

Development of a Performance Evaluation Process (PEP) for Solar Cookers

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At the 2014 SCI World Conference in Sacramento, CA the solar-cooking sector requested there be a performance evaluation process for solar cookers.



Solar Cookers International:

- SCI is a neutral international agency that represents the solar-cooking sector.
- SCI is responding to the request from 2014, and through a transparent process, is developing a performance evaluation process (PEP) for solar cookers.
- SCI is suggesting PEP based on ASABE S580.1 Testing and Reporting Solar Cooker Performance, which Harmonizes with **GACC** and **ISO 285**.

Goals

- Establish an agreed-upon PEP for testing solar cookers
- Promote PEP to GACC testing centers
- Benefit customers, manufacturers and project leaders

ASABE S580.1

- Testing time during mid day (solar noon +/- 2 hours)
- Load a solar cooker with water: 7000 g/m^2
- During evaluation, record: water temperature, ambient temperature, wind speed, and solar energy
- Calculate the cooking power for 10-minute intervals
- Normalize / adjust results according to input energy
- Plot cooking power v. temperature difference from ambient
- Provide a single power measure of thermal performance



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Testing and Reporting Solar Cooker Performance

Initiated by the Test Standards Committee at the Third World Conference on Solar Cooking (Coimbatore, Tamil Nadu, India, 9 January 1997); further input from the Third Latin American Congress on Solar Cookers (La Ceiba, Atlántico, Honduras, March 2001); final development by the ASAE Solar Energy Committee SE-414 March 2002; approved by the ASAE Structures and Environment Division Standards Committee January 2003; reaffirmed February 2008; periodic review extended for two years December 2012; revised November 2013.

Keywords: Reporting, Solar, Solar Cooking, Testing

1 Purpose and Scope

1.1 This Standard is intended to:

1.1.1 Promote uniformity and consistency in the terms and units used to describe, test, rate, and evaluate solar cookers, solar cooker components, and solar cooker operation.

1.1.2 Provide a common format for presentation and interpretation of test results to facilitate communication.

1.1.3 Provide a single measure of thermal performance so consumers may compare different designs when selecting a solar cooker.

1.2 The scope of this Standard includes:

1.2.1 All solar powered batch-process food and water heating devices (solar cookers). Devices designed to desiccate (dryers) are not covered.

1.2.2 Within the scope of this Standard a solar cooker shall be understood to include the cooking vessel(s) together with associated supporting, heat transfer and heat retention surfaces, heat storage and transfer media and associated pumps and controls, light transmitting and reflecting surfaces, and all associated adjustments, supports, and solar locating and tracking mechanisms as may be integral parts of a particular solar cooker.

1.2.3 Estimates of cost and durability vary significantly by location and are not within the scope of this standard.

1.2.4 Estimates of consumer satisfaction are subjective and are not within the scope of this standard.

2 Normative References

Indian Standard IS 13429, 1992, Solar Cooker- (3 Parts).

3 Terminology

3.1 **absorber plate:** Darkened surface converting light energy into thermal energy.

3.2 **angle, azimuth:** The angular displacement from south of the projection of beam radiation on the horizontal plane.

3.3 **angle, zenith:** The angle subtended by a vertical line to the zenith (point directly overhead) and a line directly to the sun.

3.4 **beam radiation:** Solar radiation received directly from the sun without atmospheric scattering.

3.5 **box-type cooker:** A solar cooker with a well-insulated volume for the cooking vessel(s), typical designs having from zero to four plane mirrors.

3.6 **concentrating-type cooker:** Any of various designs characterized by multiple planes or curved reflective surfaces. Many designs lack insulated walls but have large intercept areas to compensate for their comparatively greater heat loss.

3.7 **intercept area:** The sum of the reflector and aperture areas projected onto the plane perpendicular to direct beam radiation (Figure 1). For convenience, use the average beam radiation zenith angle as calculated for the entire test period.

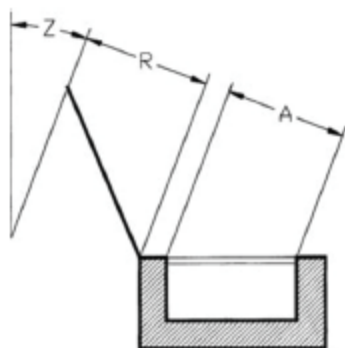


Figure 1 – Determining the intercept area. Reflector area is reflector width times its apparent height, R, and aperture area is aperture width times its apparent height, A. Apparent height is the shadow or projected height in the plane perpendicular to beam radiation of zenith angle, Z.

3.8 **load:** The mass of water being heated by the solar cooker.

3.9 **test:** All events and data comprising the measured solar heating of water in a device intended to cook food.

3.10 **tracking:** Rotating the cooker in the horizontal plane to compensate for azimuth angle changes (box-type) or following the sun in two dimensions (concentrating-type).

4 General

4.1 This Standard specifies that test results be presented as cooking power, in Watts, normalized for ambient conditions, relative to the temperature difference between cooker contents and ambient air, both as a plot and as a regression equation for no fewer than 30 total observations over three different days.

4.2 This Standard specifies that cooking power be presented as a single number found from the equation described in section 7.4 for a temperature difference of 50 °C.

5 Uncontrolled (Weather) Variables

5.1 **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.

5.2 **Maximum wind.** Should the wind exceed 2.5 m/s for more than ten minutes the test data shall be discarded.

5.3 **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.

5.4 **Ambient temperature.** Tests should be conducted when ambient temperatures are between 20 and 35 °C.

5.5 **Water temperature.** Test data shall be recorded while cooking vessel contents (water) are at temperatures between 5 °C above ambient and 5 °C below local boiling temperature.

5.6 **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.

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

6 Controlled (Cooker) Variables

6.1 **Loading.** Cookers shall have 7,000 grams potable water per square meter intercept area distributed evenly between the cooking vessels supplied with the cooker. If no cooking vessels are provided, inexpensive aluminum cooking vessels painted black shall be used.

6.2 **Water mass.** The mass of water should be determined with an electronic balance to the nearest gram using a pre-wetted container.

6.3 **Tracking.** Azimuth angle tracking frequency should be appropriate to the cooker's acceptance angle. Box-type cookers typically require adjustment every 15 to 30 minutes or when shadows appear on the absorber plate. Concentrating-type units may require more frequent adjustment to keep the solar image focused on the cooking vessel or absorber. With box-type cookers, zenith angle tracking may be unnecessary during a two hour test conducted at mid-day. Testing should be representative of local conditions, i.e.; how the typical consumer is expected to use the cooker.

6.4 **Temperature sensing.** Water and air temperature should be sensed with thermocouples. Each thermocouple junction shall be immersed in the water in the cooking vessel(s) and secured 10 mm above the bottom, at center. Thermocouple leads should pass through the cooking vessel lid inside a thermally nonconductive sleeve to protect the thermocouple wire from bending and temperature extremes. The sleeve should be secured with 100% silicone caulk to reduce water vapor loss.

7 Test Protocol

7.1 **Recording.** The average water temperature (°C) of all cooking vessels in one cooker shall be recorded at intervals not to exceed ten minutes, and should be in units of Celsius to the nearest one tenth of a degree. Solar insolation (W/m²), ambient temperature (°C), and wind speed (m/s) shall also be recorded at intervals not to exceed ten minutes. Record and report the frequency of attended (manual) tracking, if any. Report azimuth angle(s) during the test. Report the test site elevation and elevation and latitude, and the dates of testing.

$$P_s = a + b \times T_d \quad (4)$$

7.2 Calculating cooking power. The change in water temperature for each non-overlapping ten-minute interval shall be multiplied by the mass and specific heat capacity of the water contained in the cooking vessel(s). This product shall be divided by the 600 seconds contained in a ten-minute interval, as:

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

where:

P_i = cooking power (W) for interval i

T_2 = final water temperature (°C)

T_1 = initial water temperature (°C)

M = water mass (kg)

C_v = heat capacity of water (4186 J/[kg·°C])

7.3 Calculating interval averages. The average insolation, average ambient temperature, and average cooking vessel contents temperature shall be found for each interval.

7.4 Standardizing cooking power. Cooking power for each interval shall be corrected to a standard insolation of 700 W/m² by multiplying the interval observed cooking power by 700 W/m² and dividing by the interval average insolation recorded during the corresponding interval.

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

where:

P_s = standardized cooking power (W)

P_i = interval cooking power (W), as calculated in section 7.2

I_i = interval average solar insolation (W/m²)

7.5 Temperature difference. Ambient temperature for each interval is to be subtracted from the average cooking vessel contents temperature for each corresponding interval.

$$T_d = T_w - T_a \quad (3)$$

where:

T_d = temperature difference (°C)

T_w = water temperature (°C)

T_a = ambient air temperature (°C)

7.6 Plotting. The standardized cooking power, P_s (W), is to be plotted against the temperature difference, T_d (°C), for each time interval.

7.7 Regression. A linear regression of the plotted points shall be used to find the relationship between cooking power and temperature difference in terms of intercept, a (W), and slope, b (W/°C):

No fewer than 30 total observations from three different days shall be employed. The coefficient of determination (r^2) or proportion of variation in cooking power that can be attributed to the relationship found by regression should be higher than 0.75 or specially noted.

7.8 Single measure of performance. The value for standardized cooking power, P_s (W), shall be computed for a temperature difference, T_d , of 50 °C using the regression relationship found according to section 7.7.

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.

7.9 Reporting. A plot of the relationship between standardized cooking power and temperature difference shall be presented with the equation, following the example in Figure 2. The report shall also state the standardized cooking power at a temperature difference of 50 °C.

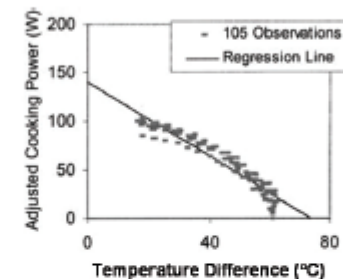


Figure 2 – Example of adjusted cooking power plotted over temperature difference and the resulting regression line. In this example the equation is: $P_s = 140 - 1.9 T_d$, with $r^2 = 0.90$. In this example the standard cooking power for a 50 °C temperature difference is: $P_{s(50)} = 45$ W.

References

- Funk, P. A. 2000. Evaluating the international standard procedure for testing solar cookers and reporting performance. *Solar Energy* 68(1): 1-7.
- Mullick, S. C., T. C. Kandpal, and A. K. Saxena 1987. Thermal test procedure for box-type solar cookers. *Solar Energy* 39(4): 353-360.

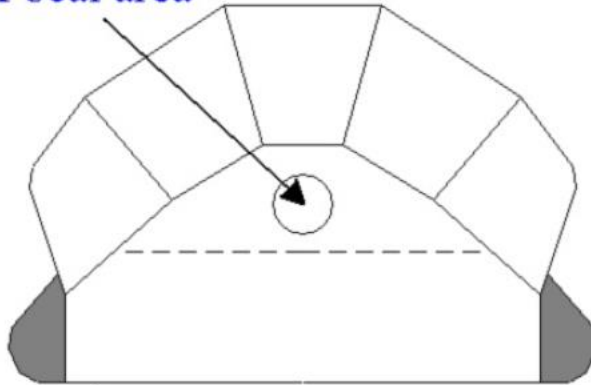
Acknowledgement

This standard is maintained by ASABE SE-414 Renewable Power Generation Committee.

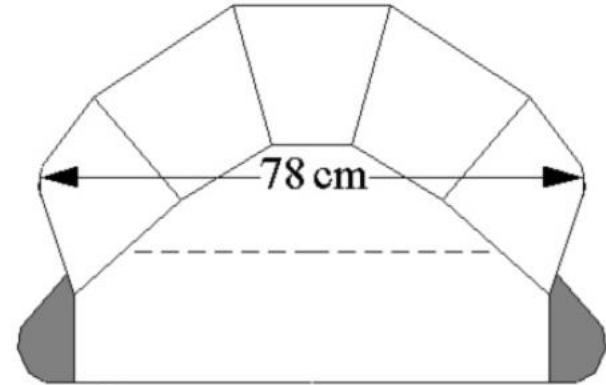
Explanations of the aperture area

Bernhard S. Müller

Brennpunkt-Zone
Focal area

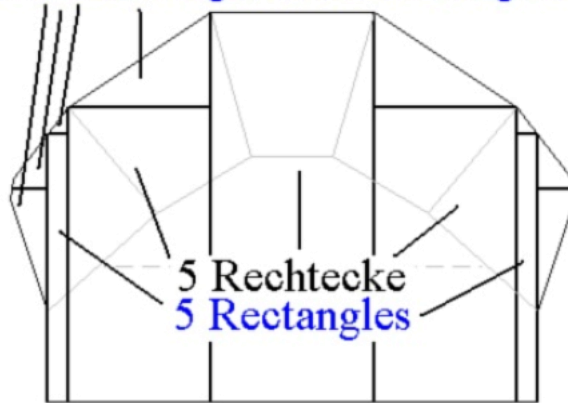


1.

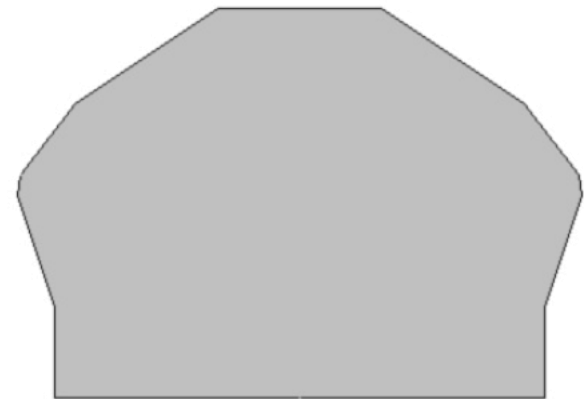


2.

Links und rechts je 4 Dreiecke
Left and right each 4 triangles



3.



4.

Aperture of a solar cooker

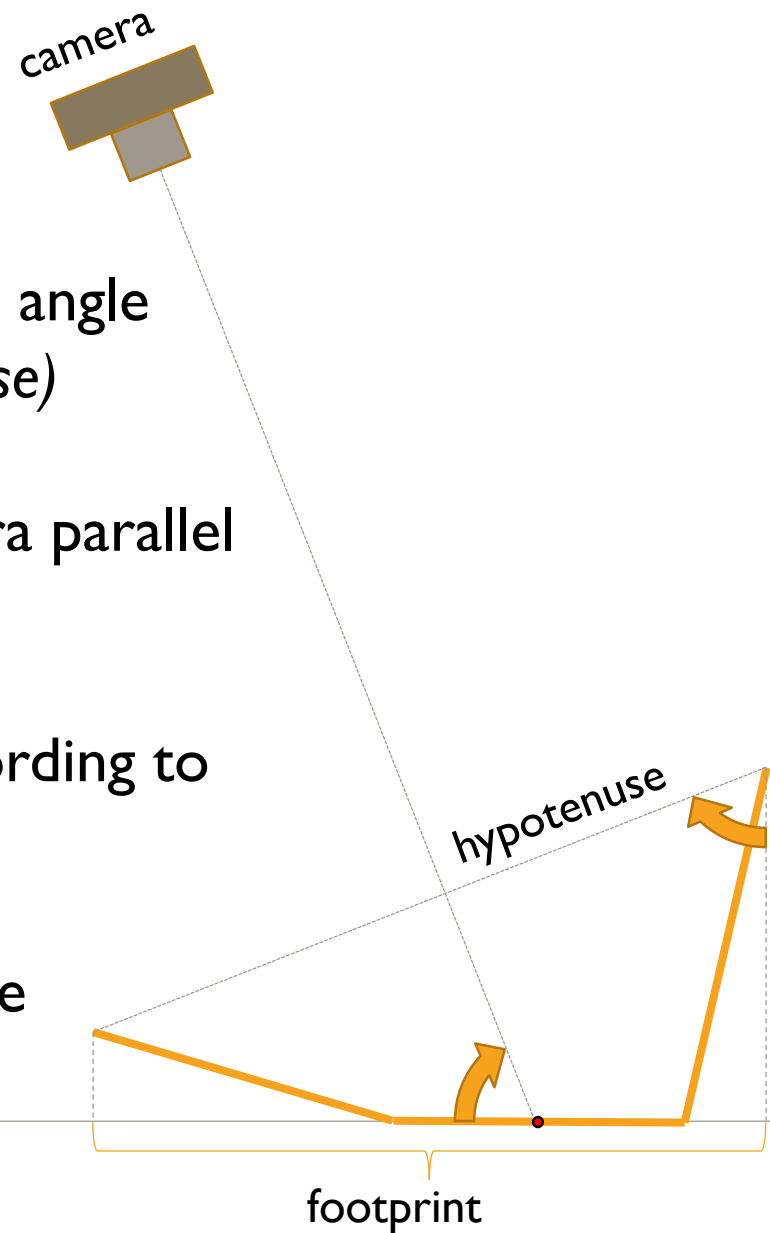
First determine the solar cooker elevation angle

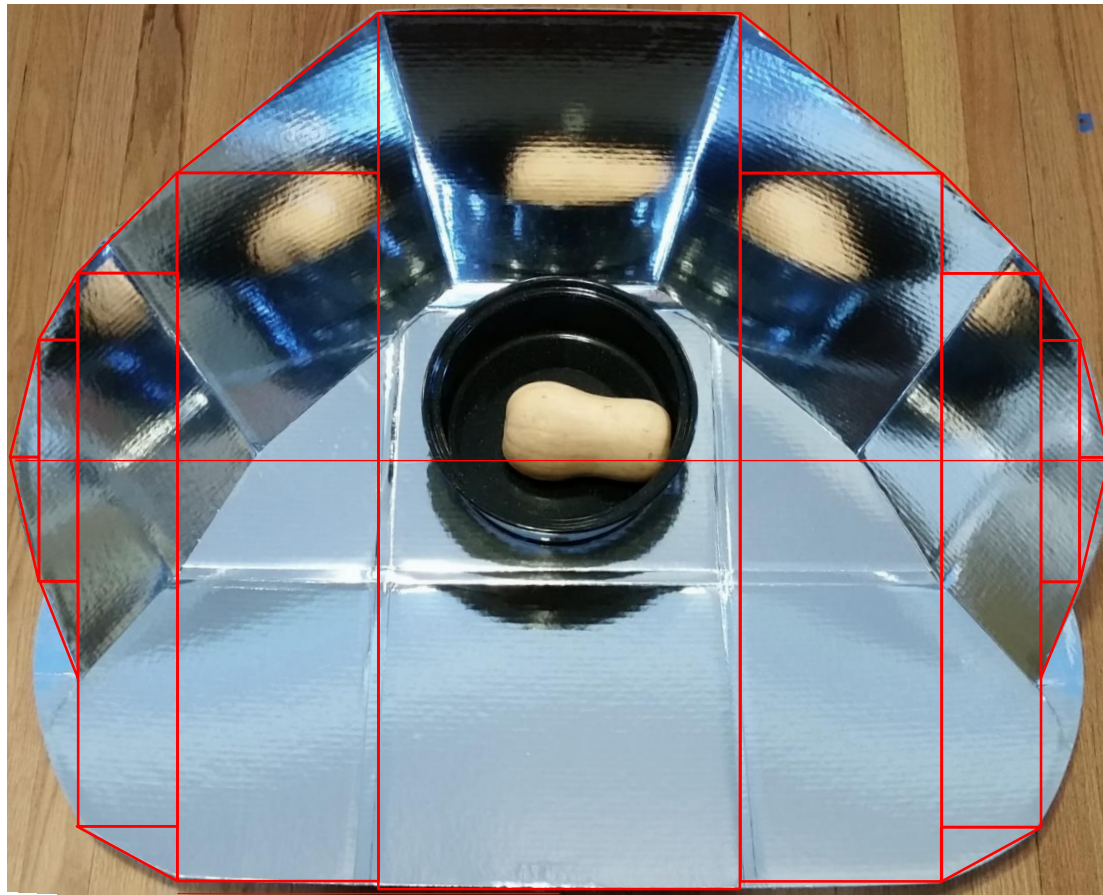
Elevation angle = arcsin (footprint / hypotenuse)

Photograph the solar cooker with a camera parallel to the solar cooker elevation angle

Sum the superimposed shapes, scaled according to the size of the cooker

Correct for sun elevation angle of test date



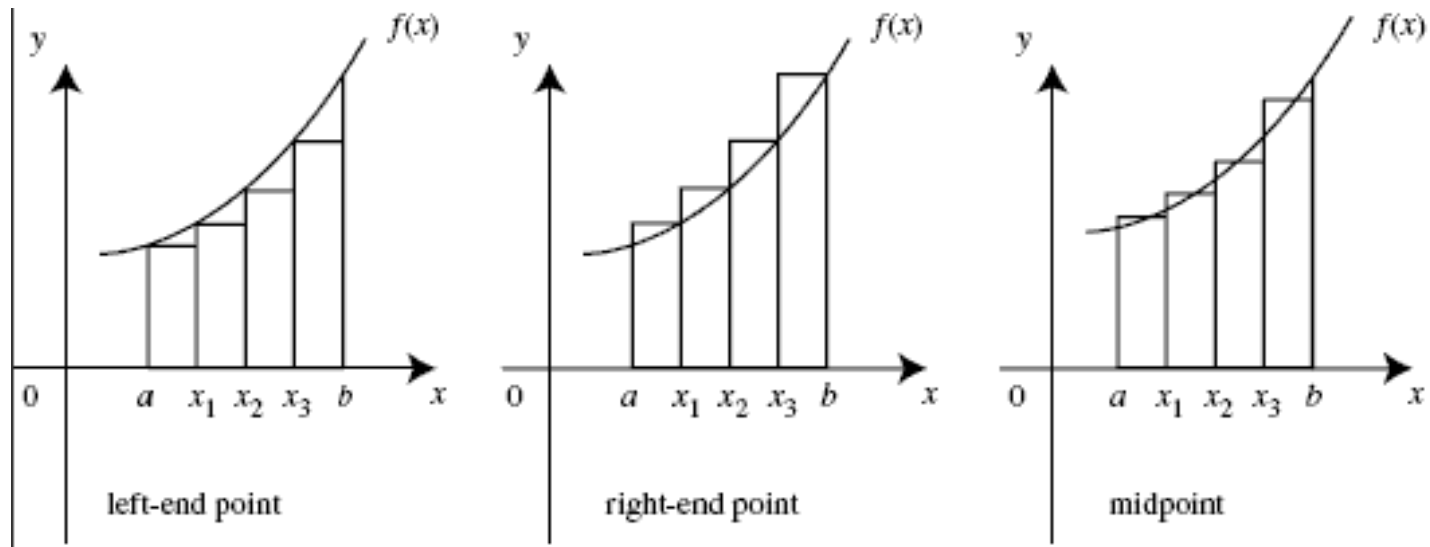


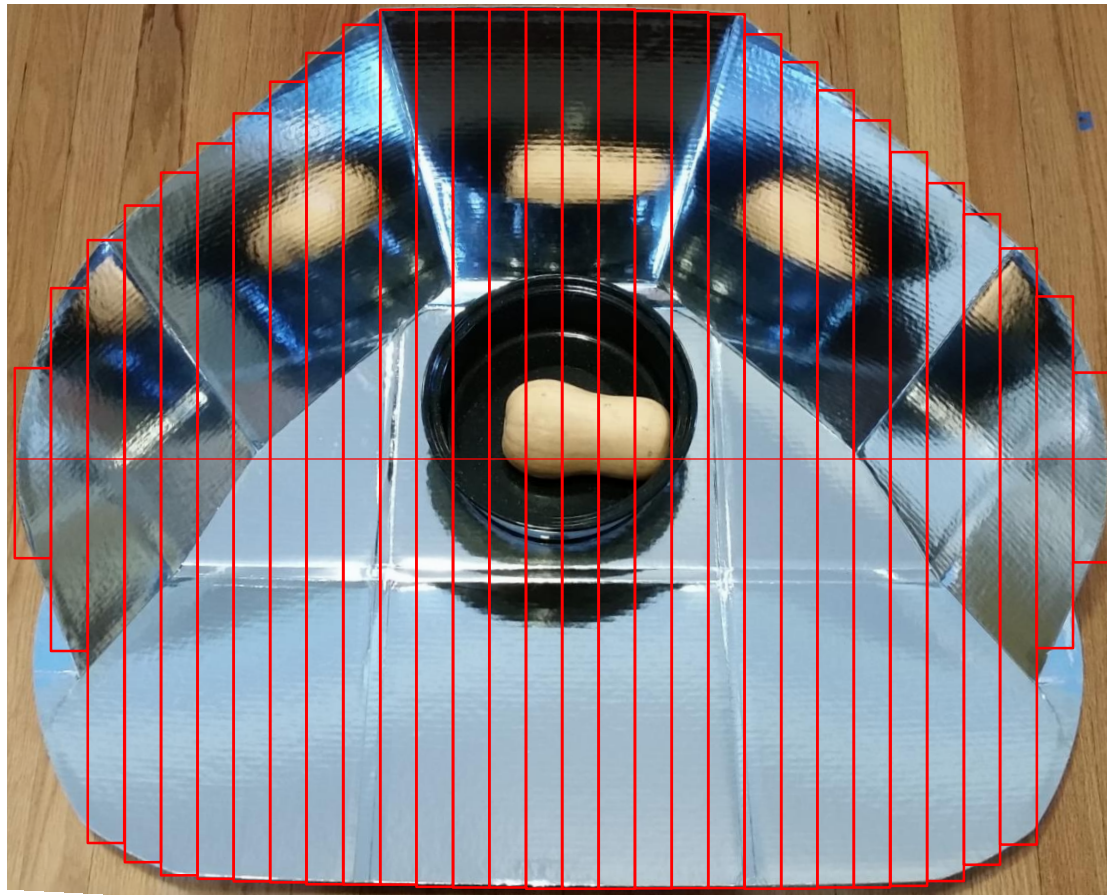
CookKit (Mid-morning, Mid-afternoon setting)

Rectangles and triangles approximate intercept area

Intercept area = 0.475 m^2

Riemann Sum





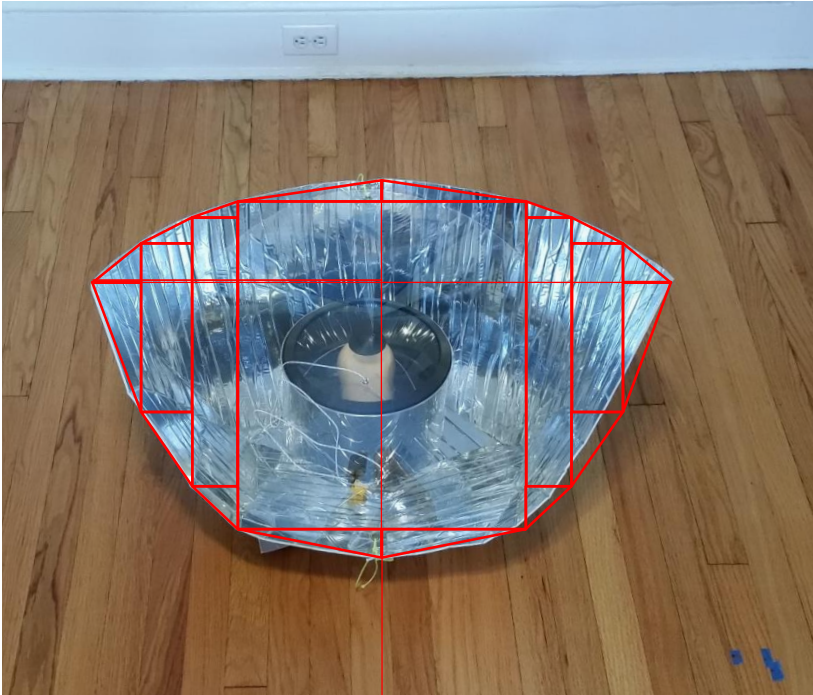
CookKit (Mid-morning, Mid-afternoon setting)

Riemann sum approximates intercept area

Intercept area = 0.477 m^2

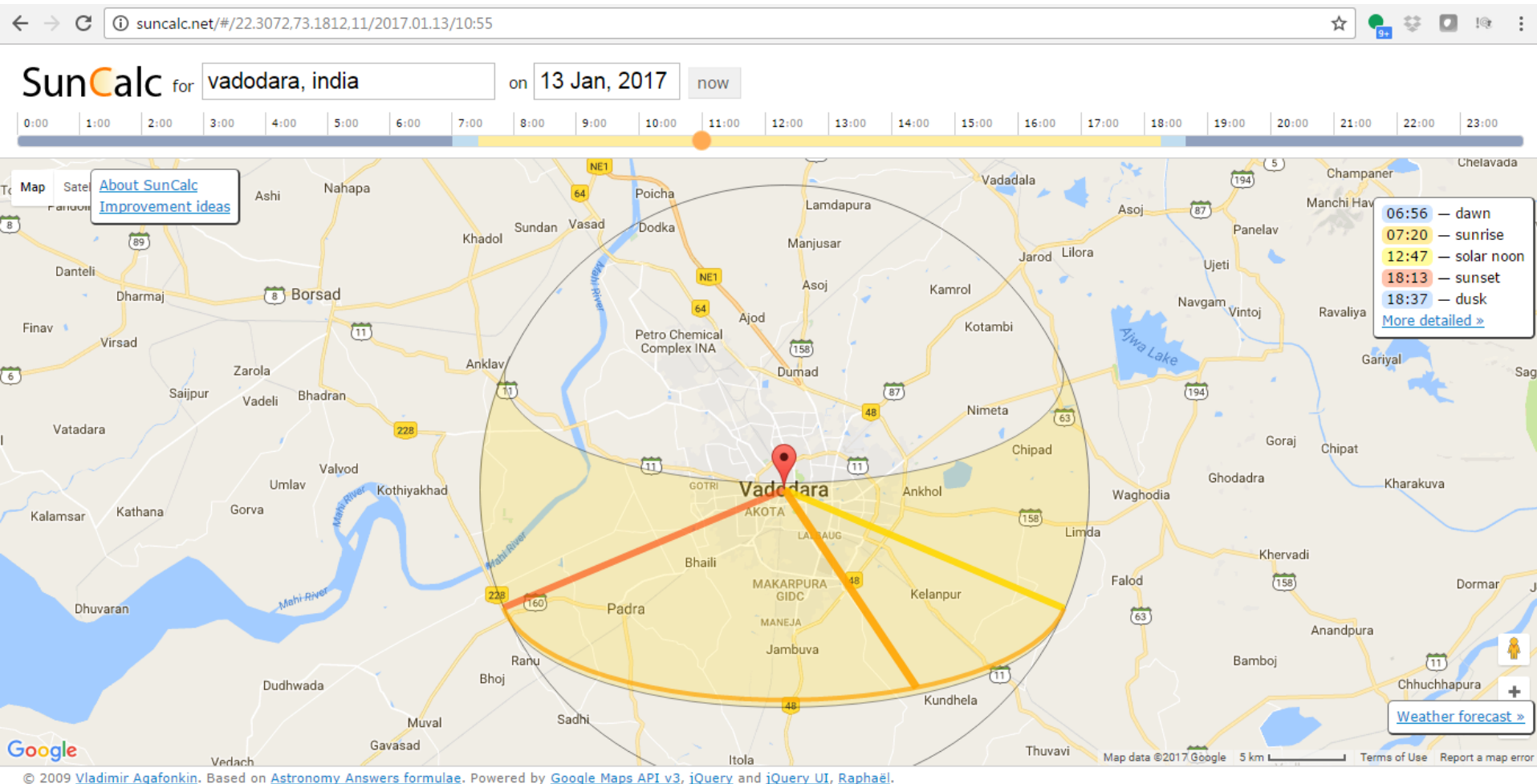
Haines Solar Cooker

Intercept area = 0.310 m²



Intercept area = 0.307 m²

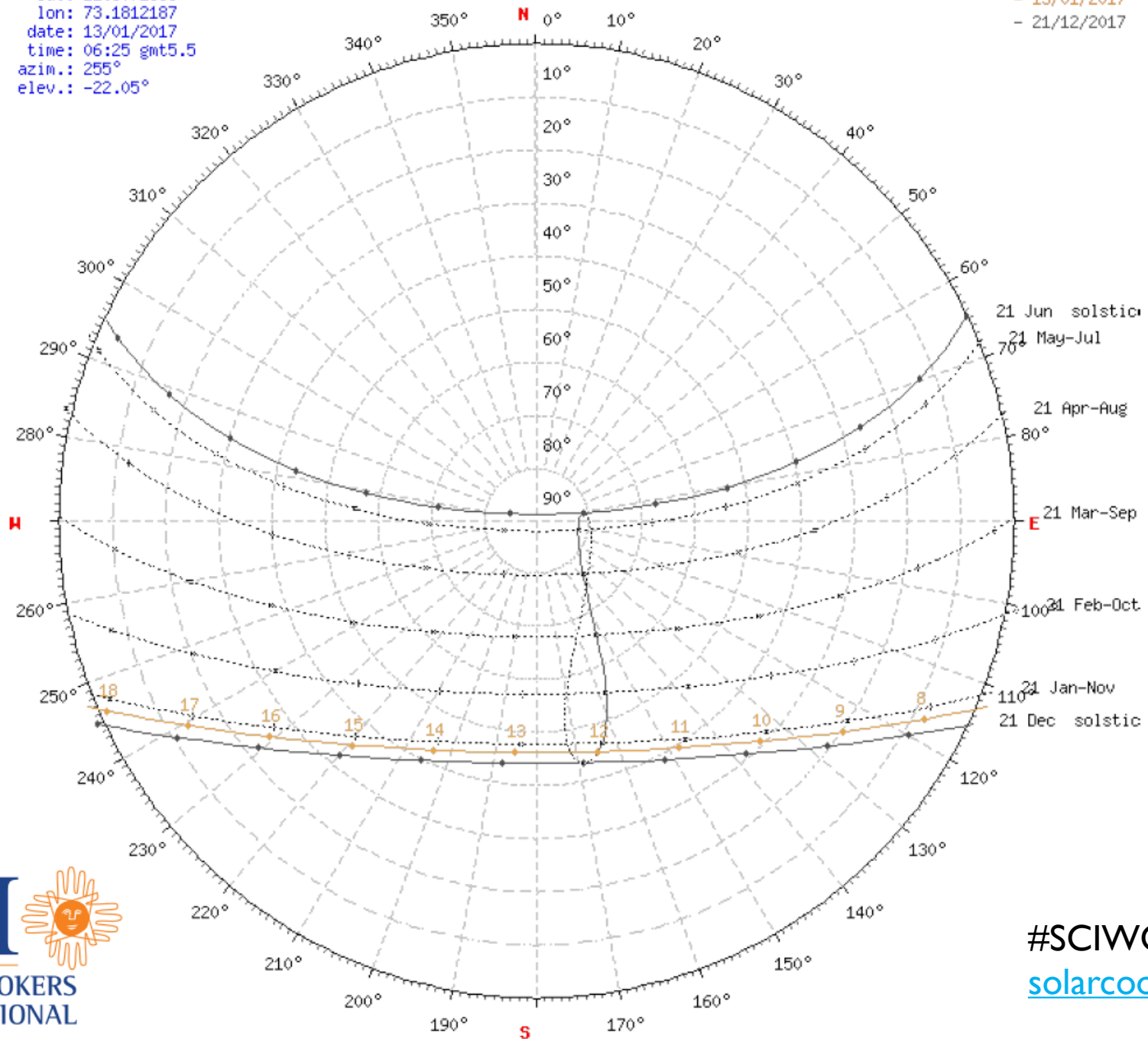




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lon: 73.1812187
date: 13/01/2017
time: 06:25 gm+5.5
azim.: 255°
elev.: -22.05°

SunEarthTools.com

- 21/06/2017
- 13/01/2017
- 21/12/2017



#SCIWC2017
solarcookers.org

SCI Testing Station for PEP

Designed and assembled by
Justin Tabatchnick
Solar Cookers International

Testing station design:

Portable

Robust

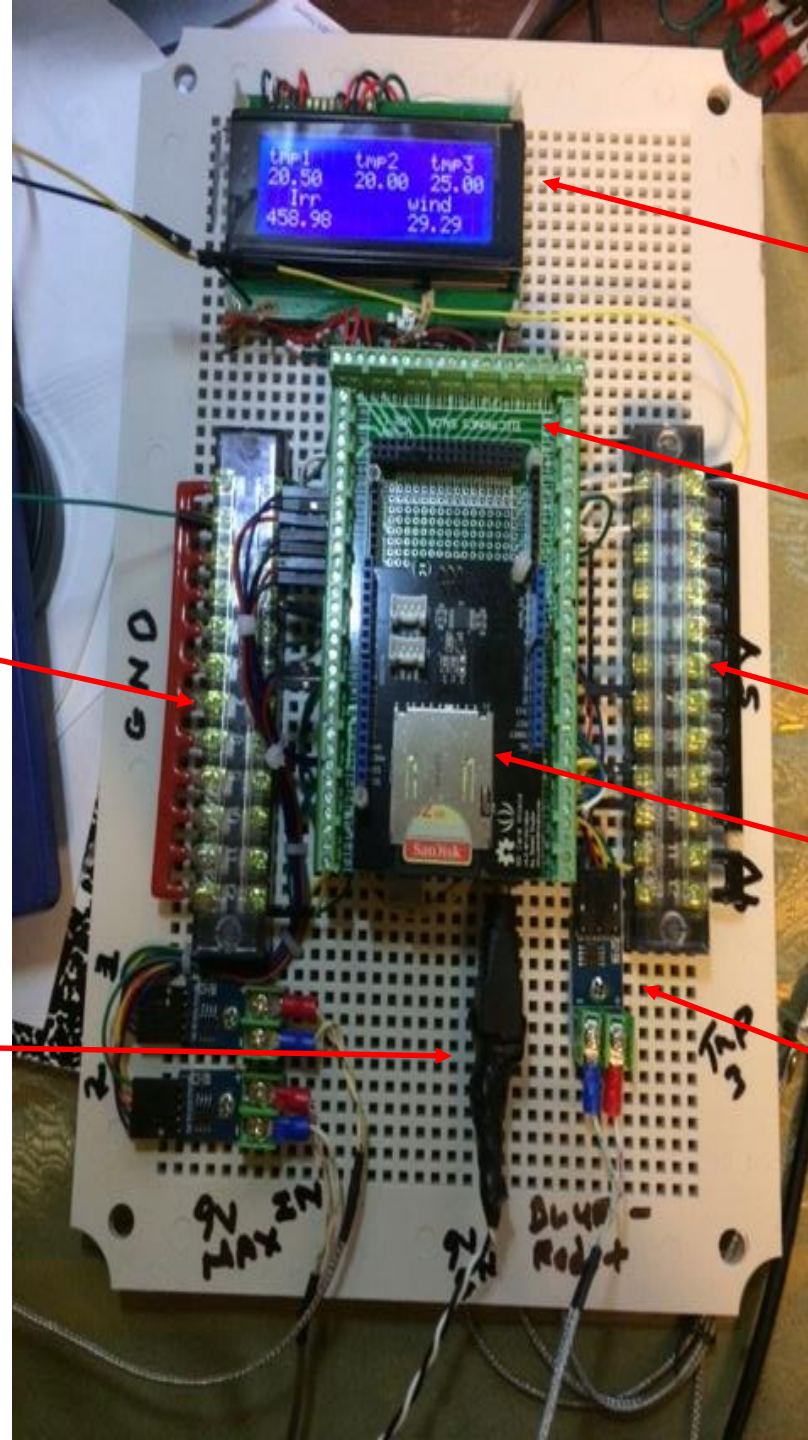
Relatively low cost (parts < \$1,000)

Simple to use

Data storage on SD card

Open source

Electronics Layout



Display

External Wiring Module

Ground Bus

Power Bus

SD module

Input Power

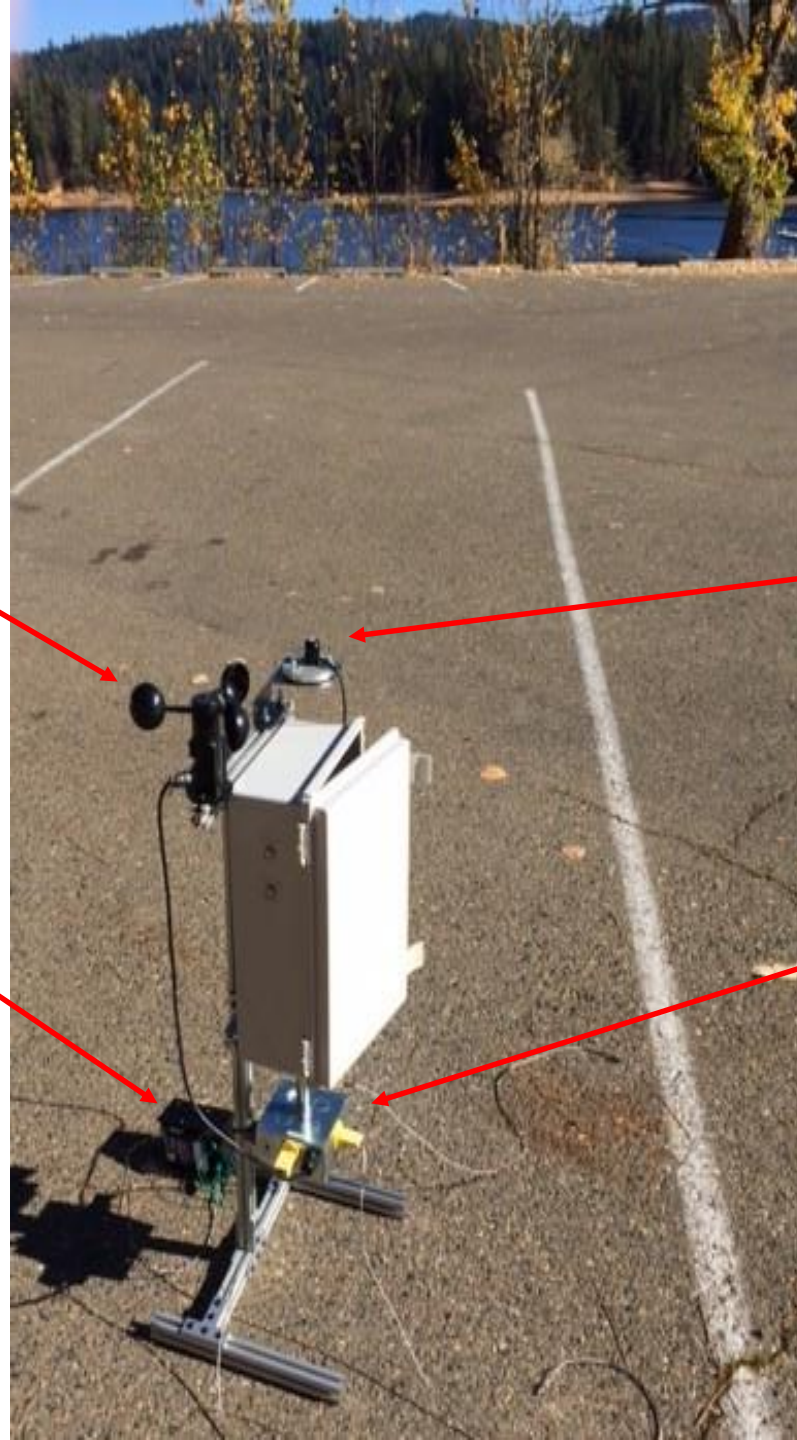
Thermocouple

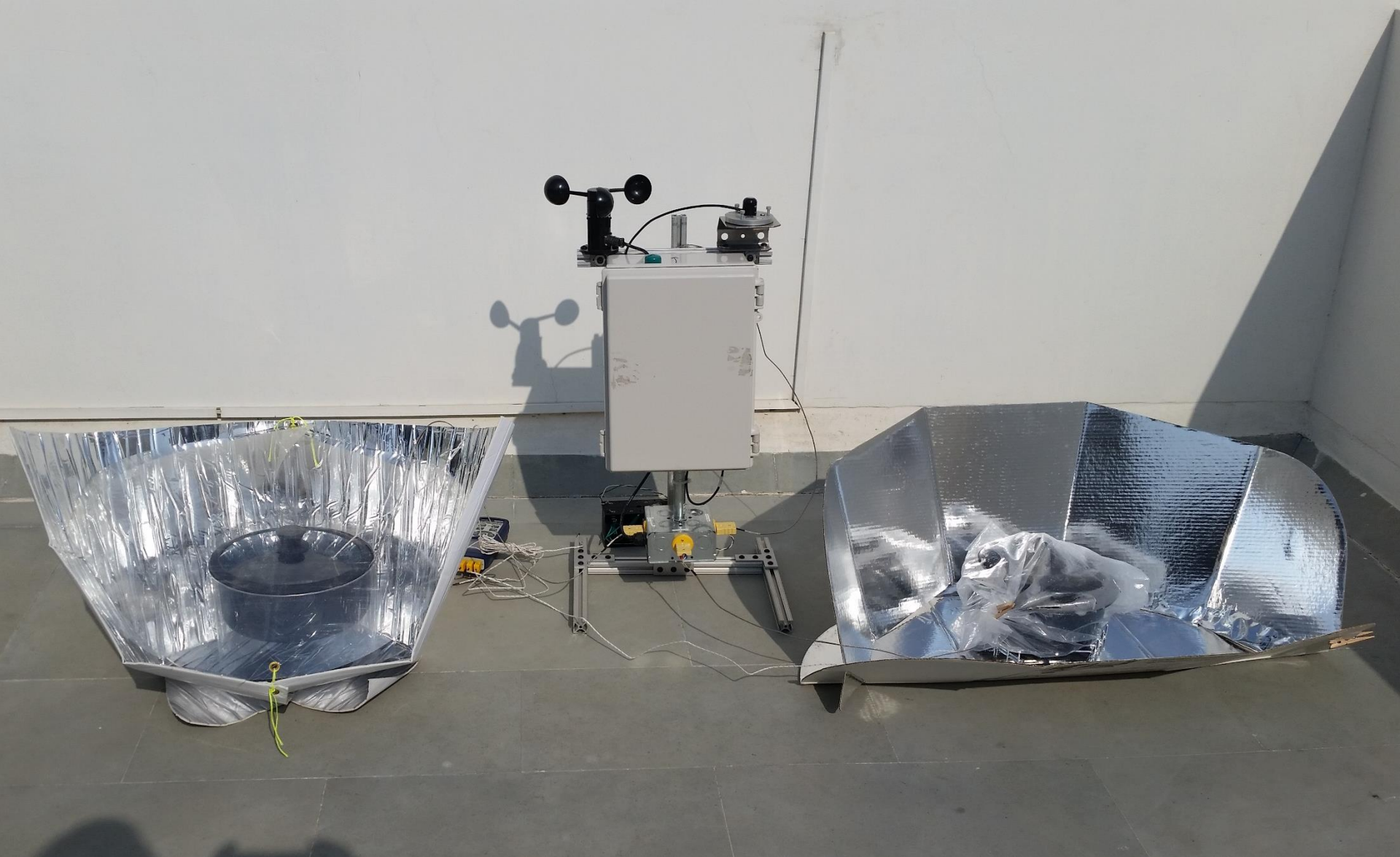
Anemometer

Pyranometer

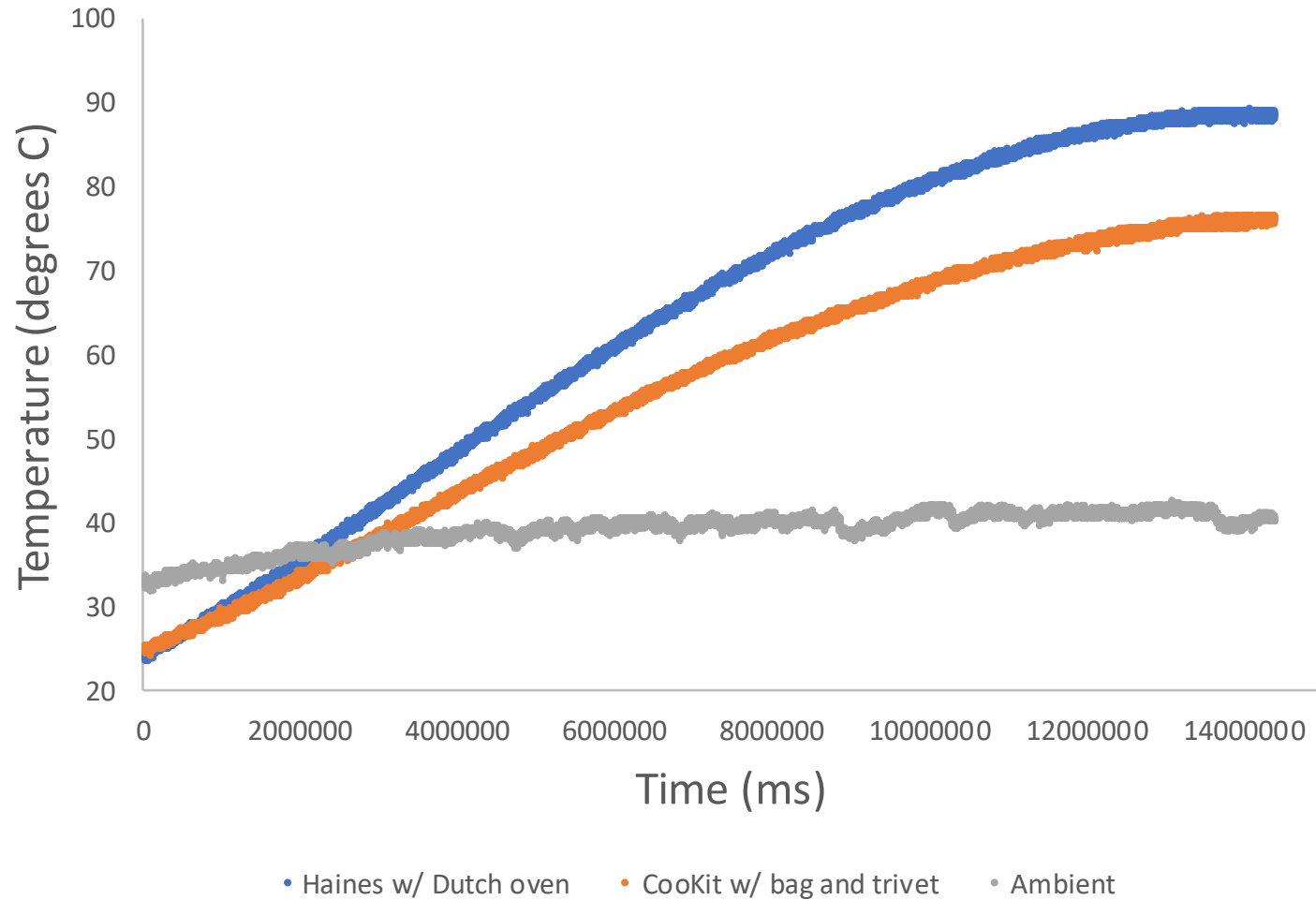
Battery Pack
(Power Supply)

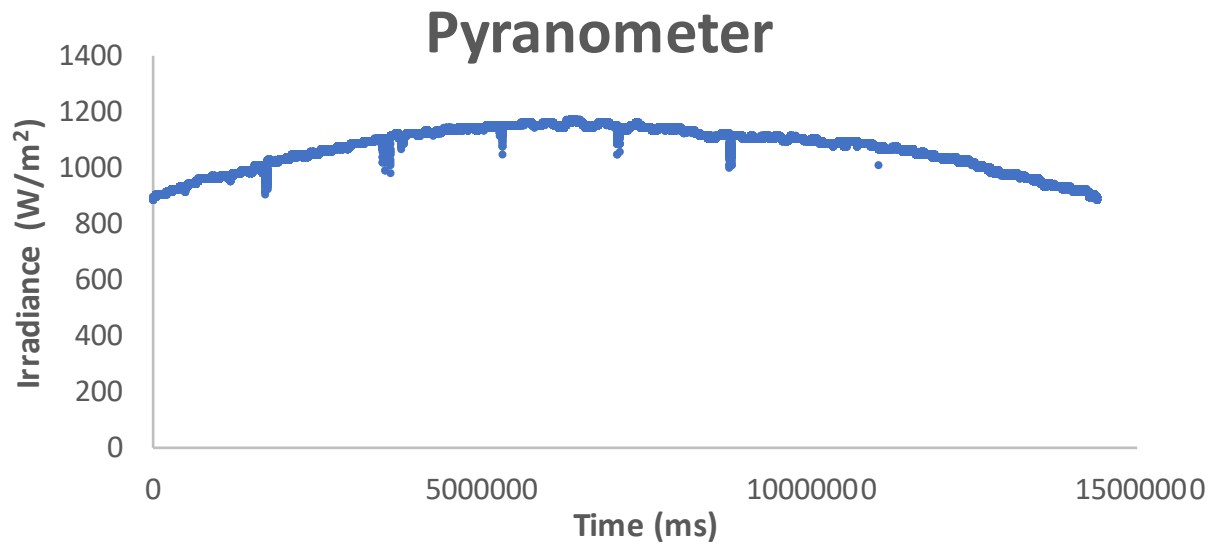
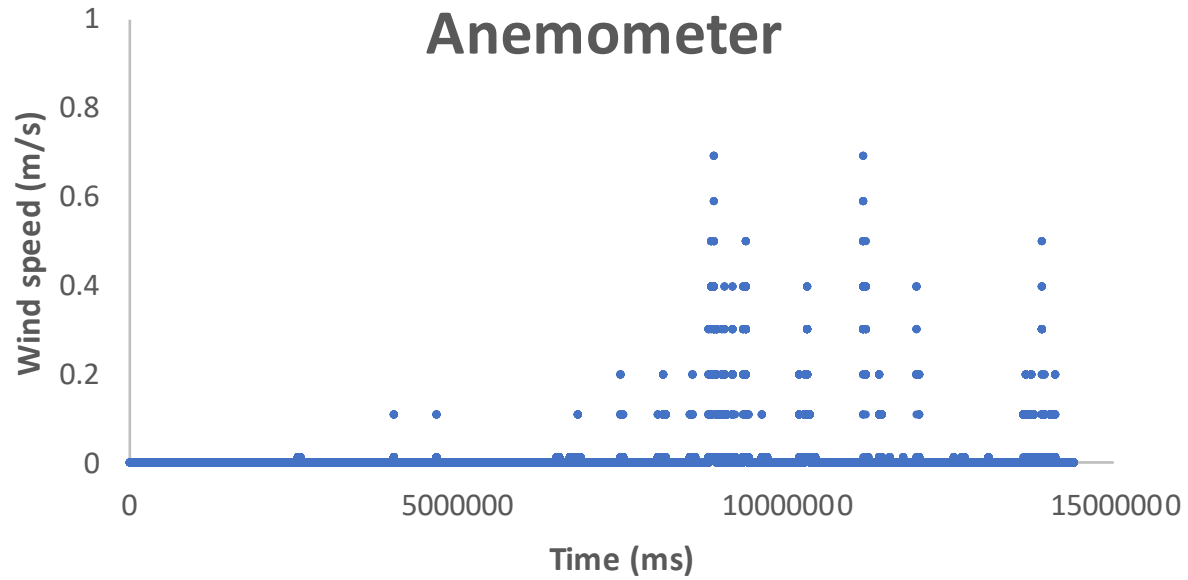
Sensor Distribution
Box



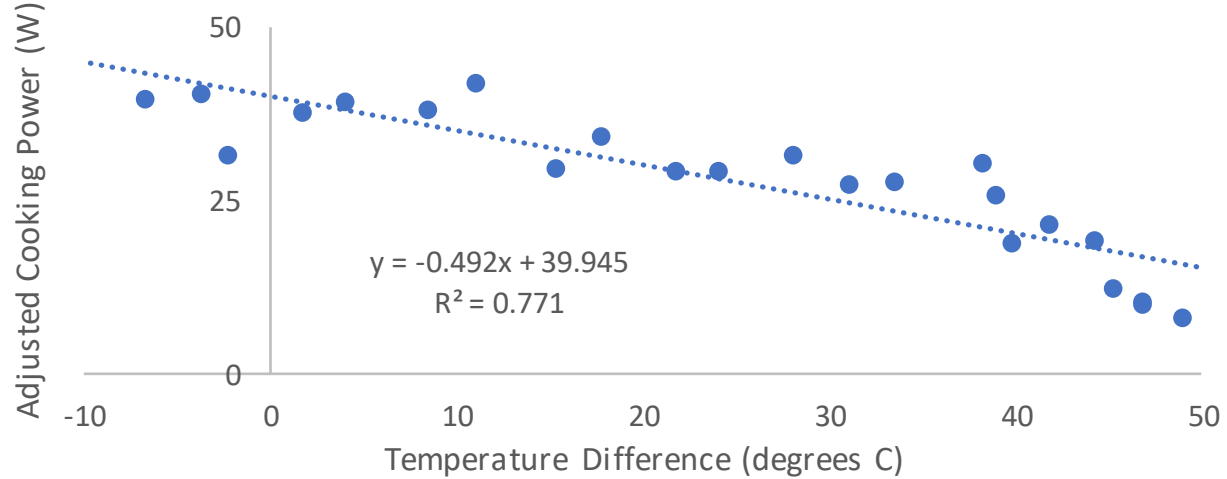


Thermocouples

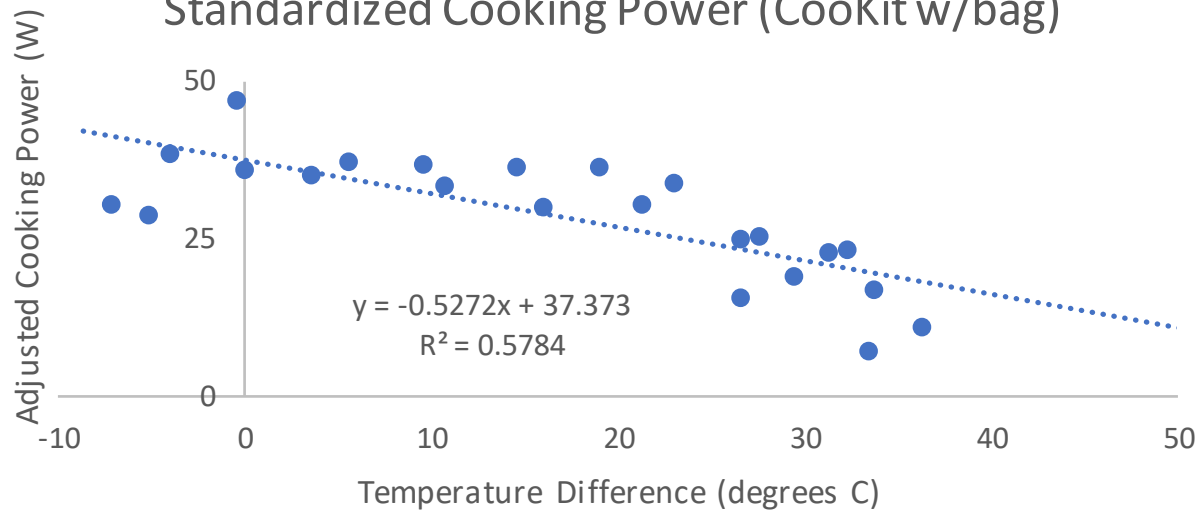




Standardized Cooking Power (Haines w/Dutch)



Standardized Cooking Power (CookKit w/bag)



Next Steps:

- SCI's testing station for PEP can also apply for testing parabolic solar cookers, using the proposed protocol to be presented by Dr. Ajay Chandak
- Manufacturers provide aperture size, cooker elevation angle and cookware, if possible
- Visit the PEP demonstrations and share your thoughts and feedback about PEP
- Unify our voices on one set of testing protocol for SCI to present to GACC
- Concluding remarks on Wednesday 18 January

Solar Cookers International

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