 is divided into two sections, the first equipped with the cold side of two 12704 TECs while the second is cooled using a distilled water film. The entire system is powered using a 300-watt PV panel.



Figure 20 TEC-Equipped Solar Distiller with Nano Silver and External Condenser Augmentations [41]



Figure 21 External Condenser Closeup [41].

The authors explored three main cases (a) solar still performance without nanoparticles or condenser, (b) solar still performance with nanoparticles and without the condenser, (c) solar still performance with nanoparticles and the condenser. Temperature distribution, insolation, water productivity was measured and recorded on an hourly basis.

The highest productivity resulted from case C, followed by case B then A. The effect of integrating the condenser seemed to have the greatest positive impact on the daily yield followed by the addition of nano particles. The condenser section with the TEC consumed 4.5 more times than the section with the water film but ended up producing 5.5 times the amount of distillate. The annual productivity was calculated to be 1394, 1767 and 2796 l/m² based on 365 operational days for cases A, B & C respectively. Finally, neither the LCOW nor the electrical consumption of the apparatus were mentioned in the paper.

5. Conclusion

Solar distillers offer multiple benefits, however; the main limitation on widespread implementation remains to be the low distillate yield compared with other desalination methods which range from 2-5 liters per square meter. This paper looks at the integration of Thermoelectric Cooler modules, otherwise known as TEC to increase the yield of solar stills.

There are multiple configurations for the integration of TECs into solar distillers, this includes utilizing the cooling side only of a TEC module, utilizing the heating side only of a TEC module, utilizing both heating and cooling sides of same TEC modules and utilizing hot and cold sides in the same device but from different modules.

- There are three main sub-configurations when it comes to utilizing the cooling side only, direct adhesion to cover and integration with a condenser or cooling channel and thin film cooling. Annual water production ranges from 90 to 1860 l/m² with an LCOW range from 0.0174 to 0.291 \$/l for this method. The modified devices utilizing this configuration have shown up to 200% productivity when compared against base models in the same studies.

- Utilizing the hot side only utilizes a single configuration of direction adhesion to basin, with annual water production ranging from 547 to 2971 l/m² with a LCOW range from 0.0174 to 0.237 \$/l. The

modified devices utilizing this configuration have shown up to 324% productivity when compared against base models in the same studies.

- Utilizing both sides of the same module, yields an annual water production ranging from 247 to 1033 l/m² with a LCOW range from 0.0326 to 0.1652 \$/l. The modified devices utilizing this configuration have shown up to 415% productivity when compared against base models in the same studies.

- Utilizing both sides of different modules yields an annual water production ranging from 1767 to 2796 l/m². The modified devices utilizing this configuration have shown up to 200% productivity when compared against base models in the same studies.

References

- [1] International Geosphere-Biosphere Programme. Great Acceleration [Internet]. 2015 [cited 2025 Feb 1]. Available from: <http://www.igbp.net/globalchange/greatacceleration.4.1b8ae20512db692f2a680001630.html>
- [2] Liu J, Yang H, Gosling SN, Kumm M, Flörke M, Pfister S, et al. Water scarcity assessments in the past, present, and future. *Earths Future* 2017;5:545–59. <https://doi.org/10.1002/2016EF000518>.
- [3] Jones E, Qadir M, van Vliet MTH, Smakhtin V and Kang S mu. The state of desalination and brine production: A global outlook. *Science of the Total Environment* 2019;657:1343–56. <https://doi.org/10.1016/j.scitotenv.2018.12.076>.
- [4] Katekar VP and Deshmukh SS. A review on research trends in solar still designs for domestic and industrial applications. *J Clean Prod* 2020;257:120544. <https://doi.org/10.1016/j.jclepro.2020.120544>.
- [5] Agrawal A, Rana RS and Srivastava PK. Heat transfer coefficients and productivity of a single slope single basin solar still in Indian climatic condition: Experimental and theoretical comparison. *Resource-Efficient Technologies* 2017;3:466–82. <https://doi.org/10.1016/J.REFFIT.2017.05.003>.
- [6] Abujazar MSS, Fatihah S, Rakmi AR and Shahrom MZ. The effects of design parameters on productivity performance of a solar still for seawater desalination: A review. *Desalination* 2016;385:178–93. <https://doi.org/10.1016/j.desal.2016.02.025>.
- [7] Dev R and Tiwari GN. *Solar Distillation. Drinking Water Treatment*, Dordrecht: Springer, Dordrecht; 2011, p. 159–210. https://doi.org/10.1007/978-94-007-1104-4_6.
- [8] Sharshir SW, Peng G, Elsheikh AH, Eltawil MA, Elkadeem MR, Dai H, et al. Influence of basin metals and novel wick-metal chips pad on the thermal performance of solar desalination process. *J Clean Prod* 2019;248. <https://doi.org/10.1016/j.jclepro.2019.119224>.
- [9] Dimri V, Sarkar B, Singh U and Tiwari GN. Effect of condensing cover material on yield of an active solar still: an experimental validation. *Desalination* 2008;227:178–89. <https://doi.org/10.1016/j.desal.2007.06.024>.
- [10] Panchal HN and Patel S. An extensive review on different design and climatic parameters to increase distillate output of solar still. *Renewable and Sustainable Energy Reviews* 2017;69:750–8. <https://doi.org/10.1016/j.rser.2016.09.001>.
- [11] Ahmed HM, Alshutal FS and Ibrahim G. Impact of Different Configurations on Solar Still Productivity. *Advance Science and Engineering Research* 2014;4:118–26.
- [12] Alfaylakawi KA and Ahmed HM. An Experimental Study on the Effect of Wind Speed and Water Sprinklers on Simple Solar Still Productivity. *International Conference on Nuclear & Renewable Energy Resources*, Turkey: 2012.
- [13] Abujazar MSS, Fatihah S, Rakmi AR and Shahrom MZ. The effects of design parameters on productivity performance of a solar still for seawater desalination: A review. *Desalination* 2016;385:178–93. <https://doi.org/10.1016/j.desal.2016.02.025>.
- [14] Rajvanshi AK. Effect of various dyes on solar distillation. *Solar Energy* 1981;27:51–65. [https://doi.org/10.1016/0038-092X\(81\)90020-7](https://doi.org/10.1016/0038-092X(81)90020-7).

- [15] Sharshir SW, Peng G, Elsheikh AH, Eltawil MA, Elkadeem MR, Dai H, et al. Influence of basin metals and novel wick-metal chips pad on the thermal performance of solar desalination process. *J Clean Prod* 2019;248. <https://doi.org/10.1016/j.jclepro.2019.119224>.
- [16] Omara ZM, Kabeel AE and Abdullah AS. A review of solar still performance with reflectors. *Renewable and Sustainable Energy Reviews* 2017;68:638–49. <https://doi.org/10.1016/J.RSER.2016.10.031>.
- [17] Voropoulos K, Mathioulakis E and Belessiotis V. Solar stills coupled with solar collectors and storage tank—analytical simulation and experimental validation of energy behavior. *Solar Energy* 2003;75:199–205. <https://doi.org/10.1016/J.SOLENER.2003.08.001>.
- [18] Badran O, Alahmer A, Hamad FA, El-Tous Y, Al-Marahle G and Al-Ahmadi HMA. Enhancement of solar distiller performance by photovoltaic heating system. *International Journal of Thermofluids* 2023;18:100315. <https://doi.org/10.1016/J.IJFT.2023.100315>.
- [19] Hemmatian A, Kargarsharifabad H, Abedini Esfahlani A, Rahbar N and Shoeibi S. Improving solar still performance with heat pipe/pulsating heat pipe evacuated tube solar collectors and PCM: An experimental and environmental analysis. *Solar Energy* 2024;269:112371. <https://doi.org/10.1016/J.SOLENER.2024.112371>.
- [20] Hemmat Esfe M, Esfandeh S, Toghraie D and Vaisi V. Optimization of solar still equipped with TEC by Taguchi and genetic algorithm methods: A case study for sustainable drinking water supply in the villages of Sistan and Baluchestan with new technologies. *J Clean Prod* 2022;380:135020. <https://doi.org/10.1016/J.JCLEPRO.2022.135020>.
- [21] Ferrotec. A Guide to Thermoelectrics. Thermoelectric Modules - Ferrotec 2020. <https://thermal.ferrotec.com/technology/> (accessed February 1, 2025).
- [22] Pourkiaei SM, Ahmadi MH, Sadeghzadeh M, Moosavi S, Pourfayaz F, Chen L, et al. Thermoelectric cooler and thermoelectric generator devices: A review of present and potential applications, modeling and materials. *Energy* 2019;186:115849. <https://doi.org/10.1016/j.energy.2019.07.179>.
- [23] Masoud Parsa S, Rahbar A, Javadi D, Koleini MH, Afrand M and Amidpour M. Energy-matrices, exergy, economic, environmental, exergoeconomic, enviroeconomic, and heat transfer (6E/HT) analysis of two passive/ active solar still water desalination nearly 4000m: Altitude concept 2020. <https://doi.org/10.1016/j.jclepro.2020.121243>.
- [24] Rahbar N, Gharaiian A and Rashidi S. Exergy and economic analysis for a double slope solar still equipped by thermoelectric heating modules - an experimental investigation. *Desalination* 2017;420:106–13. <https://doi.org/10.1016/j.desal.2017.07.005>.
- [25] Vivek Natarajan. S, Vivek Anandhanhan. B and Armstrong M. Aggrandizement in the Performance of Double slope Solar Still with the Incorporation of Peltier Effect in Addition To Water Depths. *International Journal of Innovative Technology and Exploring Engineering* 2019;9:200–4. <https://doi.org/10.35940/ijitee.b1052.1292s219>.
- [26] Esfahani JA, Rahbar N and Lavvaf M. Utilization of thermoelectric cooling in a portable active solar still - An experimental study on winter days. *Desalination* 2011;269:198–205. <https://doi.org/10.1016/j.desal.2010.10.062>.
- [27] Rahbar N and Esfahani JA. Experimental study of a novel portable solar still by utilizing the heatpipe and thermoelectric module. *Desalination* 2012;284:55–61. <https://doi.org/10.1016/j.desal.2011.08.036>.
- [28] Rahbar N, Esfahani JA and Asadi A. An experimental investigation on productivity and performance of a new improved design portable asymmetrical solar still utilizing thermoelectric modules. *Energy Convers Manag* 2016;118:55–62. <https://doi.org/10.1016/j.enconman.2016.03.052>.
- [29] Rabishokr K and Daghigh R. A portable solar still's productivity boost combining a magnetic stirrer and thermoelectric. *Desalination* 2023;549:116340. <https://doi.org/10.1016/J.DESAL.2022.116340>.
- [30] Nazari S, Safarzadeh H and Bahiraei M. Performance improvement of a single slope solar still by

- employing thermoelectric cooling channel and copper oxide nanofluid: An experimental study. *J Clean Prod* 2019;208:1041–52. <https://doi.org/10.1016/j.jclepro.2018.10.194>.
- [31] Nazari S, Safarzadeh H and Bahiraei M. Experimental and analytical investigations of productivity, energy and exergy efficiency of a single slope solar still enhanced with thermoelectric channel and nanofluid. *Renew Energy* 2019;135:729–44. <https://doi.org/10.1016/j.renene.2018.12.059>.
- [32] Mandev E, Muratçobanoğlu B, Manay E and Şahin B. Desalination performance evaluation of a solar still enhanced by thermoelectric modules. *Solar Energy* 2024;268:112325. <https://doi.org/10.1016/J.SOLENER.2024.112325>.
- [33] Khanmohammadi S, Khanjani S and Musharavati F. Experimental study and economic examination of double-glazed solar still desalination with a thermoelectric cooling system. *Sustainable Energy Technologies and Assessments* 2022;54:102854. <https://doi.org/10.1016/J.SETA.2022.102854>.
- [34] Shatar NM, Sabri MFM, Salleh MFM and Ani MH. Energy, exergy, economic, environmental analysis for solar still using partially coated condensing cover with thermoelectric cover cooling. *J Clean Prod* 2023;387:135833. <https://doi.org/10.1016/J.JCLEPRO.2022.135833>.
- [35] Shatar NM, Sabri MFM, Salleh MFM and Ani MH. Investigation on the performance of solar still with thermoelectric cooling system for various cover material. *Renew Energy* 2023;202:844–54. <https://doi.org/10.1016/J.RENENE.2022.11.105>.
- [36] Al-Madhhachi H and Min G. Effective use of thermal energy at both hot and cold side of thermoelectric module for developing efficient thermoelectric water distillation system. *Energy Convers Manag* 2017;133:14–9. <https://doi.org/10.1016/j.enconman.2016.11.055>.
- [37] Shoeibi S, Rahbar N, Abedini Esfahlani A and Kargarsharifabad H. Application of simultaneous thermoelectric cooling and heating to improve the performance of a solar still: An experimental study and exergy analysis. *Appl Energy* 2020;263:114581. <https://doi.org/10.1016/j.apenergy.2020.114581>.
- [38] Shoeibi S, Rahbar N, Abedini Esfahlani A and Kargarsharifabad H. Improving the thermoelectric solar still performance by using nanofluids– Experimental study, thermodynamic modeling and energy matrices analysis. *Sustainable Energy Technologies and Assessments* 2021;47:101339. <https://doi.org/10.1016/j.seta.2021.101339>.
- [39] Aghakhani S, Kavehfarsani M, Hajatzadeh Pordanjani A and Afrand M. Energy and exergoeconomic analysis of solar stills integrated with thermoelectric technology: A case study on environmental and economic sustainability. *Renew Energy* 2025;239:121989. <https://doi.org/10.1016/J.RENENE.2024.121989>.
- [40] Jam RF, Gholizadeh M, Deymi-Dashtebayaz M, Khanjani S and Dartoomi N. Experimental investigation of the thermoelectric and double-glazed glass effects on the performance of a solar still. *Appl Therm Eng* 2024;246:122898. <https://doi.org/10.1016/J.APPLTHERMALENG.2024.122898>.
- [41] Masoud Parsa S, Rahbar A, Koleini MH, Aberoumand S, Afrand M and Amidpour M. A renewable energy-driven thermoelectric-utilized solar still with external condenser loaded by silver/nanofluid for simultaneously water disinfection and desalination 2020. <https://doi.org/10.1016/j.desal.2020.114354>.