Solar water purifiers for small rural African homesteads: Evaluation of alternative designs

K Kanyarusoke
Mechanical Engineering Department, Cape Peninsula University of Technology, Cape Town, South Africa

E-mail: kanyarusokek@cput.ac.za

Abstract. This paper presents five different designs of single slope solar water stills. These still designs would probably be useful in small homes wishing to purify water for their daily drinking needs. Models of the stills ranging between 1 m² and 1.5 m² glazing area are manufactured and tested in real outdoor conditions. Two of the stills are double glazed and have external condensers, with one of them using forced steam extraction. A third still is mounted on a sun tracking pillar. The remaining two are simple collapsible and portable units but of different slopes. A method of evaluating the designs is illustrated. It relies on a focus on the purpose of a solar still and what scarce resources are required to get outputs from it. Thus, the stills are evaluated based on function, quality, productivity and cost. It is found that the tracking unit out performs the others on function and quality criteria but it is outcompeted on efficiencies and cost criteria. Condensate drip-back was found to be an issue that necessitates use of slopes that do not necessarily yield maximum energy incidence on the stills. It was also found that double glazing and external condensation did not help improve performance on any of the criteria. It is concluded and recommended that an ideal single slope solar water purifier operating in weather similar to Cape Town’s summer season, would need to have a thin single glazing, sloped towards 45°, portable and sun tracking.

1. Introduction
Energy and water are twin utilities whose provision is problematic in rural Africa. As a result, over 681 Million Africans have no access to modern forms of energy [1], while 319 Million lack safe drinking water [2]. The lack of reliable modern energy means rural dwellers have to depend on biomass for their heating and cooking needs [3]. But also, the urban areas have had to rely on rural areas for sourcing charcoal as either a supplement to, or a total replacement of electricity in cooking. This, together with the rapidly growing populations of some African countries, is leading to environmental degradation at a scale never witnessed before. For example, in Uganda East Africa, it is estimated that the tropical rain forest has diminished by 50% in the period 1988 to 2008 [4] as the population almost doubled from 16.3 to 31.3 Million in same period [5]. As of July 2018, estimates vary between 38.8 and 40 Million [5,6].

Along with the environment degradation problem, comes the water scarcity issue, especially in dry seasons, which have now become longer and hotter. The fewer watering points then, are shared with domestic and wild animals, helping spread both water borne and zoonotic diseases. The situation is not any better during rainy seasons because flooding, facilitated by hillside soil erosion and wetland encroachments, is on the rise [7], making the health situation even worse. Therefore, in whatever
season, there is an urgent need for water purification systems at the home level. At present, the commonest method in use is to boil the water for drinking purposes [8]. Other methods include use of chlorine-releasing tablets and filtration but these are not widespread because they are expensive, require recurrent renewals and are less easily understood by rural people. Good filtration also requires a pressurized supply of water which generally is neither available nor affordable by rural homesteads. Besides, it needs an input of up to four times the clean water it produces for it to run reliably [9]. This makes the scarcity even worse.

Boiling water as recommended and practiced in many rural homes has two major problems associated with it. First, it still uses wood fuel, which is a bio-mass, as a source of energy. Apart from environmental issues alluded to above, firewood collection costs valuable time especially of women and children. Agea et al [10] found that firewood collectors in central Uganda spent 4 to 6 hours a day to walk between 8 and 12 km in search for the fuel. Then, there is the additional issue of poor combustion and its associated health effects as was reported in an earlier paper [11]. The second problem with boiling is that it does not remove harmful inorganic salts that may be dissolved in the water. In areas where there are plenty of iron deposits for example, it is known that teeth of people drinking water therefrom, are discolored, perhaps making social interactions with others less eventful than would otherwise have been the case.

In light of the above problems, an alternative source of energy was sought – and solar energy was chosen because of its universal availability in reasonable quantities across the continent. Annual solar irradiance ranges between 1400 and 2100 kWh/m² on the continent, with more than 75% of the continent getting at least 1500 kWh on a horizontal plane [12]. To directly use this resource, solar water purifiers using the distillation principle are being developed by a multi-national team at the author’s university. It is intended that participating graduate students will eventually tailor the designs to local environments in specific countries. This paper therefore describes and compares simultaneous performances of a few designs of single slope stills in Cape Town’s summer weather. Its originality and value is in provision of sizing, performance indication and costing guides for the now non-existent rural home solar water purifiers on the continent. Consequently, it is structured as follows: section 2 briefly explains the science of single slope solar stills. This is followed by a description of the designs tested. Section 4 gives the experimental protocol and is then followed by a discussion of results. In the penultimate section of the paper, a short commentary on applicability of the work outside South Africa is given and illustrated with an installation in Uganda, East Africa. We conclude in section 7 with some recommendations.

2. A brief science of solar stills
A simple solar still as would be most suitable for a rural family starting off to have a modern way of solar-purifying water would be the single slope basin type shown in figure 1. It consists of a trapezoidal hollow prism having its top inclined surface made of glazing material. The bottom is painted black while the sides are best if coated with a reflective film. Both sides and bottom are insulated. A channel runs along the lower edge of the glazing to receive condensing water and deliver it outside the still.

There are other types of stills in the literature but they are a little more complex. They include the double slope [13], pyramid [14], reverse absorber [15], and many others listed in reviews like that of [16] and [17]. All work on the same principle of using sunlight to evaporate water from a saline or brackish mixture in an enclosed air-tight space, and then condense the resulting vapour, collecting the condensate as ‘purified’ water in a container, outside the still. Temperatures and times of exposure achieved in the still will generally be high enough to destroy most pathogenic microbes [18]. The slow and gentle mass transfer of the vapour leaves nonvolatile contaminants, including the few heat resistant microbes, in the still. An occasional emptying of the still and subsequent exposure to sunlight would destroy even the heat resistant organisms either from the ultraviolet part of the spectrum [19] or from the higher still stagnation temperatures that would arise. In the remainder of this brief, we focus on the thermodynamics inside and outside the still.
2.1. The energy equation for a simple basin solar still

An operating still, such as in figure 2 below, is an unsteady thermodynamic open system from which purified water is flowing at a rate $m_{dis}$ and with specific enthalpy $h_f$. At a given place, the still receives total solar irradiance $G_{gl}(t, b)$ at its glazing of emissivity $e_{gl}$. It reflects a fraction $\rho_{gl}$ back to space, reradiates and convects $Q_t$ to the sky, ground and environment. Radiation is also received on sides of the still but most of this is reflected and scattered off the sides. Depending on the colour and texture of the surfaces, a little is absorbed at the side surfaces. Together with what may be coming from inside the still, the energy on sides is partly convected to the environment and the rest reradiated to the sky and ground as $Q_s$. At the bottom of the still, energy is convected and radiated to the ground if the still is on a stand. Otherwise, it is directly conducted to the ground. Applying the generalized first law of Thermodynamics to the open system, we have equation (1) which on simplification, approximates (2).

$$
\frac{d}{dt}(m_{w}h_f) + A_{g}G_{g}(t, \beta) + \sum A_{g}G_{g} - (A_{g}\rho_{g}G_{g} + \sum A_{g}\rho_{g}G_{g} + \dot{Q}_t + \dot{Q}_s) + \frac{d}{dt}(m_{w}c_{w}T_{w} + m_{c}T_{c} + \sum m_{c}T_{c} + m_{c}T_{c})
$$

$$
\frac{d}{dt}(T_{c}) + A_{g}G_{g}(1 - \rho_{g}) - \dot{Q}_{s} - \dot{Q}_{t} = m_{w}c_{w}\dot{T}_{w} - m_{c}c_{c}\dot{T}_{c} = m_{w}h_{f}
$$

Where the following simplifying assumptions have been made to get equation (2):

- The reflectivity of the sides is close to unity and the incident radiation there is negligible because it is the glazed surface which should be facing the sun.
- Capacitance effects of the sides and bottom are negligible in comparison with those of the still water, $m_{w}h_{w}$ which in turn can be approximated using an average specific heat capacity $c_{w}$.
- The outer surface temperature of the sides is very nearly equal to that at the bottom of the still, since the still outer casing might be made of one conductive material.

The transfers $\dot{Q}_{s}$ and $\dot{Q}_{t}$ are given by equations (3) and (4): In these equations, $e$ is the surface emissivity. The terms involving $\beta$ are the respective radiation view factors.

$$
\dot{Q}_{s} = \dot{Q}_{ra} + \dot{Q}_{rm} + \dot{Q}_{re}
$$

Where we have:
\[
\dot{Q}_{rg} = \alpha A_{gl} \left[ \frac{T_{gl}^4 - T_s^4}{R_{gl} + R_s} \right] \left( R_{gl} + R_g \right) \left( T_{gl}^4 - T_s^4 \right)
\]

(3a)

\[
\dot{Q}_{rs} = \alpha A_{gl} \left[ \frac{T_{gl}^4 - T_s^4}{R_{gl} + R_s} \right] \left( R_{gl} + R_g \right) \left( T_{gl}^4 - T_s^4 \right)
\]

(3b)

\[
\dot{Q}_{stu} \equiv (T_{gl} - T_s)A_{gl}(2.8 + 3C_{wind})
\]

(3c)

And: thermal resistances for glazing surface, ground view and sky view, per unit area given as:

\[
R_{gl} = \frac{1 - \varepsilon_{gl}}{\varepsilon_{gl}}; R_g = \frac{2}{1 - \cos \beta}; R_s = \frac{2}{1 + \cos \beta}
\]

(3d)

\[
\dot{Q}_b = \dot{Q}_{rby} + \dot{Q}_{rs} + \dot{Q}_{stu} \equiv A_{gl} \cos \beta \left( 1 + \frac{A_t}{A_{gl} \cos \beta} \right) (T_u - T_s)U_b
\]

(4)

Where \( U_b = \left[ \frac{1}{h_w + \frac{x_{ins}}{k_{ins}}} + \frac{1}{5.7 + 3.8C_{wind}} \right]^{-1} \)

(4a)

Here, \( h_w \) is the water–bottom convection coefficient, \( x_{ins} \) and \( k_{ins} \) refer to insulation thickness and conductivity respectively. \( C_{wind} \) is wind speed. The \( 5.7 + 3.8C_{wind} \) term has catered for radiation to the ground as well.

\( \alpha \) – ambient air
\( b \) – bottom
\( c \) – convected
\( g \) – ground
\( gl \) – glazing
\( G \) – Radiation flux \( (W/m^2) \)
\( h_f \) – specific enthalpy of distillate \( (J/kg) \)
\( m_{wm} \) – rate of distilled mass \( (kg/s) \)
\( q \) – energy flux \( (W/m^2) \)
\( r \) – radiated
\( s \) – sideds of still
\( S \) – sky
\( t \) – top of still
\( \rho \) – reflectivity

**Figure 2.** Energy onto and off the still.
It is seen in equation (2) that heat loss rates $\dot{Q}_t$ and $\dot{Q}_b$ for a running still filled with water $m_w$ under irradiance $G_{gl}$, determine the rate of purified water yield $m_{dis}$ and the heating rate of the still water as determined through $\dot{T}_w$. The relationships between these parameters originate from events inside the still. These are discussed next.

2.2. Energy transformations inside a simple basin solar still

Once inside the still, energy is transferred in different forms between the glazing, the water and the basin structure as shown in figure 3. When the various parts of the system are considered, equations (5) to (11) result. These can then be combined with (2) to give two simultaneous first order differential equations for the temperatures $T_g$ and $T_w$, solution of which, yields all other quantities if the weather data are available.

$$G_{in} = \eta_{opt} G_{gl}$$  \hspace{1cm} (5)

Where, the optical efficiency $h_{opt}$ of the glazing is now introduced. In addition to the transmissivity and absorptivity of the glazing, it depends on the relative magnitudes of the radiation components (beam, ground reflection and sky diffuse) arriving at the top surface of the glazing. The Perez diffusion radiation model [20], Bouguer’s law on beam radiation extinction in a medium, and the Brandemuehl - Beckman’s modelling of diffuse radiation extinction as cited in [21], relate $G_{gl}$ to $G_{in}$ and hence, determine $h_{opt}$.

For the water and basin combination,

$$m_w c_w T_w = (1 - \rho_w) A_g G_{in} - (\dot{Q}_{ewg} + \dot{Q}_{cwg} + \dot{Q}_{b} + \dot{Q}_t)$$  \hspace{1cm} (6)

For the glazing,

$$\dot{Q}_{ewg} + \dot{Q}_{cwg} + \dot{Q}_{b} + \rho_c A_g G_{in} = \dot{Q}_t = \dot{Q}_{eq} + \dot{Q}_{es} + \dot{Q}_{eg}$$  \hspace{1cm} (7)

Here, it is assumed that the sides’ reflectivity $\rho_c$ is approximately unity so that all $A_g G_{in}$ reaches the water surface while all reflected $\rho_c A_g G_{in}$ goes back to the glazing.

The transfers $\dot{Q}_{ewg}$, $\dot{Q}_{cwg}$, $\dot{Q}_{b}$ are given according to Dunkle as cited by [21] as:

$$\dot{Q}_{ewg} = 0.884 A_g (T_w - T_{gl}) \cos \beta \left( T_w - T_{gl} \right) + \frac{P_{wb} - P_{sg}}{268.9 \times 10^3 - P_{wb}} T_w^{\frac{1}{3}}$$  \hspace{1cm} (8)
\[
\dot{Q}_{rwg} = 0.9A_g \sigma \cos \beta (T_w^d - T_{gl}^d) \\
\dot{Q}_{rwg} = \dot{m}_{w} h_{fg} = 0.013X0.884A_g (T_w - T_{gl}) \cos \beta \left[ T_w - T_{gl} + \frac{P_{wb} - P_{wgl}}{268.9 \times 10^3 - P_{wb}} \right]^{1/3}
\]

Where \(P_{wb}\) and \(P_{wgl}\) are saturation pressures at \(T_w\) and \(T_g\) respectively, all units being standard SI and are given as:

\[
P = \exp \left( 25.317 - \frac{5144}{T} \right)
\]

Because properties and convective transfer rates depend on water temperature \(T_w\), the above equations can be computer-programmed to predict purifier performance if weather data is available. The programs can also be used to guide decision making in selection of key parameters e.g. sizing, installation and even overall economics of the systems. In this paper however, focus is on the experimental comparisons of designs.

3. The designs

Five different single slope stills were designed and constructed. Two of these were with the author’s students. The Mbadinga [22] still is a 50° slope unit with external evaporative cooling-assisted condensation. In the remainder of the paper it is referred to as SS1. The second, SS2 is the Engohang 30° slope unit with forced convection-assisted external condensation [23]. The detailed mathematics of these two stills is slightly different from what is presented above because of external condensation. SS1 however, had a bit of internal condensation because steam extraction was not forced. A small portable and foldable unit (SS3) was developed by the author. Then, together with Engohang, a higher slope and bigger version of SS3 was made. This is SS4. The SS5 unit is - but an ordinary unit as described in section 2. Only that it was mounted on a sun tracking platform designed by two other students, Nteka and Peter. Figure 4 illustrates the purifiers while table 1 gives the key specifications.

![Stills](image1.png)

**Figure 4.** The stills investigated.
Table 1. Key specifications of the 5 stills.

| Still distinguishing characteristic | MBADINGA (SS1) | ENGOHANG (SS2) | KK (SS3) | KK-ENGOHANG (SS4) | PETERNTEKA (SS5) |
|------------------------------------|----------------|----------------|----------|-------------------|------------------|
| Condensation                       | Evaporative cooling, condensation | Fanned steam extraction | Foldable, Portable | Minimal drip-back | Sun tracking |
| Glazing type                       | Double Internal | Double External | Single Internal | Single Internal | Single Internal |
| Glazing thickness                  | 2 X 3mm + 5 mm air | 2 X 3mm + 5 mm air | 1 mm | 3 mm | 3 mm |
| Glazing area (m$^2$)               | 1.000 | 1.500 | 1.200 | 1.500 | 1.500 |
| Base area $A_b$ (m$^2$)            | 0.642 | 1.300 | 0.960 | 1.060 | 1.300 |
| Sides area $A_s$ (m$^2$)           | 1.587 | 1.570 | 1.430 | 2.000 | 1.570 |
| Slope $\beta$°                     | 50.0 | 30.0 | 36.8 | 45.0 | 30.0 |
| Water quantity at 15 mm depth (Litre) | 9.6 | 19.5 | 14.4 | 15.9 | 19.5 |
| Empty solar still mass (kg)        | 42.0 | 28.0 | 9.8 | 15.8 | 18.8 |

4. Experimentation
Sets of experiments were carried out in the month of February 2018 to compare performances of these different units. Although the units are very different from each other, and were tested at different slopes and for the tracking unit, at varying azimuths, it was still possible to evaluate their relative consumer-appeal by considering respective energy efficiencies, costs and productivity on a mass to mass ratio. In this section we give a simple description of the experiments and results as directly obtained. It is in the next section that we critically analyse the results and make comparisons.

4.1. Tools and equipment
- The 5 solar stills as described in section 3
- A Campbell Scientific weather station complete with its data logging system as described in either of [22] and [24].
- Analogue liquid immersion thermometers reading to 0.5 of a Celsius degree
- Type K based fluid immersion Thermometers reading to 0.01 of a Celsius degree
- Measuring jars, graduated in mls as described in [25]
- A purpose-designed hourly sun tracking pillar mount, run by an arduino system programmed stepper motor

4.2. Procedures
- The solar stills were mounted on a flat roof near an adjacent weather station and where the sun tracking pillar had been erected – so that they could all experience approximately the same wind speed as the weather station.
- Liquid immersion thermometers were inserted in holes that had been provided at the bottom of the stills and appropriately sealed off using a silicone compound. These provided the water temperature $T_w$ every 30 minutes.
- For each still, fluid immersion type K based thermometers were inserted through holes in the poly carbonate (PC) glazing to points in middle of the still and just off the inner surface of the glazing. The latter recorded the temperature $T_g$ while the former were intended to check
whether the steam temperature inside was similar to the water temperature $T_w$.

- The 4 stills intended to run in non-tracking mode were oriented to face true North using an i-phone campus, while the tracking still was initially set up to face East.
- Measuring cylinders were positioned at the condensate outlets of the 4 fixed orientation stills while a different container was secured to the exit the tracking still so that the two could turn together. For this, only hourly readings could be taken because of necessity to unsecure the container and pour the condensate into a measuring jar.
- Volumes of cold water to give a 15 mm depth as in table 1 above were filled into the stills and the initial temperature $T_{w-in}$ recorded. At the end of working day, after 7 pm, the stills were drained of all water, and left empty overnight, ready for the next day.
- Readings of temperatures and condensate collection were taken manually as explained above. Ambient weather conditions of horizontal plane total and diffuse radiation flux, temperature and wind speed were however logged automatically every 15 minutes.

Figure 5 shows one of the stills on test.
4.3. **Results**

A lot of data was accumulated in the last two weeks of February 2018. Here, typical data for two of the stills is shown in graphical form in figure 6. The main point is that performance in form of distillate output $m_{ds}$, water and glazing emperatures $T_w$, $T_g$, tended to follow the trend of incident radiation. Save for the sun tracking still SS5, distillate output tended to start later (after 09 00) and in many cases stopped early evening between 18 00 and 18 30, way before sunset.

5. **Analysis and discussion**

The results are discussed from the viewpoints of: Functionality (Energy utilisation and efficiencies), Quality (Still water Temperatures and times), Costs and potential customer appeal (investment productivity). To aid the discussion, table 2 has been prepared from an analysis of the above results.

| Table 2. Performance indicators of the stills: Bold = Best; Italics = least performer. |
| GLAZING AREA (m$^2$) | SS1 | SS2 | SS3 | SS4 | SS5 |
| STILL MASS (kg) | 1.00 | 1.50 | 1.20 | 1.50 | 1.50 |
| ENGINEERING + MANUFACTURING COST (US$ equiv.) | 42.00 | 28.00 | 9.80 | 15.80 | 18.80 |
| FUNCTIONALITY INDICATORS | 240.7 | 233.4 | 164.1 | 218.8 | 328.2 |
| DISTILLATE OUTPUT (L) | 0 | 1 | 1 | 2 | 3 |
| INCIDENT ENERGY (MJ) | 1.53 | 2.95 | 3.61 | 3.45 | 5.11 |
| ENERGY TO PRODUCE DISTILLATE (MJ) | 0.97 | 6.39 | 5.83 | 8.12 | 9.59 |
| TOTAL USEFULLY UTILISED ENERGY (MJ) | 6.50 | 9.35 | 9.43 | 11.57 | 14.70 |
| EFFICIENCIES | 20.7 | 26.6 | 2.45 | 3.40 | 4.04 |
| STILL OPTICAL EFFICIENCY | 24.59 | 27.82 | 27.03 | 25.64 | 36.05 |
| STILL DISTILLATION EFFICIENCY | 16.13 | 18.52 | 22.17 | 18.97 | 27.95 |
| STILL SENSIBLE HEAT EFFICIENCY | 60.50 | 58.50 | 82.00 | 73.50 | 84.00 |

Figure 6. Typical performance of the solar stills: Distillate output tends to follow the incident radiation although it starts ‘late’ and ends ‘early’.
5.1. Functionality indications
Using the Perez diffuse radiation model [20] and the weather station data, incident flux data were derived. Integration of these data across the day for the respective glazing area yielded the total incident energy. The respective components of beam, sky diffuse and ground reflected diffuse radiation and their optical modifiers as received by the glazing yielded the energy which entered the stills. It is seen that the tracking still, SS5 outperformed the others on all these indicators. This is because it had smaller angles of incidence for beam radiation during all hours except for the mid-day hour. Correspondingly, it was able to generate higher temperatures sooner and maintain them longer than any other still.

5.2. Efficiencies
The optical efficiency is the ratio of energy that enters the still to that which is incident on it. It is seen that still SS3 outperformed the others on this indicator. This is because it had the thinnest glazing at 1 mm. This meant very little attenuation of light – much unlike the double glazed units SS1 and SS2. SS1 performed a little worse than SS2 because of its slope (50°) which is more beneficial for a winter sun than for a summer test period. Overall, SS4 had the best thermal efficiency at 45%, accounted for mainly by its best distillation efficiency (32%). This was due to much reduced condensate drip-back into the still when compared with the 30° slope tracking still, SS5.

5.3. Quality
Although the primary purpose of a solar still is to produce distilled water, the fact is that the residual water could be used for hygiene purposes as well. This means the greater the probability to have killed harmful bacteria, the better is the quality of that still. Moreover, the higher the water temperature, the higher the evaporation rate because latent heat of evaporation decreases with temperature. For these two reasons, the author regards still water temperature and how long the water remains at a high enough temperature to kill most bacteria, as a technical indication of still quality. In this case, stills SS5 and SS3 perform best. SS5 does well because of tracking. SS3 does well because of its high optical efficiency and its small mass – meaning it has a low thermal inertia for the increased energy that enters into it.

5.4. Productivity
Productivity may be defined as a ratio of desired result achieved to scarce resource spent. It is different from efficiency in that it is generally not dimensionless. Efficiency compares like quantities (e.g. energy in 5.2 above) while productivity compares often unrelated quantities. In this case, the primary quantity of interest is litres of distillate per day. Four different input resources were chosen for comparison as follows:
- Glazing area – because this item was the most expensive and most useful part in these projects. Still SS5 performed best at 2.69 L/m².day because it kept its glazing exposed to the sun at
better angles than any other.

- Cost – this item may be of greatest interest to potential buyers. Although only materials and manufacturing costs are included here, it is assumed potential sale prices would be in similar relative ratios. Still SS4 performed best at 1.55 L per day for every 100 US$ spent, because of its minimal drip-backs.
- Mass of still – this item may be of interest in regard to handling, transportation and even space occupied vis-à-vis expected outcomes. Still SS3 performed best by virtue of its design as a small, collapsible and portable unit.
- Energy resource – Given the same energy incidence on the stills, should we expect the same distillate output? This is a question most relevant to technical personnel. In this case, still SS4 performed best at 0.48 L/day for every kWh energy incidence. This was again because of its reduced drip-back since less water had to be redistilled.

A secondary output of interest – arising from the discussion on quality in 5.3 is the useful heating power extracted by the still for every square metre of glazing. It combines both sensible and evaporative heating. It is seen that the tracking still uses its glazing best at 0.23 kW for every square metre.

6. Applicability beyond Cape Town
These designs were developed and tested in Cape Town. Would general manufacture, usage and indicated performance be universal, say in the entire developing world? These are three questions in one. A brief attempt will be made to answer them as such.

6.1. Manufacture elsewhere
Whereas aluminium and polycarbonate sheets were the main raw materials in these solar stills, other materials could be used in other countries and regions, depending on availability, cost and local/national standards requirements in those countries. To reduce capital cost, galvanised iron sheets could replace aluminium for example. Or even, a treated wooden outer box could replace the outer aluminium plates. The stills manufacturing processes are fairly straightforward, requiring simple and common hand tools like grip spanners, a riveting gun, etc. A sturdy work bench and sheet metal bending and cutting devices are perhaps the most costly capital items required. Skills requirements are elementary. In short, the units described or their variants could easily be made elsewhere outside South Africa because the material and technical skills requirements are not sophisticated, and are at a level that could be easily obtained in many developing countries.

6.2. Usage and performance elsewhere
That the purifiers can be of use to reduce incidences of water-borne diseases is not for debate. The issue, however, could be the reliability of their performance because of varying climatic conditions throughout the developing world. Regions with weather similar to Cape Town’s summer all year round, i.e. hot, sunny and dry, would be best suited for these stills. In sub-Saharan Africa, these include most of Southern Africa, the Horn region (Somalia and south eastern Ethiopia, Northern Sudan, and the Sahel region.

Places with equatorial and tropical rain patterns, would experience the highest unreliability of the stills because of cloud cover in many months of the year. As an example, figure 7 shows a 2 m² purifier installed in April 2018 by the author at the edge of an equatorial forest in Uganda, East Africa. The unit did not start yielding its design quantity of distilled water (5 Litre/day) until the middle of June 2018, when the dry season began to set in.
Figure 7. A 2 m² solar water purifier installed at a Ugandan homestead in April 2018.

7. Conclusions
This paper has discussed five solar water purifier designs for small households. They were all of single slope mode, as would most easily be adopted by willing and able small homes in rural Africa. Each was unique in its own ways. For example, one tracked the sun while another was collapsible and portable. Yet others had condensation outside the main body. Experimentation as done in Cape Town’s summer month of February was described. Also shown, were the potential applicability of the work in areas beyond the development and test area. Irrespective of differences in sizing, operation modes or even actual shapes, rational methods of comparing the designs in real operating conditions were given. The point was to focus on what is important in use of these units and what it takes to get them to do their job. Thus, means were outlined and illustrated to compare functionality, quality, productivity and costs of the units. Excluding safety and aesthetic appeal, these are the key decision drivers for any would be customer and/or user of the units.

From the results and ensuing discussion, it is concluded as follows:

- Sun tracking is by far a most beneficial mode. It gives superior yields on a per square metre basis and it gives better quality performance as measured by temperatures achieved and how long the useful temperatures are maintained.
- Relatively high slopes (in this case 36 to 45°) are advantageous in so far as they help reduce condensate drip back into the still. This single factor has profound effect on still productivity and on energy efficiencies.
- Use of thin glazing is a cost effective method of improving optical efficiency and still water quality.
- Use of double glazing is neither cost effective nor helpful in improving any of the still performance indicators discussed. Nor is external condensation helpful in improving the indicators.

From these conclusions, the author would like to recommend that: Whenever possible, in such single slope stills of polycarbonate glazing and in weather conditions similar to those of Cape Town’s summer season, use should be made of thin sheets, at slope angles between 35° and 45° in a tracking mode application.

References
[1] IEA 2016 World energy outlook 2016 http://www.iea.org/publications/freepublications/publication/WorldEnergyOutlookSpecialReport2016EnergyandAirPollution.pdf
[2] Akinyemi B E, Mushunje A and Fashogban A E 2018 Factors explaining household payment for potable water in South Africa Cogent Social Sciences 4 1464379 https://doi.org/10.1080/23311886.2018.1464379
[3] Makonesa T, Ifegbesan A P and Rampedi I T 2017 Household cooking fuel use patterns and
determinants across southern Africa: Evidence from the demographic and health survey data Energy & Environment 29 29-48
[4] Barlas R and Yong J L 2010 Cultures of the World Uganda (New York, USA: Marshall Cavendish)
[5] Wabwire F M 2018 State of Uganda Population Report 2017 (Kampala, Uganda: National Population Council)
[6] Mungyereza B P 2017 Population Projections 2015-2020 (Kampala, Uganda: Uganda Bureau of Statistics)
[7] Government of Uganda 2016 Uganda Wetlands Atlas Volume 2 Popular Version (Kampala, Uganda: GOU)
[8] Backer H 2002 Water disinfection for international and wilderness travelers Travel Medicine 2002-34 355-64
[9] Jiang L, Tu Y, Li X and Li H 2018 Application of reverse osmosis in purifying drinking water E3S Web Conferences 38 01037 https://doi.org/10.1051/e3sconf/20183801037
[10] Agea J G, Kirangwa D, Waiswa D and Okia C 2010 Household firewood consumption and its dynamics in Kalisizo sub county, Central Uganda Ethnonotanical Leaflets 14 841-55
[11] Kanyarusoke K E 2017 Solarising Tropical Africa’s rural homes to sustainably overcome energy poverty Proceedings of 2nd New Energy and Future Energy Systems (NEFES) (22-25th Sept 2017, Kunming, China) IOP Conf. Series: Earth and Environmental Science 93 012047
[12] Solargis 2017 Solar resource maps for sub-Saharan Africa The World Bank. Solar resource data: Solargis. https://solargis.com/maps-and-gis-data/download/sub-saharan-africa/
[13] Murugavel K K and Srithar K 2011 Performance study on basin type double slope solar still with different wick materials and minimum mass of water Ren. En. 36 612-20
[14] Nai K H and Modi K V 2018 Pyramid still: A comprehensive review Renewable and Sustainable Energy Reviews 81 136-48
[15] Dev R, Abdul-Wahab S and Tiwari G N 2011 Performance study of the inverted absorber solar still with depth and total dissolved solid APEN 83 252-64
[16] Kalita P, Dewan A and Borah S 2016 A review on recent developments in solar distillation units Sadhana 41 203-23
[17] Yadav S and Sudhakar K 2015 Different domestic designs of solar stills: A review Renewable and Sustainable Energy Reviews 47 718-31
[18] Shultze L M, Rutledge J E, Gfodner R M and Biede S L 1984 Determination of the thermal death time of vibrio cholerae in blue crans (Callinectes sapidus) J Food Prot. 47 4-6
[19] Caslake L F, Connolly D J, Menon V, Duncanson C M, Rojas R and Tavakoli J 2004 Disinfection of contaminated water by using solar irradiation Applied and Environmental Microbiology 70 1145-50
[20] Perez R, Ineichen P, Seals R and Zalenka A 1990 Making full use of the clearness inde for parameterising hourly insolation conditions Solar Energy 45 111-4
[21] Duffie J A and Beckmann W A 2013 Solar Engineering of Thermal processes 4th ed (Hoboken NJ: John Wiley)
[22] Mbadinga P J K 2015 A solar water purification system for rural areas (MTech. Thesis, Mech. Eng. CPUT, Cape Town)
[23] Engohang D and Kanyarusoke K E 2018 Solar water purification: how helpful is double glazing? Presented at The August 2018 ICUE Conf (Cape Town, South Africa)
[24] Kanyarusoke K E, Gryzogaridis J and Oliver G 2016 Validation of TRNSYS modelling for a fixed slope photovoltaic panel Turk. J. EE & CS 24 4763-72
[25] Kanyarusoke K E, Gryzogaridis J and Modify Kaunda M 2018 Component energy efficiencies in a novel linear to rotary motion inter-conversion hydro-mechanism running a solar tracker IJETI 8 49-63