



Performance Evaluation Process (PEP)
Preliminary Results Report
31 July 2017

Solar Cooker: SK-14
Manufacturer: Muni Seva Ashram
Cookware: Granite-Ware
Greenhouse material: None
Standard Cooking Power: 347 Watts
SCI Test Code: PEP.P07

Solar Cookers International (SCI) Testing Center: Hastings-on-Hudson, New York, USA
A Regional Testing and Knowledge Center, listed by the Global Alliance for Clean Cookstoves
Tester – Alan Bigelow, Ph.D.

Introduction:

Solar Cookers International (SCI) developed dedicated instrumentation and software for a performance evaluation process (PEP) to conduct the ASAE S580.1 protocol for testing and reporting solar cooker performance. Testing is conducted at SCI testing centers in California and New York as well as at partnered, regional network testing centers. In addition, SCI is the testing center convener, providing standard operating principles (SOPs) and quality assurance recommendations. SCI also maintains a global data bank of solar cooker testing results accessible by testing participants, NGOs and those in a decision-making position. This enables informed choices as far as what is best suited for a specific application based on the comparative data.

Background:

SCI conducted preliminary tests on the SK-14 parabolic reflector solar cooker in accordance to the ASAE S580.1 protocol. The cooker was manufactured and donated by Muni Seva Ashram. The SCI standard PEP test station was used for automated, real-time data acquisition for wind speed, solar irradiance, geographic position, and ambient and cooking temperatures. Data were stored in a space delineated file on an SD card for subsequent post processing. Test equipment was calibrated prior to testing. Data acquisition occurred over the course of one day, under atmospheric conditions suitable for the testing protocol. Test results are summarized in this report with raw data available upon request. Raw data and results can be posted on the SCI PEP website (www.solarcookers.org/PEP) once customer agrees and releases it in writing.

Test Equipment:

Electronics platform	Weather-proof enclosure contains: Arduino Mega open-source electronics, liquid crystal display and removable SD card
Temperature	Type K thermocouples for measuring water and ambient temperatures
Wind speed	Anemometer (Adafruit, New York, New York, USA)
Solar irradiance	SP-215 amplified pyranometer (Apogee Instruments, Inc., Logan, Utah, USA) mounted to a horizontal, bubble-leveled plane, as suggested by the manufacturer
Additional	global positioning system

Test Setup:

- Position test station with pyranometer wire connector parallel to North / South compass direction.
- Level the pyranometer using the bubble level on mount fixture.
- Insert thermocouple plugs into sockets and ensure ambient probe is out of direct sunlight.
- Insert test probes into pot lids securing with threaded nut.
- Setup Solar cookers and place test pot bottom in cooker.
- Connect 12 VDC battery pack to test station.
- Add pre-measured quantities of test water to cookers and cover with pot lids.
- Compare ambient temperature to cooker temperatures on display and if they are within 2 °C then press the reset button to restart test and begin testing. If cooker temperatures are below ambient then wait until temperatures approximately equalize to start testing by pressing reset. If starting temperatures are more than 2 °C above ambient then change water and wait for it to reach ambient temperature in cooker and then push reset to start testing.
- Adjust cooker every 20 minutes to track the sun.

Test Station Variables (sample from 31 July 2017):

Variables	Value	Variables	Value
test_time_hrs	4	Interval (min)	10
Delays (mS)	400	Ambient (C)	3
wind_min_volt	0.4	smth_wndw	10
temp_cal	1	Elevation(Angle)	62.78
GPS_Wait (min)	10	norm_aptr(Angle)	62.78

Solar cooker parameters:

- Solar cooker type: Parabolic reflector
- Cookware: Granite-Ware 15.5 U.S. Qt. Stock Pot
- Greenhouse: None
- Cooker elevation angle: adjustable
- Aperture area, maximum: 0 m²
- Reflector area, maximum: 1.539 m²
- Intercept (Aperture + Reflector) area, maximum: 1.539 m²

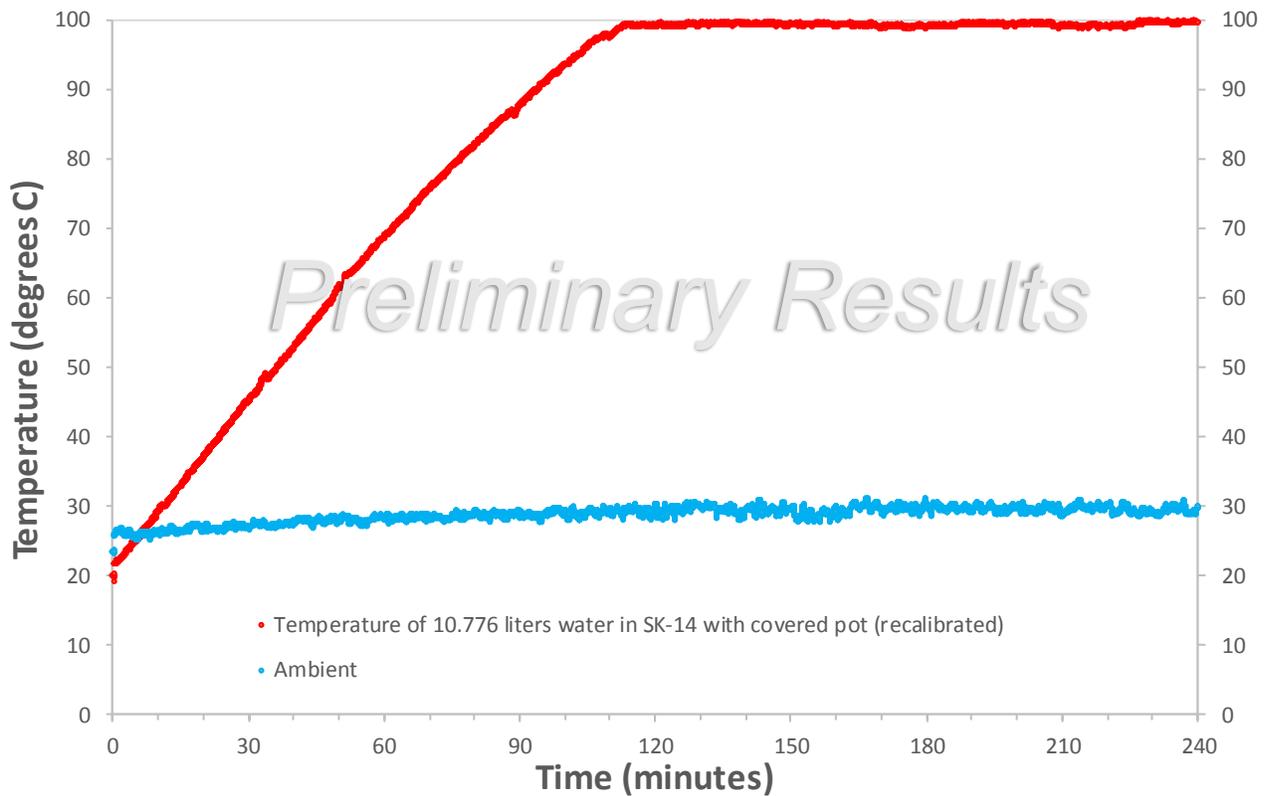
Test Results:

	Test 1	Test 2	Test 3
Test Date	31 July 2017		
Latitude	40°59'33.2"N		
Longitude	73°52'47.1"W		
Altitude	46 m		
Average Sun Elevation Angle	62.78 degrees		
Effective intercept area	1.539 m ²		
Test Load	10,776 g		
Solar Noon	13:03 PM		
Test Duration	4 hours		
Time Start	11:15 AM		
Time Finish	3:15 PM		
Tracking interval	20 minutes		
Average ambient temperature	28.9 °C		
Average Wind Speed	0.00 m/s		
Number of observations	8		

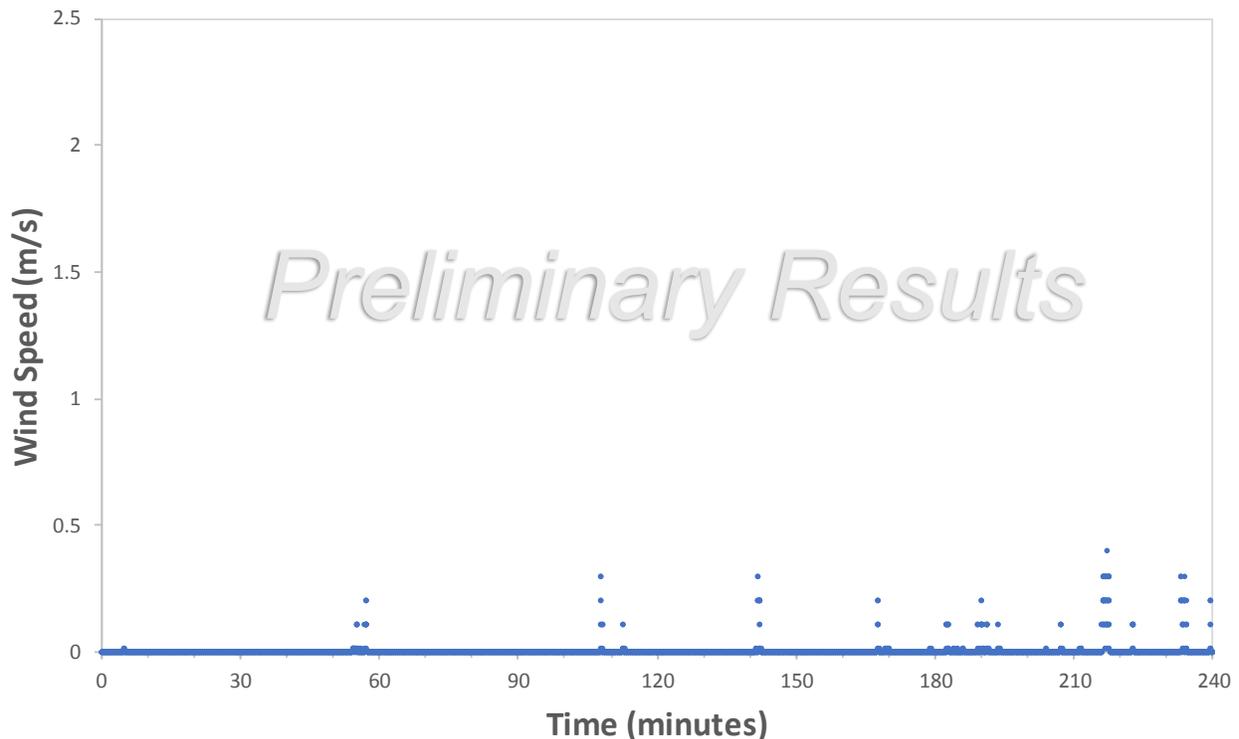
Results

This thermal performance evaluation for the SK-14 parabolic reflector solar cooker took place on 31 July 2017. Graphical visualizations of acquired data are shown below for temperature, wind speed and solar irradiance. Following customer's approval, files of raw data for this one-day test will be available at the SCI PEP website, for SCI Test Code: PEP.P07: www.solarcookers.org/PEP

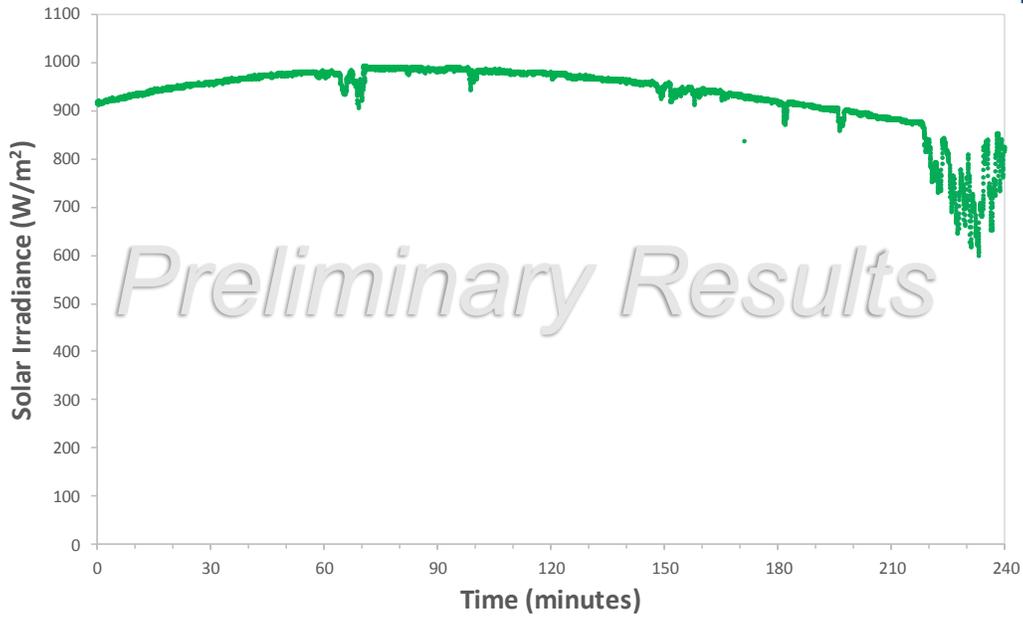
Test day 1: 31 July 2017



Temperature profile of 10.776 liters of water (in red) and ambient air (in blue) recorded on 31 July 2017 while monitoring an SK-14 parabolic reflector solar cooker and a Granite-Ware cooking vessel.

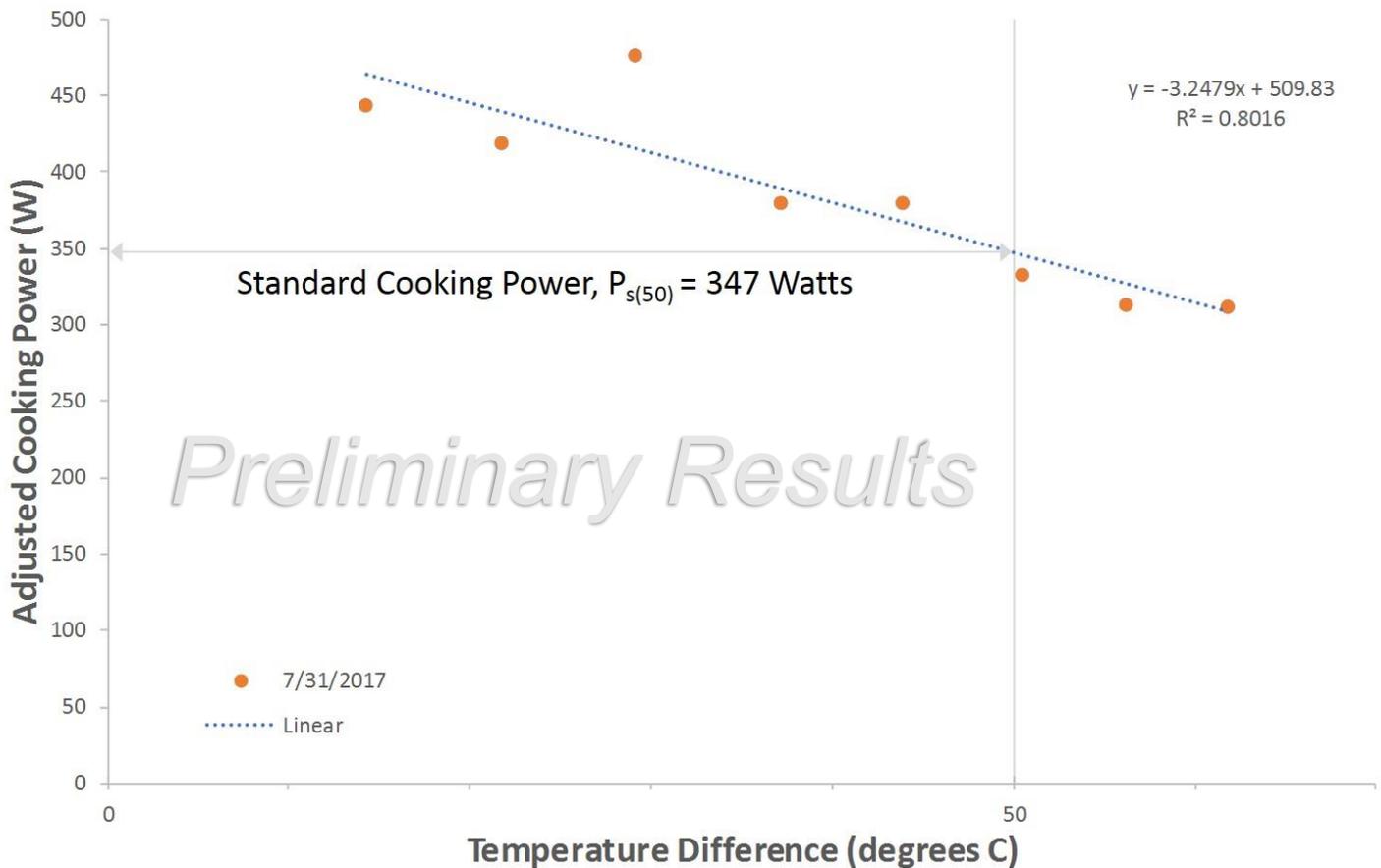


Wind speed recorded on 31 July 2017. This graph shows windspeed values within the constraints of the ASAE S580.1 protocol; hence, there were no rejected data points due to excessive wind conditions.



Solar irradiance recorded on 31 July 2017. This graph suggests cloud coverage toward the end of the test; hence, some 10-minute observations may have been rejected due to excessive variation of solar irradiance.

Final Results: Adjusted cooking power values and the standard cooking power



Adjusted cooking power for the SK-14 solar cooker recorded by an SCI PEP test station on 31 July 2017. While these preliminary results from one day of testing produced fewer than the 30 observations required by the ASAE S580.1 protocol, the linear fit suggests a value for the standard cooking power: 347 Watts.

APPENDIX A: Standard Cooking Power Calculation

The ASAE S580.1 protocol¹ provides a single measure of performance for solar cookers: the standard cooking power, $P_{s(50)}$, in Watts, for a cooking temperature 50 °C above ambient temperature. Cooking power is calculated from measurements of temperature change in an amount of water proportional to a cooker's intercept area (7000 g/m²). Results are normalized using incident solar radiation, allowing comparable results independent of testing date and location.

To summarize the ASAE S580.1 protocol, it first calculates the cooking power for a solar cooker using the following equation, where P_i is the cooking power (W) for a 10 minute interval i ; T_2 is the final water temperature (°C); T_1 is the initial temperature (°C); M is water mass (kg); and C_v is heat capacity of water (4186 J/[kg °C]).

$$P_i = \frac{(T_2 - T_1)MC_v}{600} \quad (\text{eq. 1})$$

Adjusted cooking power, P_s , for each 10-minute interval is corrected to a standard insolation of 700 W/m² by multiplying cooking power P_i by 700 and dividing by the interval average insolation I_i ; a term used interchangeably with irradiance in this article.

$$P_s = P_i \left(\frac{700}{I_i} \right) \quad (\text{eq. 2})$$

Standard cooking power, $P_{s(50)}$ (W), the single measure of performance for a solar cooker, is determined where a linear regression fit to adjusted cooking power values (from no fewer than 30 ten-minute observations, and plotted with respect to temperature above ambient) crosses the temperature-difference value of 50 °C.

ASAE S580.1 data collection

The test results are presented as adjusted cooking power values (in Watts) with no fewer than 30 total (10-minute) observations over three different days. The standard cooking power is determined from a linear fit to the adjusted cooking power values and is presented as a single measure of thermal performance (in Watts) so consumers may compare different designs when selecting a solar cooker

NOTE: for product labeling and sales literature an independent laboratory using a statistically adequate number of trials shall determine this number. While this value, like the fuel economy rating of an automobile, is not a guarantee of performance, it provides consumers with a useful tool for comparison and product selection.

ASAE S580.1 protocol requirements for data collection satisfy the following constraints:

1. **Average wind.** Tests shall be conducted when average wind during the duration of the test is less than 1.0 m/s, measured at the elevation of the cooker being tested and within ten meters of it.
2. **Maximum wind.** Should the wind exceed 2.5 m/s for more than ten minutes the test data shall be discarded.
3. **Wind shielding.** If a wind shelter is required, 1) it shall be designed so as to not interfere with incoming total radiation and 2) the wind instrumentation shall be co-located with the cooker in the same wind shadow.
4. **Ambient temperature.** Tests should be conducted when ambient temperatures range between 20 and 35 °C.
5. **Water temperature.** Test data shall be recorded while cooking vessel contents (water) are at temperatures between 5 °C above ambient and 5 °C below the local boiling point.
6. **Insolation.** Available solar energy shall be measured in the plane perpendicular to direct beam radiation (the maximum reading) using a radiation pyranometer. Variation in measured insolation greater than 100 W/m² during a ten-minute interval, or readings below 450 W/m² or above 1100 W/m² during the test shall render the test invalid. For convenience, the pyranometer may be fixed on the cooker at the average

beam radiation zenith angle as calculated for the entire test period. NOTE: The pyranometer on an SCI PEP test station mounts to a horizontal, bubble-leveled plane, as suggested by the manufacturer. While this positioning differs from the ASAE S580.1 protocol, trigonometric corrections to SCI solar irradiance measurements give accurate results within instrument tolerance, for solar irradiance incident on solar cookers being tested.

7. **Solar zenith and azimuth angle.** Tests should occur between 10:00 and 14:00 solar time. Exceptions necessitated by solar variability or ambient temperature shall be noted.

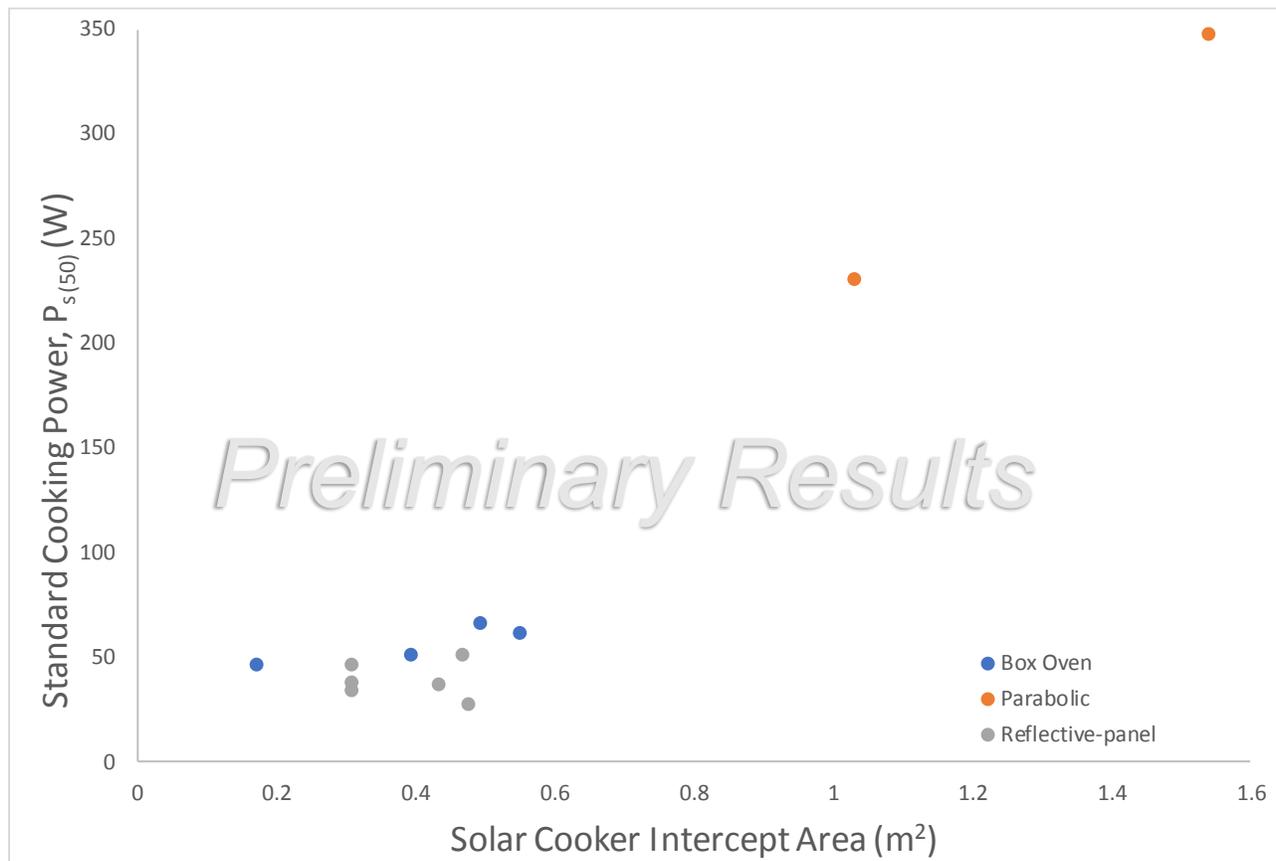
References:

1. American Society of Agricultural and Biological Engineers. (2013). ASAE S580.1 Testing and Reporting Solar Cooker Performance. St. Joseph: American Society of Agricultural and Biological Engineers; <https://www.asabe.org/media/200979/s580.1.pdf>

APPENDIX B: Comparative results

During spring and summer of 2017, SCI applied the PEP testing stations at SCI testing centers in New York, USA and in California, USA for preliminary trials for the three basic types of solar cookers: reflective-panel, box oven, and parabolic reflector. Several solar cooker manufacturers donated products for these trials, and given the preliminary nature of these trials, these manufacturers remain anonymous here.

Preliminary SCI PEP results indicate the standard cooking power (in Watts) for each solar cooker tested. These standard cooking powers, which are each a single measure of performance for a particular solar cooker, are plotted below as a function of intercept area. This graph depicts the general trend that standard cooking power tends to scale with intercept area. These preliminary results are shown for informational purposes only.



Graph of standard cooking powers for the basic types of solar cookers (box oven in blue, parabolic reflector in orange, and reflective-panel in grey, plotted as a function of intercept area.