



Solar Household Energy, Inc.

Solar Cooking for Human Development and Environmental Relief

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Instructions for conducting solar cooker power tests using commercial instruments

Paul Arveson

*Director of Research,
Solar Household Energy, Inc.*

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Instructions for conducting solar cooker power tests using commercial instruments

Paul Arveson

Solar Household Energy, Inc.

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The following instructions are for use in measuring the power of solar cookers in accordance with the ASAE S.580.1 protocol (reference 1), which is a standard included in the ISO-19867 standard for cookstove power measurements. Note that in this context, a "test" means activities done in accordance with this standard. An "experiment" is any other kind of activities involving solar cookers.

This procedure uses commercial off-the-shelf instrumentation that is described in reference (2), "A system for standard power measurements of solar cookers". This system allows from two to four items to be tested at one time.

It is assumed that the test items are household-sized panel or box solar cookers with a maximum weight of 15 kg (33 lbs.) each. Water load requirements for each test item have been determined based on the standard protocol. For details on determining the load mass, see reference (3).

Test Instrumentation

The following equipment is used, as prescribed in reference (2):

1. 4-channel 16-bit analog data logger, UX120-006M, Onset Computer Co.
2. 4 signal cables, 2.5mm x 10 ft., Video Products Inc.
3. 4-channel thermocouple data logger, UX120-014M, Onset Computer Co.
4. Type T thermocouple sensors, pack of 5, STC-TT,T,24-72, Omega Engineering Inc.
5. 4 Miniature thermocouple connectors, SMPW-CC-T-M, Omega Engineering Inc.
6. Silicon diode pyranometer, Institute for Earth Science Research and Education OR Apogee SP-212 amplified pyranometer (or both).

The system of reference (2) is battery powered, so no extra power supplies are needed with these instruments and they are fully portable.

The data loggers require a Windows PC laptop computer loaded with the free HOBOWare software, which can be downloaded from <http://www.onsetcomp.com/products/software/hoboware>. Manuals for the data loggers are also available online from the manufacturer (reference 4).

Additional Equipment needed for tests

- White, ventilated box for test instruments (or a "Stevenson box")
- Small level
- Duct tape

- A collection of clips or clothespins
- 1-liter polypropylene graduated pitcher
- 1-liter beaker
- Bottles of distilled water sufficient for test items (store outside in a dark location)
- Large funnel
- Digital kitchen scale with capacity up to 5 kg, resolution 1 g
- Kitchen timer
- Digital camera
- Test record binder with blank test forms (see Appendix A)
- Electronic weather gauge with anemometer, thermometer and hygrometer (optional)
- Hand-held lux meter (optional; see report TR-17)
- Cooking pots as recommended by the manufacturer. In some cases, it may be necessary to pre-drill a small hole in the side of the cooking pot for the thermocouple wire, which is then sealed with silicone sealant.

Preliminary decisions

Decide on the purpose of the test. Typically, only one test can be done in a day. The instruments allow up to four solar cookers to be measured at one time, but a minimum of two are to be measured. Generally, there are two types of tests:

1. Power measurements of two or more cookers that are copies of the same manufactured product. The purpose of these measurements is to determine the power and its repeatability across different copies, under the same sun conditions.
2. Comparison measurements between item A and item B, where there is one (and only one) change between A and B. Such controlled tests will permit answers to questions about which design is better than another (at least within the limits of repeatability previously established).

A location for the tests must be identified that is free from shade from 10am – 3pm, and not vulnerable to disturbance by people or animals. If possible, the tests should be conducted on the flat roof of a building.

According to the standard (1), tests cannot be done when the ambient temperature is less than 20 C or greater than 35 C. Wind speed near the cookers should be lower than 1 m/s in a 10-minute average.

Preliminary steps

The following steps should be done early in the morning prior to a test. Allow about an hour to set up test vessels and instruments before the test.

Fill in a test record form to describe the purpose of each test, along with a description of each test item and current weather data.

Measure the dry mass of each test item prior to the test and record the data on the test record form. A blank form is included at the end of this document as Appendix A.

It is strongly recommended not to place thermocouple wires across the lid in covered pots. Experiments have shown that lid gaps are a major cause of heat loss in low-powered solar cookers. If there is no suitable hole in the pot lid, you will need to drill a small hole in the side of metal pots to accommodate a thermocouple wire.

Preparing the data loggers

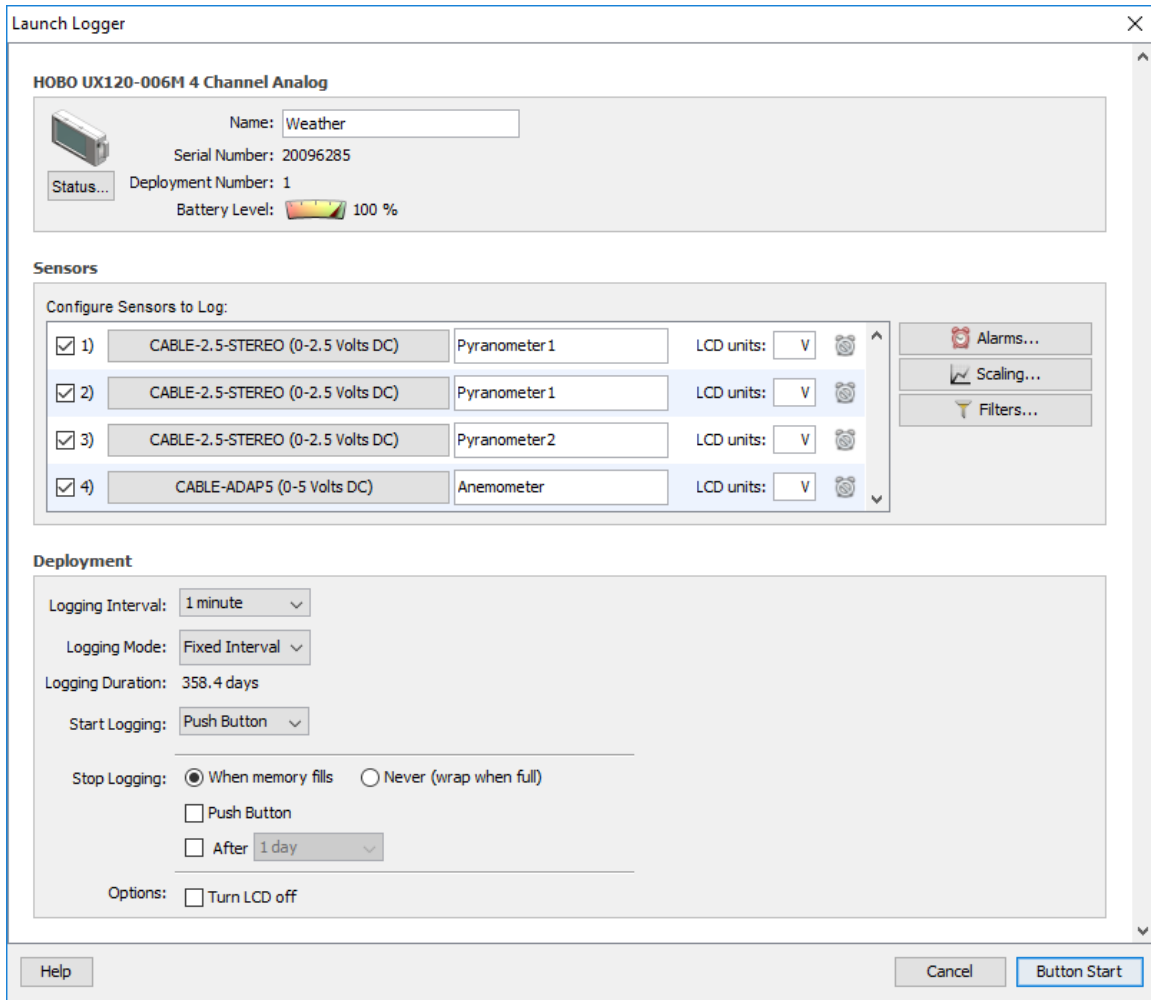
Using a laptop computer, start HOBOWare.

Launch the Weather data logger:

Plug the 4-channel Analog data logger into the laptop computer using a USB to mini-USB cable. You should see the device type and serial number identified at the bottom of the HOBOWare window.

Select Device -> Launch

This will open a window that provides fields in which you can label the name of the data and the names of each channel. This will allow you to keep track of what is on what channel.



For the analog data logger, enter the name "Weather" at the top.

Note that for the analog data logger, to label the channels you need to click the pulldown menu and select Adapter cable, which then allows you to select the CABLE-2.5-STEREO option. Then the full range of the data logger is 2.5 V. This is the range recommended for self-powered pyranometers; they have very low voltage output.

When the channels are properly labeled, select:

Logging Interval: 1 minute

Logging Mode: Fixed Interval

Start Logging: Push Button - this option will start the data logger when the little button on the top left of the unit is pressed and held for a few seconds. This is recommended so that you can start two or more data loggers at nearly the same time. (If desired, one of the other start options may be used: Now, or at a specified future time).

Stop logging: When memory fills (this will not actually happen in these tests).

Click the "Button Start" button at the lower right side of the window. This will send signals to the unit to get it set for the requested measurements. It will display "...". Then unplug the USB cable from the computer.

Launch the thermocouple data logger


For the 4-channel thermocouple data logger, please carefully note the numbers on each thermocouple connector and plug them into the corresponding channel on the data logger. (The thermocouple wires should have tags or labels added mid-length to help identify the channel numbers.)

Now plug the 4-channel thermocouple data logger into the laptop computer using a USB to mini-USB cable. Select Device -> Launch.

This will open a window that provides fields in which you can label the name of the data and the names of each channel. This will allow you to keep track of what is on what channel.


Launch Logger

HOBO UX120-014M 4 Channel Thermocouple

 Name:





Serial Number: 20104844

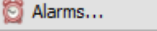
Status... Deployment Number: 1

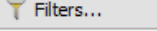
Battery Level:  100 %

Sensors

Configure Sensors to Log:

<input checked="" type="checkbox"/>	1)	Thermocouple (T-Type)	<input type="text" value="T1"/>	
<input checked="" type="checkbox"/>	2)	Thermocouple (T-Type)	<input type="text" value="T2"/>	
<input checked="" type="checkbox"/>	3)	Thermocouple (T-Type)	<input type="text" value="T3"/>	
<input checked="" type="checkbox"/>	4)	Thermocouple (T-Type)	<input type="text" value="T4"/>	
<input checked="" type="checkbox"/>	5)	Temperature	<input type="text" value="T5"/>	

 Alarms...

 Filters...

Deployment

Logging Interval: ▾

Logging Mode: ▾

Logging Duration: 249.3 days

Start Logging: ▾

Stop Logging: When memory fills Never (wrap when full)

Push Button

After ▾

Options: Turn LCD off

For the thermocouple data logger, enter the name "Therm" at the top.

Add the numbers on the thermocouple connectors in the Sensors channel fields. Note that there is an additional fifth channel, which is for the internal reference thermistor that measures the ambient temperature.

When the channels are labeled, select:

Logging Interval: 1 minute

Logging Mode: Fixed Interval

Start Logging: Push Button - this option will start the data logger when the little button on the top left of the unit is pressed and held for a few seconds. This is recommended

so that you can start two or more data loggers at nearly the same time. (If desired, one of the other start options may be used: Now, or at a specified future time).

Stop logging: When memory fills (this will not actually happen in these tests)

Click the "Button Start" button at the lower right side of the window. This will send signals to the unit to get it set for the requested measurements. It will display "....". Then unplug the USB cable from the computer; you are ready to conduct a test.

Create metadata file

All of the descriptive data for this test must be recorded in a "metadata" file in Excel. This file has the format as shown in Appendix B. The file name should be "Meta_" followed by the date, as yyymmdd. Also, change the name of the worksheet to match the file name (without .xlsx).

Load the test vessels with water

The ASAE S.580.1 standard requires a load of 7 kg of water per square meter of reflector intercept area for each solar cooker. This requires the intercept area of the solar cooker to be measured before tests can be performed. See reference (2) for detailed steps for measuring the intercept area. The table in Appendix C gives a list of the amount of water to use for several common solar cooker models.

Since the power measurement is entirely dependent on a change in water temperature, it is important to maintain the starting temperature near the ambient and identical in all test vessels. The following points are recommended:

- Use distilled water. That way the water can be reused in subsequent tests without building up residues due to boiling of typical tap water.
- Store the water in the shade but outdoors. This will ensure that the water is nearly at ambient temperature at the start of the measurements.
- Use a graduated plastic pitcher of 1-liter capacity. Measure the mass of the dry pitcher with the digital scale and record it. This pitcher will be used to fill the test vessels.

After filling each test vessel, keep the reflectors pointed away from the sun and/or place a white cloth over it. This will help to keep the starting temperature near the ambient.

Position thermocouples in cooking pots

It is strongly recommended not to place thermocouple wires across the lid in covered pots. Experiments have shown that lid gaps are a major cause of heat loss in low-powered solar cookers (reference 5). If there is no suitable hole in the pot lid, you will need to drill a small hole in the side of metal pots to insert the thermocouple wire, and then seal it with silicone sealant. Since four channels are available, you may insert redundant thermocouples in the same pot. The PFA insulation of the wires is fairly stiff and suitable for temperatures up to 260 deg. C. Bend the end of the thermocouple sensors in a small U shape to keep them from touching the sides of the pot. Ensure that

sensor tips are submerged and are not touching the pot. (It has been found by experiment that precise positioning of thermocouples is not necessary, so long as they remain submerged.)

If cooking bag(s) are to be used in the test, place them around the pots before filling to reduce the risk of spillage, and place the thermocouples through the bags and into the pots. Then seal the bags.

When to start the test

According to the ASAE protocol, the test must be conducted between 10am and 2pm local solar time. Determine the weather forecast for the day. Examine web sites, radio and/or TV for this information. Examine satellite imagery if available. Tests should be conducted only on relatively clear days with less than 10% cloud cover.

Set up the instrument box at the test location to allow its internal thermometer to equilibrate to the ambient temperature. Then set out the test items near the instrument box but aim their reflectors away from the sun or cover the test items with white or reflective cloth until the test starts. An even better method would be to cover the entire set of instruments and cookers with a reflective roof to keep them in the shade until the data loggers are started.

If clouds are present after 10am, you may want to wait a while before starting the data loggers. The initial hour or two is the most important for power calculations, so these measurements should be made only when the sky is clear.

Start the test

Keep test vessels covered while preparations are made, to prevent premature heating. When all thermocouples have been installed, remove covers to expose the cookers and aim them in the sun direction. Immediately press the start buttons on both data loggers (top left side). You will need to hold the buttons down for a few seconds until the word "Hold" disappears. The units will display four numbers representing the signals from all channels, and the display will say "logging".

Fill in the weather data in the test record form. This will provide a backup data set.

Take photographs of the test arrangement as part of the documentation. Suggested views: a) overall test arrangement; b) closeups of each cooking vessel showing thermocouple wires. It is important to confirm that thermocouple tips are always submerged in water in the pots.

Turn the solar cookers at intervals in accordance with the manufacturers' recommendations. Typically, a 1-hour interval is used. You may wish to use a cooking timer to facilitate this. At these times, also check the data logger displays to see that values are as expected.

End the test

According to the ASAE protocol, the test must be conducted between 10am and 2pm local solar time. (Extensions of 9am to 3pm may be acceptable). Near the end of the test you can use a hand-held pyrometer or an infrared imaging camera, if available, to identify the “hot spots” where most heat is being lost.

If the water in all cooking vessels has appeared to reach boiling, there is no need to continue collecting data. When you decide to stop the test, turn the reflectors away from the sun and remove the lids or cooking bags from all pots to let them cool.

Plug each data logger, one at a time, into the laptop computer with the USB cable. Select Device -> Readout.... It will ask "Do you want to stop the data logger?" to which you say Stop. The data is then quickly dumped into the computer and the data logger enters the Stop mode.

The software then gives you the opportunity to plot the data. Then a quick plot of the time series for each sensor is plotted on the screen. You can examine this to get a quick check on the validity of the data.

Export the logger data

The raw data from the two data loggers is stored in a proprietary “.hobo” format. In order to make use of the data in other programs, you will need to store the values in Excel (.xlsx) format, which can be read directly by Excel. Go to File -> Export Table Data. Then click Export on the button in the lower right. This will do the conversion and allow you to store the data in a file name of your choice. The required file name format for the pyranometer/anemometer data is “Weather_” followed by the date, as yyyyymmdd. Likewise, for the thermocouple data the format is “Therm_” followed by the date.

Each of the three input files must have one worksheet with the same file name (minus the extension .xlsx). This worksheet name is automatically added to the exported data by the HOBO software.

Make sure to complete the information on the manual test record form (Appendix A). You are welcome to modify this form as needed to include space for useful information. Keep these test record forms in a binder for future reference.

When cooled, recycle the distilled water into storage containers and leave outside in a shaded place.

Process the data to calculate power

Power calculations in accordance with ASAE standard S.580.1 have been programmed in Python 2.7, and a distribution package has been prepared with all of the necessary code and documentation (reference 6). This program accepts data from the three Excel files specified earlier (Meta_, Weather_ and Therm_).

This program is intended to run within the Anaconda – Jupyter Notebook environment. This software is freely available from the Anaconda download site, <https://www.anaconda.com/download/>. It is available for Windows, Mac or Linux platforms. The program will process the data and show all the intermediate steps, including graphics, so that the user can diagnose any issues easily.

A more compact, executable program is in development. User comments and suggestions are welcome.

Report final data

The output from the Python program is a set of four Excel files that contain the power estimates for each of the four channels of data. The distribution package (6) contains a complete example of input, program and output data, as well as a manual compilation of the four data files onto one spreadsheet with a composite graphic. This format would be useful for comparison of the performance of two or more solar cookers.

Appendix A. Solar Cooker Test Record Form – 4 Test Items

Purpose of test: _____

Technician: _____ Date: _____

Location: _____

Photos taken? _____ Dataloggers started? _____ Timer started? _____

	Test item 1	Test item 2
Reflector description		
Pot description		
Thermocouple no.		
Load description		
Mass of load before		
Mass of load after		

	Test item 3	Test item 4
Reflector description		
Pot description		
Thermocouple no.		
Load description		
Mass of load before		
Mass of load after		

Turning interval: _____ **Data at each turning interval:**

Time	Amb. Temp. F	Humidity %	Wind Speed mi/hr	Sky Appear.	Luminance lux	Angle re. sun

Appendix B.
Metadata file content and format for input into Python program
Cooker_Power3.ipynb

Note: Channel numbers are labeled 0,1,2,3 to be consistent with Python indexing, which starts at 0.

Variable	Channel	Description	Example
<i>date</i>	0	Date of test	20160923
<i>location</i>	0	Location of test	Rockville, MD USA
<i>technician</i>	0	Name of person conducting test	Paul Arveson
<i>latitude</i>	0	Latitude of test	39.047563
<i>longitude</i>	0	Longitude of test	-77.141155
<i>elevation</i>	0	Elevation at test location in meters	122
<i>pdesc</i>	0	Description of primary pyranometer	Brooks pyranometer
<i>poffset</i>	0	Pyranometer offset voltage	0
<i>psens</i>	0	Pyranometer calibration in W/m ² /V	4650
<i>adesc</i>	0	Anemometer description	Adafruit anemometer
<i>aoffset</i>	0	Anemometer offset voltage	0.4
<i>asens</i>	0	Anemometer calibration in m/s/V	21.17
<i>label</i>	0	Thermocouple channel 0	T1
<i>label</i>	1	Thermocouple channel 1	T2
<i>label</i>	2	Thermocouple channel 2	T3
<i>label</i>	3	Thermocouple channel 3	T4
<i>disregard</i>	0	Channel data not used	0
<i>disregard</i>	1	Channel data not used	0
<i>disregard</i>	2	Channel data not used	0
<i>disregard</i>	3	Channel data not used	0
<i>cooker</i>	0	Description of test item in channel	Haines #1 pot Ultra-black with #1 reflector
<i>cooker</i>	1	Description of test item in channel	Haines #1 pot Ultra-black with #1 reflector
<i>cooker</i>	2	Description of test item in channel	Haines #2 pot with #3 reflector
<i>cooker</i>	3	Description of test item in channel	Haines #2 pot with #3 reflector
<i>intercept</i>	0	Altitude angle in deg. for maximum intercept area of reflector for this channel	30
<i>intercept</i>	1	Altitude angle in deg. for maximum intercept area of reflector for this channel	30
<i>intercept</i>	2	Altitude angle in deg. for maximum intercept area of reflector for this channel	30

<i>intercept</i>	3	Altitude angle in deg. for maximum intercept area of reflector for this channel	30
<i>area</i>	0	Reflector area in sq. m at angle of maximum area for this channel	0.35
<i>area</i>	1	Reflector area in sq. m at angle of maximum area for this channel	0.35
<i>area</i>	2	Reflector area in sq. m at angle of maximum area for this channel	0.35
<i>area</i>	3	Reflector area in sq. m at angle of maximum area for this channel	0.35
<i>mass</i>	0	Load mass in kg for this channel	2.45
<i>mass</i>	1	Load mass in kg for this channel	2.45
<i>mass</i>	2	Load mass in kg for this channel	2.45
<i>mass</i>	3	Load mass in kg for this channel	2.45
<i>cv</i>	0	Heat capacity of load, J/g deg. C for this channel	4186
<i>cv</i>	1	Heat capacity of load, J/g deg. C for this channel	4186
<i>cv</i>	2	Heat capacity of load, J/g deg. C for this channel	4186
<i>cv</i>	3	Heat capacity of load, J/g deg. C for this channel	4186
<i>notes</i>	0	Notes about test to be displayed in report	Reflector #1 is slightly more hazy than #3; see photographs.

Appendix C. Area measurements of some solar cookers

These measurements were acquired using the procedure described in Technical Report TR-10 (reference 3). The data represent an average of two or more calculations of area using program ImageJ. There is an uncertainty of about 5% in these data and they should be considered preliminary.

Description	Area, m²	Load, liters of water	Angle of max. area
HotPot with "Morningstar" reflector	.332	2.324	
Solavore "Sport" box cooker with added reflector	.430	3.01	
All Season Solar Cooker v. 1.0	.339	2.373	
All Season Solar Cooker v. 2.0	.414	2.90	
Solar Clutch "Polyfurnace"	.495	3.45	
Haines Solar Cooker Model 1	.35	2.45	30
Haines Solar Cooker Model 2			

References

1. American Society for Agricultural and Biological Engineers ASAE S.580.1, "Testing and Reporting Solar Cooker Performance", Nov. 2013.
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