Solar Household Energy, Inc.
Solar Cooking for Human Development and Environmental Relief

SHE Technical Report no. TR-11

Compilation of Solar Cooker Heating Experiments, Summer 2016

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April 30, 2017

Citation: Technical Report no. TR-11, Solar Household Energy, Inc., (Apr. 30, 2017)

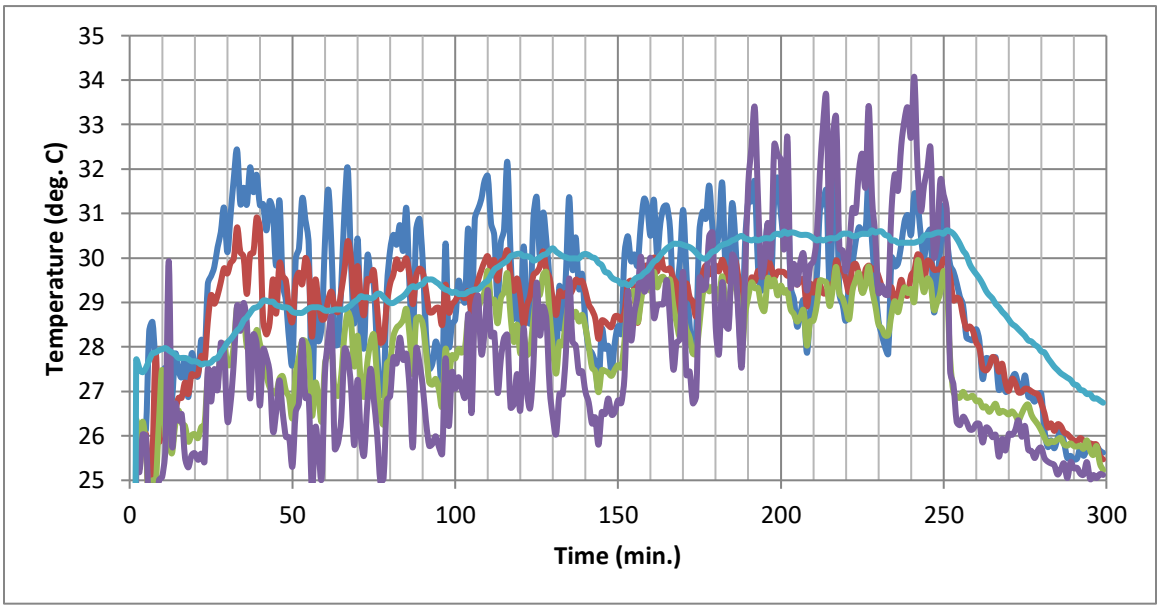
Solar Household Energy (SHE) strives to unleash the potential of solar cooking to improve social, economic and environmental conditions in sun-rich areas around the world. SHE Technical Reports are intended for use within the solar cooking community, for the rapid dissemination of findings related to solar cookers. They may contain information that is based on limited data, and/or conclusions and recommendations that are solely the opinions of the author, not of the organization. Please contact the author for further correspondence.

Compilation of Solar Cooker Heating Experiments, Summer 2016, Rockville, MD

This is a compilation of solar cooker internal temperature, solar irradiance and wind speed data collected in 2016 at latitude 39.0475 deg N, longitude 77.1412 W (in Rockville, MD). Dates of each experiment are shown on the graphs, in yyyymmdd format. Plot color code: B=blue, R=red, G=green, P=purple, LB=light blue.

These are "raw" data that in most cases have not been time-averaged or otherwise processed. In some cases a load of 1 liter of water was used, but in most cases the load was determined based on standard ASABE S.580.1, which calls for 7 liters per square meter of intercept area of solar cooker reflectors (at the angle for maximum power). The latter data can be used to derive power in accordance with the protocol described in the standard. These results will be published later.

The above photo shows a typical test setup. Usually two cookers are measured at the same time in order to exclude variations in solar irradiance in the comparisons. The box in the center is a "Stevenson box" that contains the data loggers and instruments for measuring temperatures, solar irradiance and wind speed. (A small solar PV panel is used to provide power to the instruments.)
Most of the temperature plots contain data from four thermocouples and one thermistor (which is used to measure the ambient temperature). Often two thermocouples are placed inside each pot, so that there is a check on the placement of the sensors in the water of the pots.



20160614 – Measurement of internal temperatures in the Stevenson box. These data indicate the degree of consistency in measurements of all five temperature sensors.

Blue - T5 - Inside box, top center

Red - T2 - Inside box, bottom center

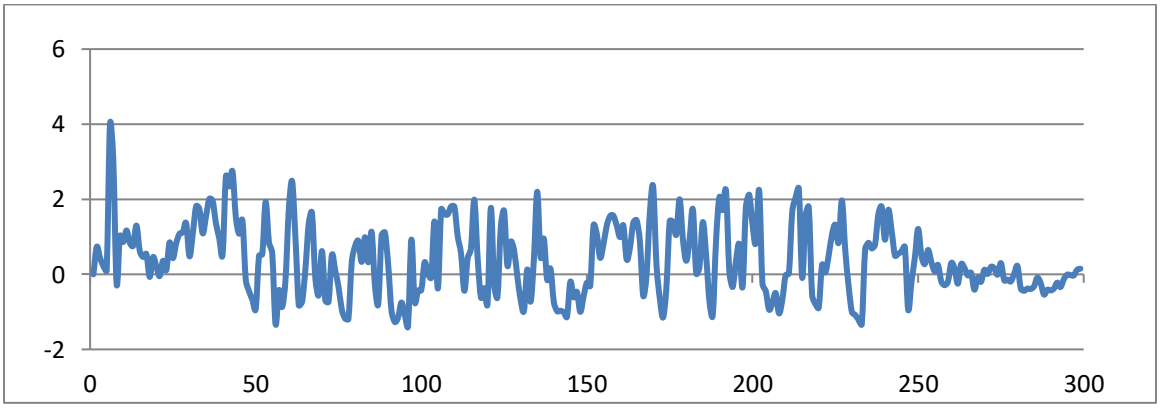
Green - T3 - Inside box, in center on panel

Violet - T4 - Outside box, in shade

Cyan - Thermistor in data logger (serves as temperature reference for the thermocouples).

The box was in place about 20 minutes after start. Clear sky. Wind speed was light to calm. Avg. 1 mph.

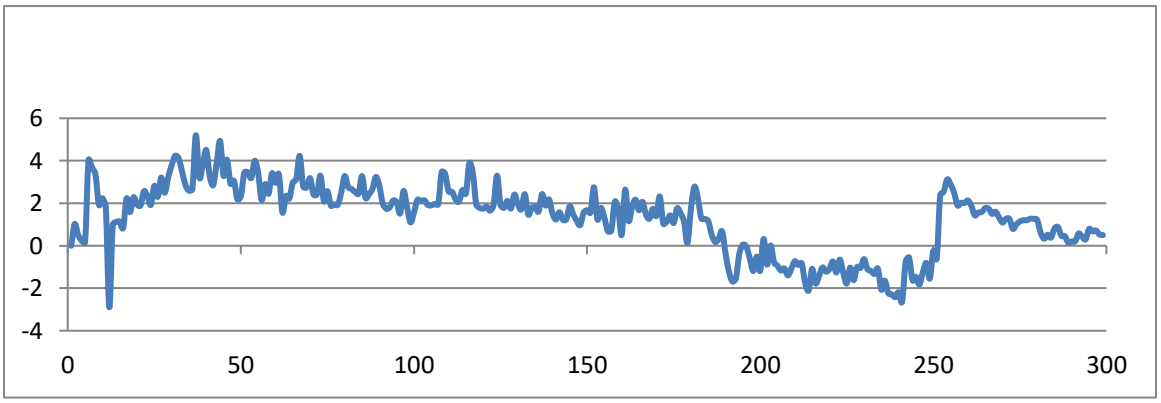
At about 250 minutes, the box was moved into the shade.



20160614

Internal temperatures: difference between top and bottom thermocouples.

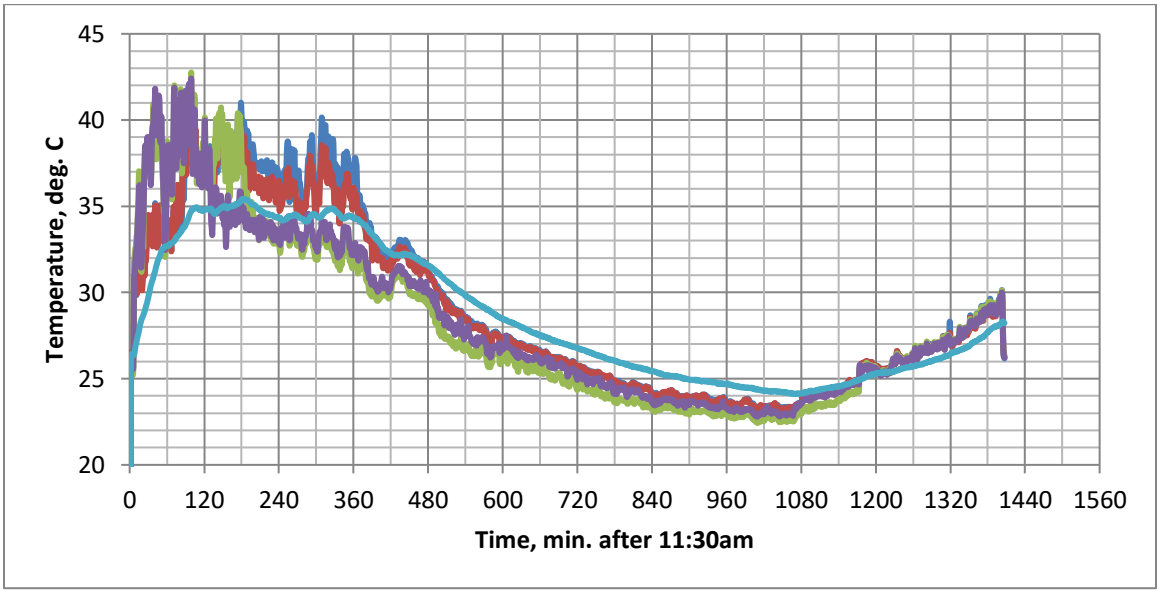
The top of the interior is slightly higher than the bottom, but the average difference is less than 1 degree C.



20160614

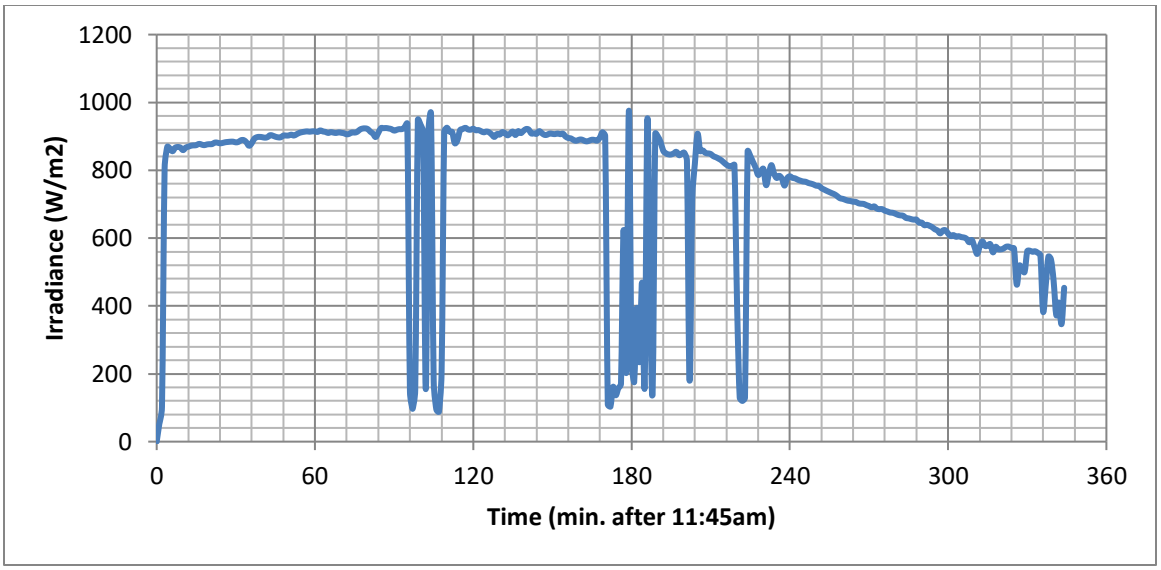
Difference between outside and inside temperatures.

Temperatures inside the top of the box exceed the outside shaded temperatures by up to 4 deg. C. Later, after 180 min., the outside thermocouple was out of the shade, and it heated up 3 deg. Higher than the internal sensors.
Generally, the box adds 1 or 2 deg. C to the outside temperature (when the wind speed is low).
After 250 min. the outside thermocouple cooled much more rapidly than the internal thermocouples.

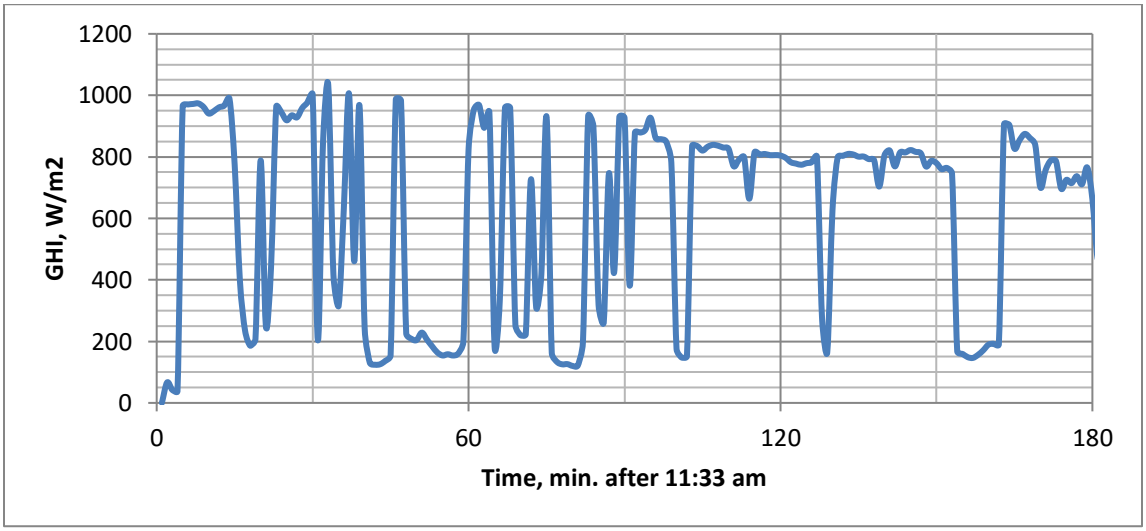


20160723

All day and night internal Stevenson box temp.

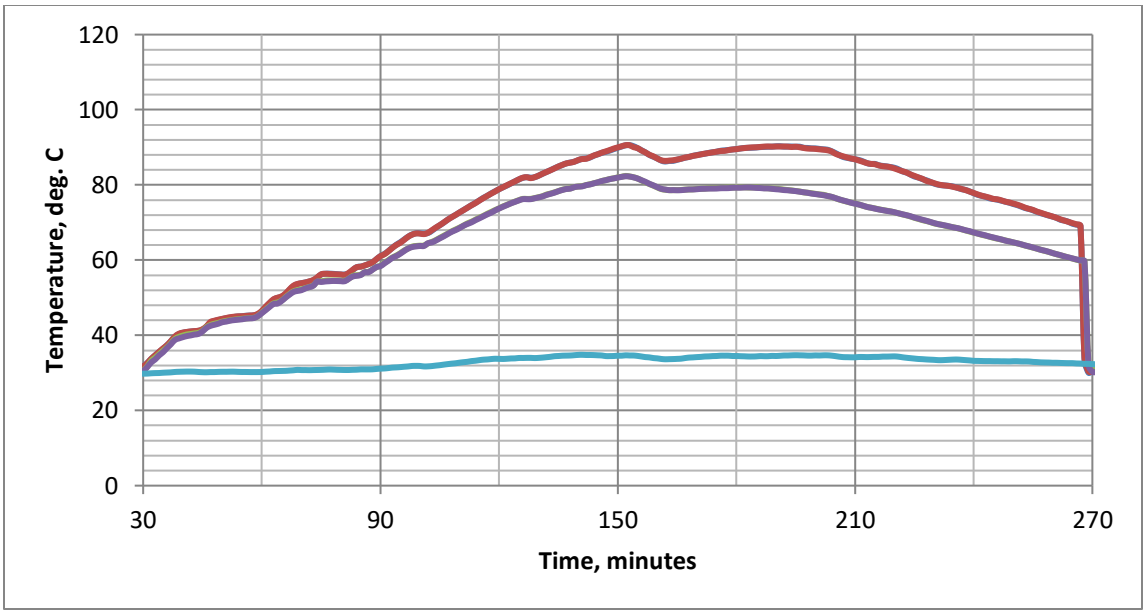


20160724
(No temp. data)



20160729

Partly cloudy. No wind speed data.



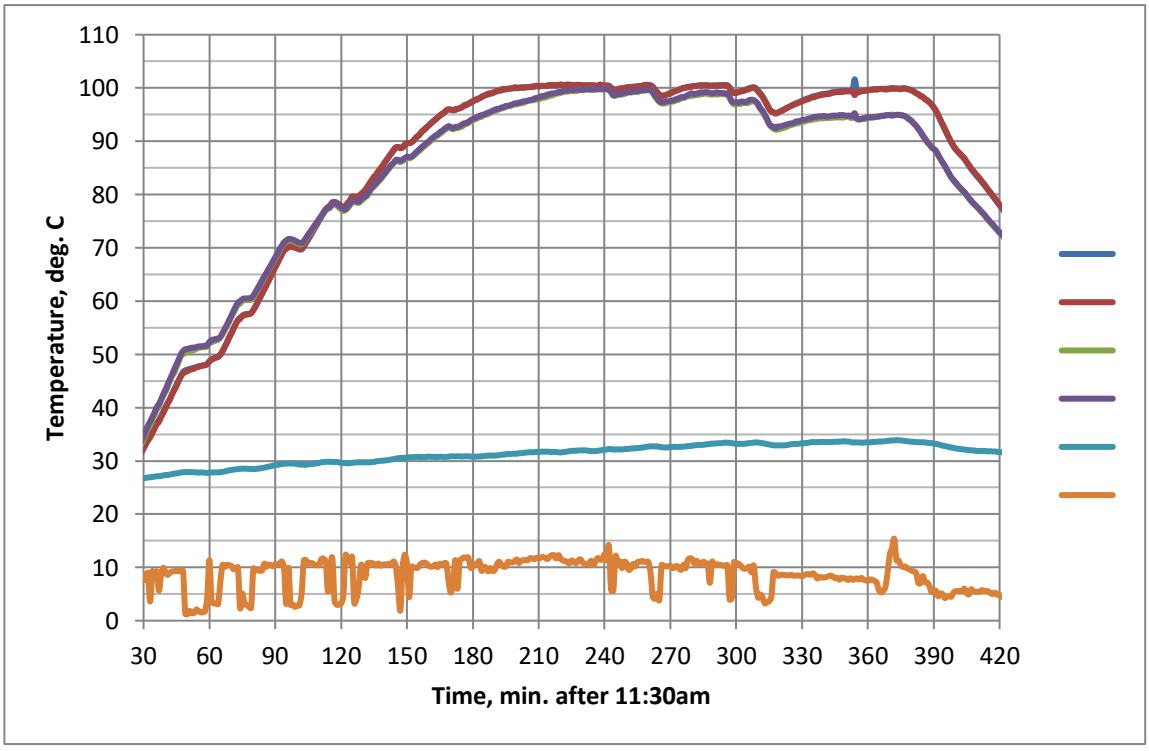
20160729

B-R: Haines reflector with GraniteWare black pot

G-P: Haines reflector with Haines “Dutch oven” pot. LB: ambient.

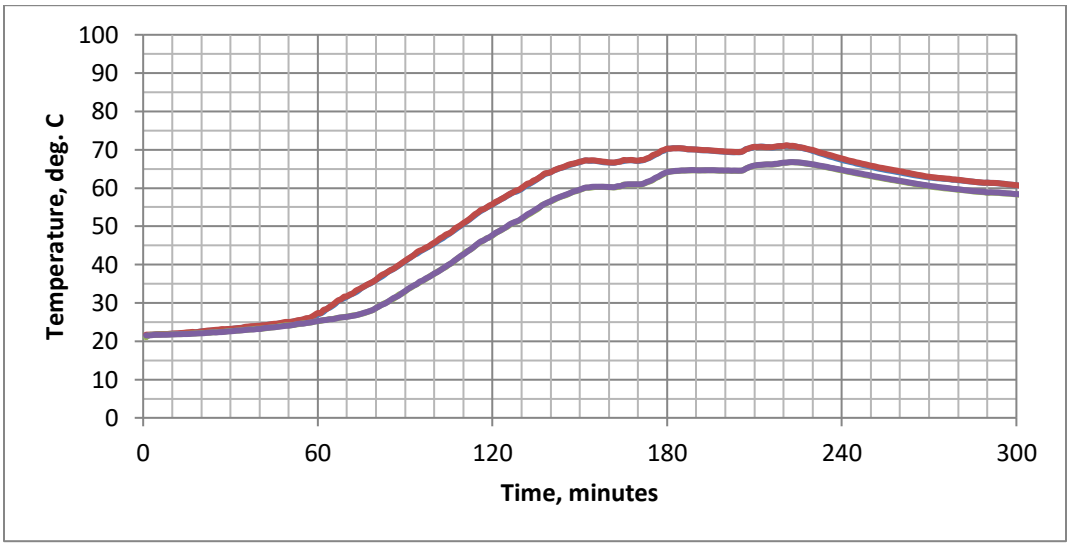
Load: 1 liter tap water

Weather: partly cloudy



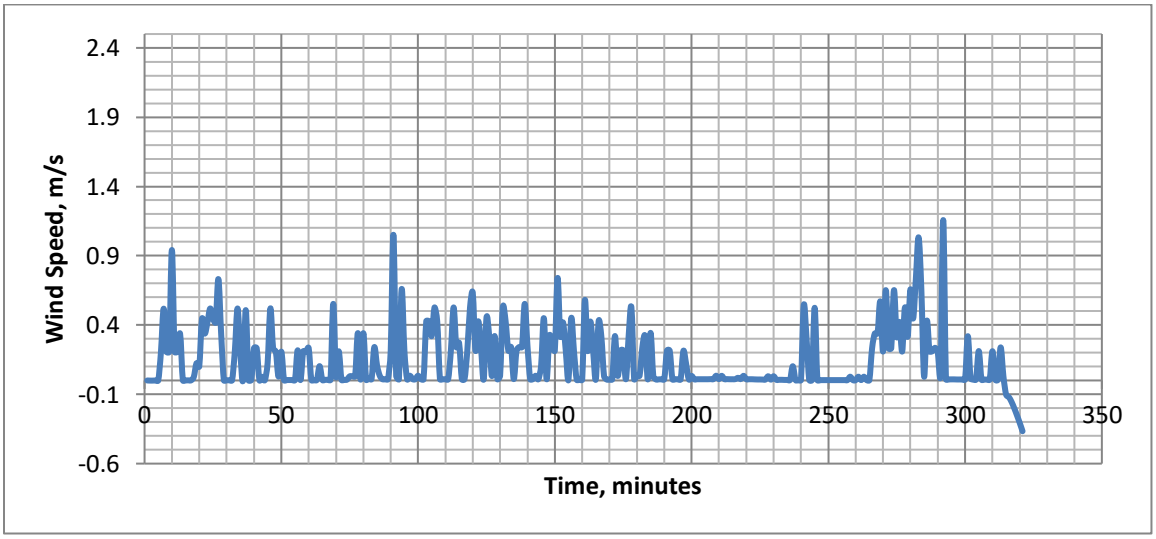
20160802 - Combined temperature data plus, at the bottom the solar irradiance divided by 100 to fit on plot (orange).

B&R: Haines pot #2; G&P: Haines pot #1, Load 1 liter tap water. LB: ambient.



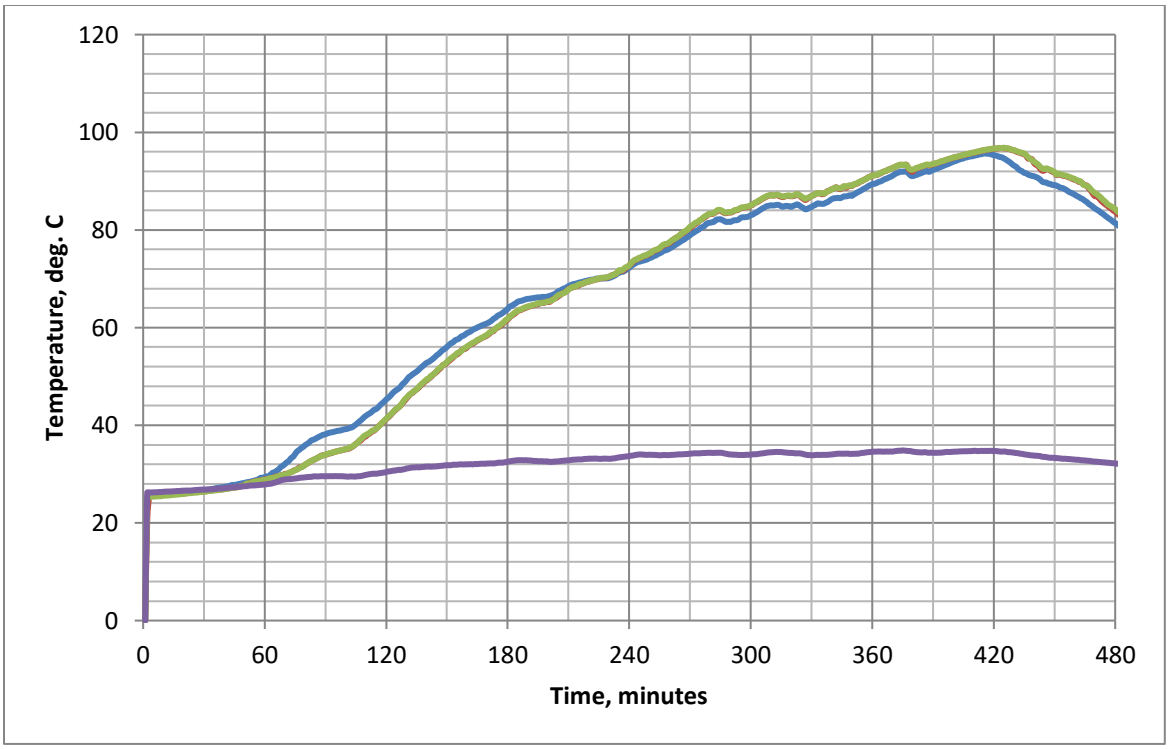
20160808 – R: Haines #1, P: Haines #2, Load 2.45 liters tap water. P: ambient. Purpose: check on repeatability. Note: pot #1 mass=368 g. pot #2=505 g.

Solar irradiance data were not obtained.

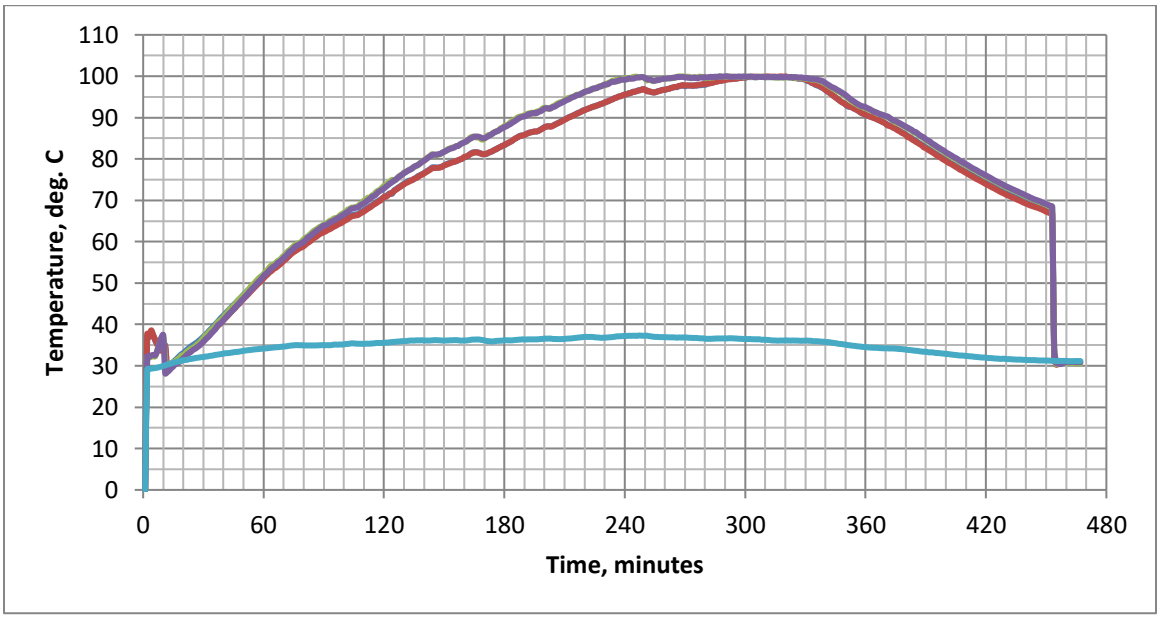


20160808

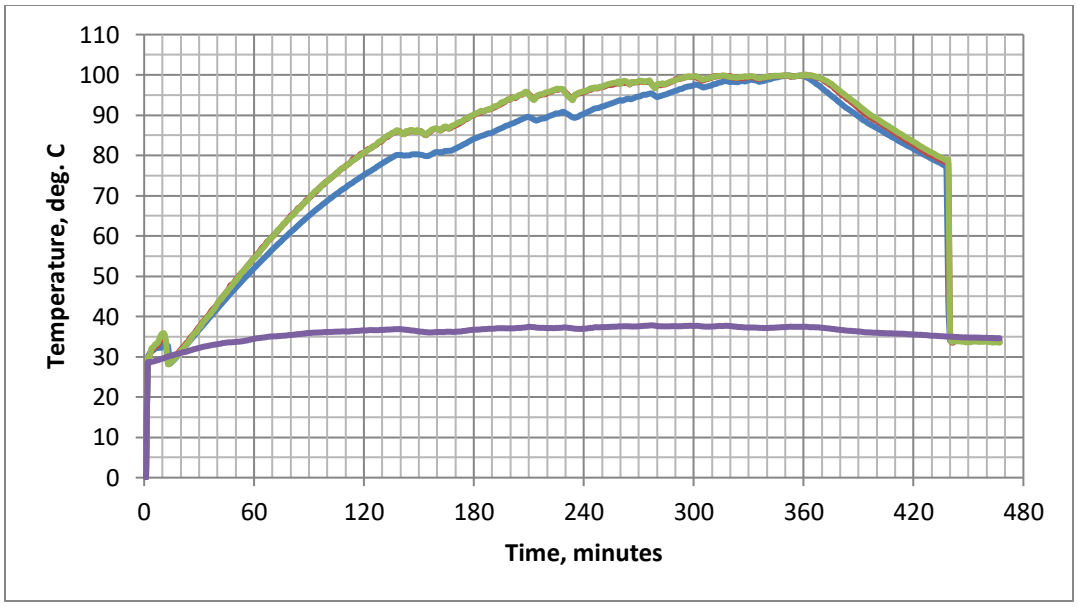
Wind speed data went negative slightly at the end because the power supply was turned off.



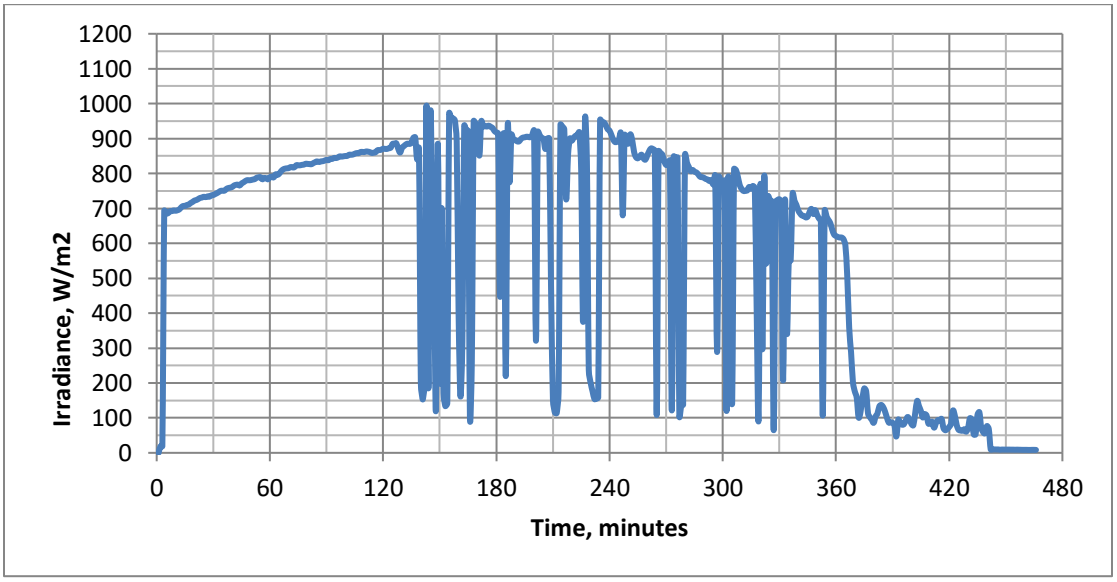
20160810 – B&R: Haines #1, G: Haines pot #3, P: ambient. Load 2.45 liters distilled water. These two pots had the same mass of 368 g.
(No weather data)



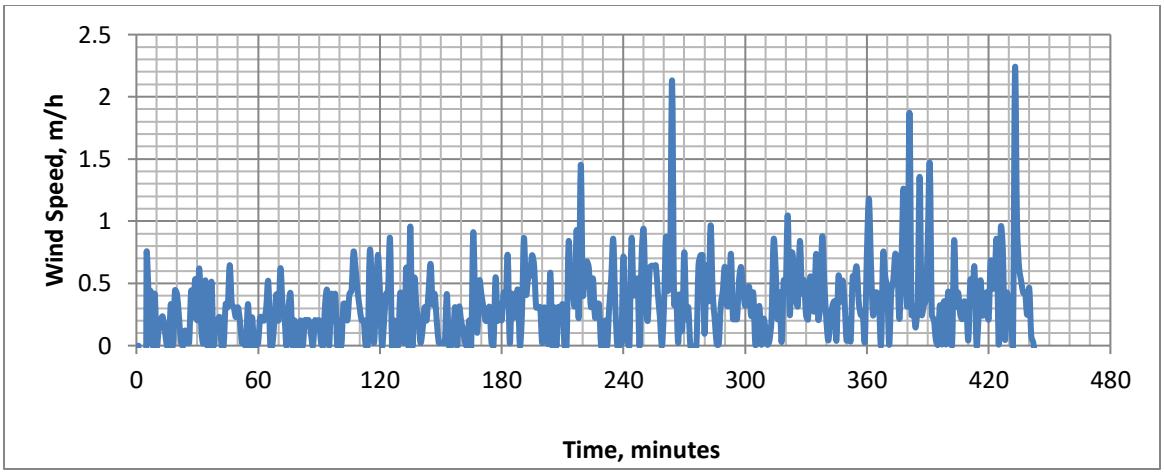
20160811 – Haines pots, repeat of 8/10 test. Load 2.45 liters water. LB: ambient.
No solar data obtained.



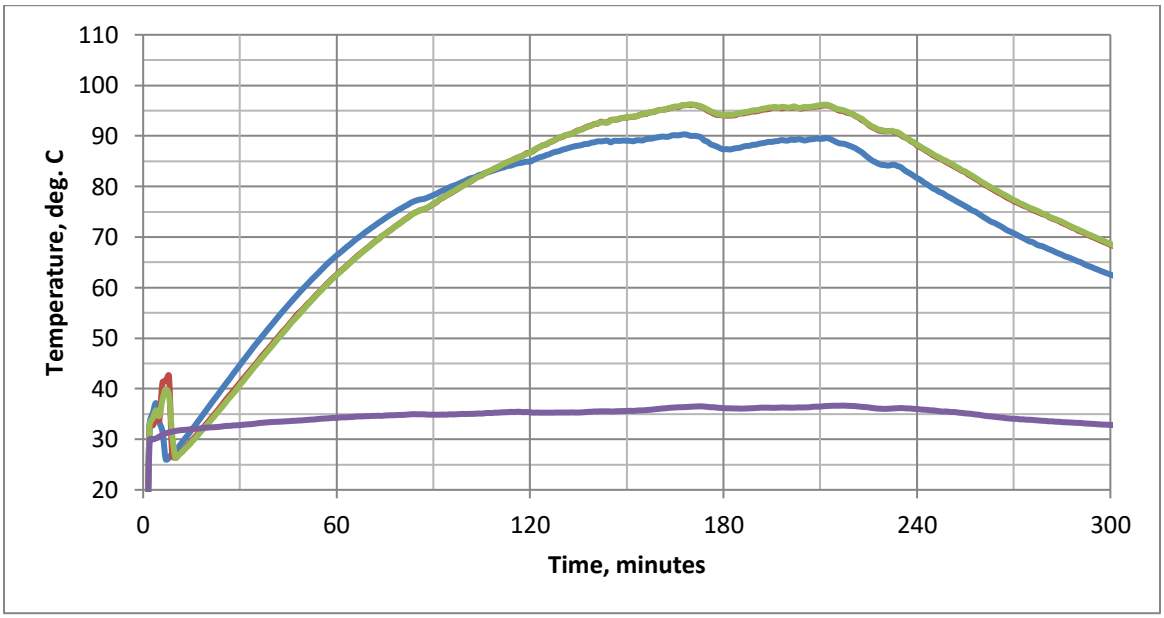
20160813 – R: HotPot #1, P: HotPot#2. Both have lid seals, but only #1 has lower seal. Load 2.32 liters water. All parts aligned to marks. P: ambient.



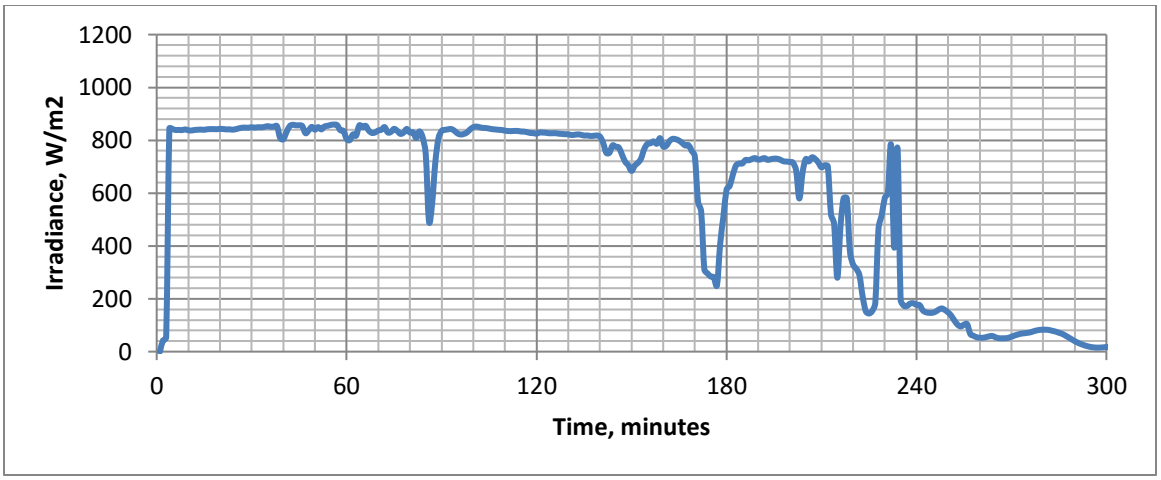
20160813



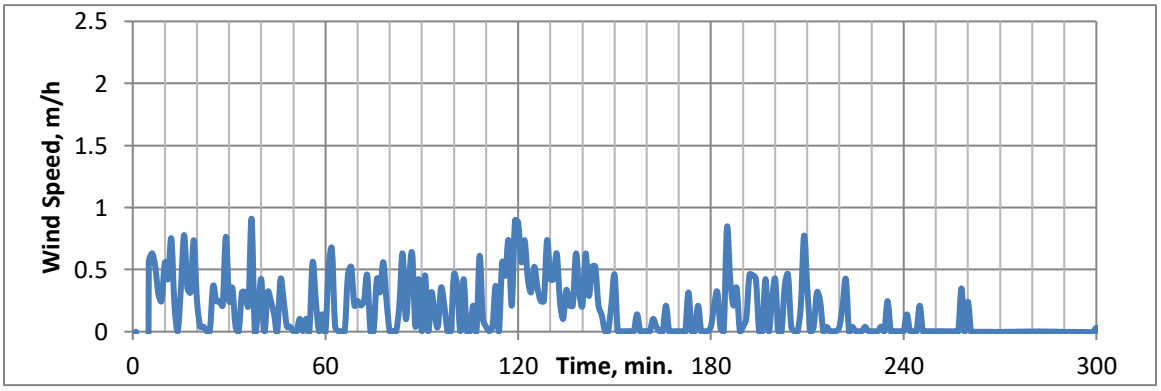
20160813



20160815 – Repeat of 8/13



20160815



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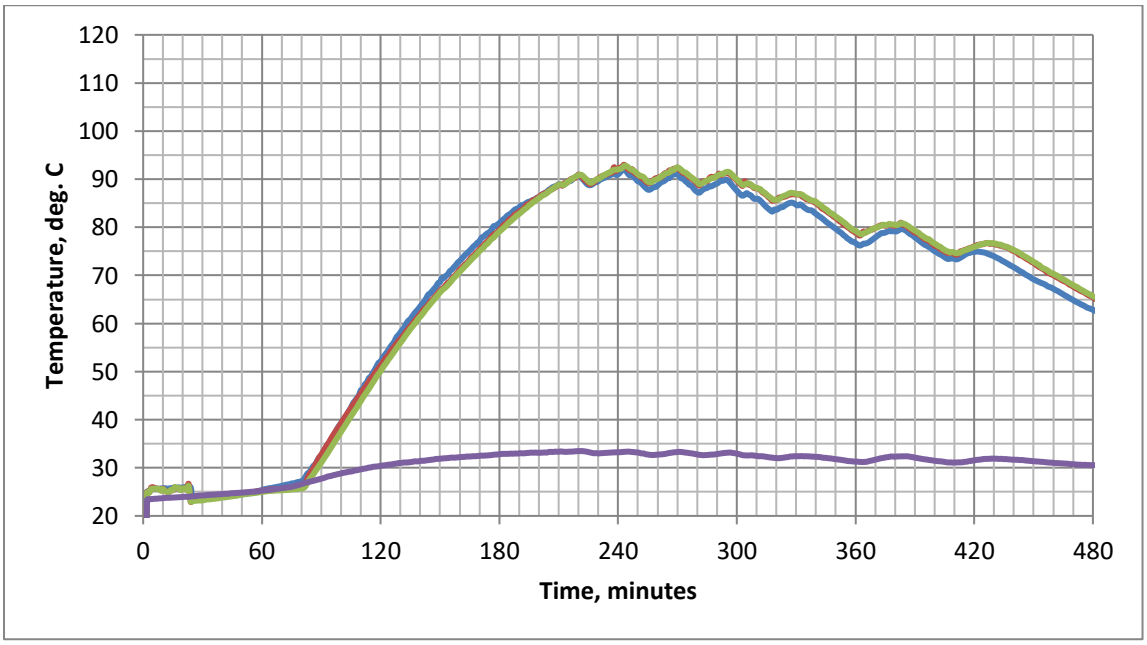
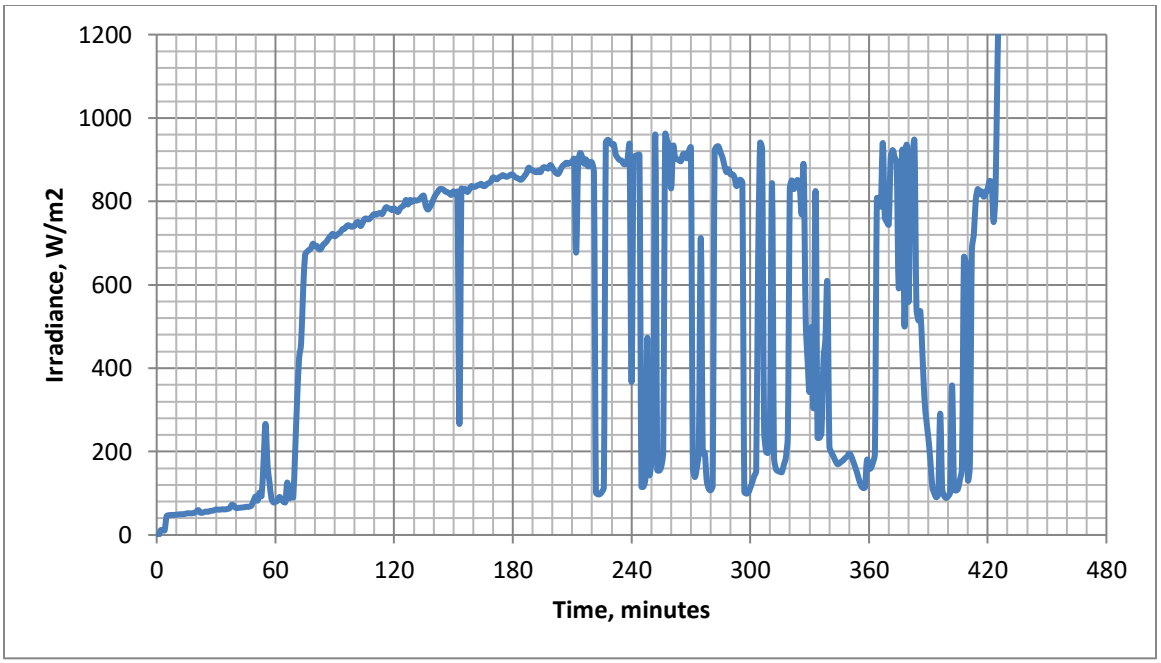


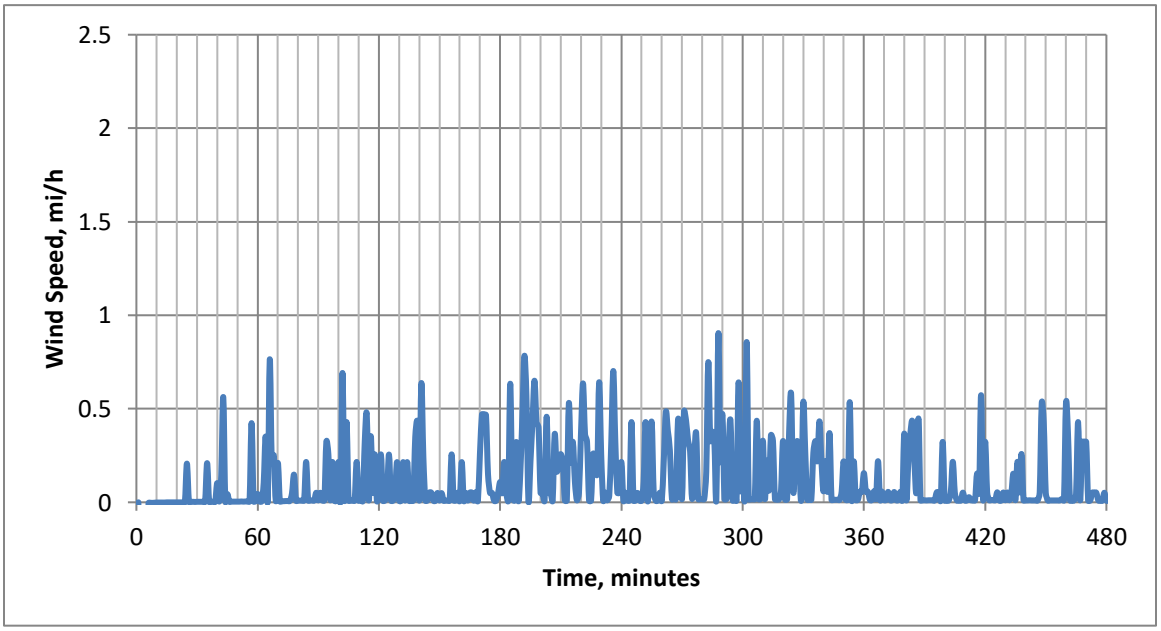
20160820 – B&R: HotPot #1, G: HotPot#2, load 2.32 liters water. P: ambient.



20160820

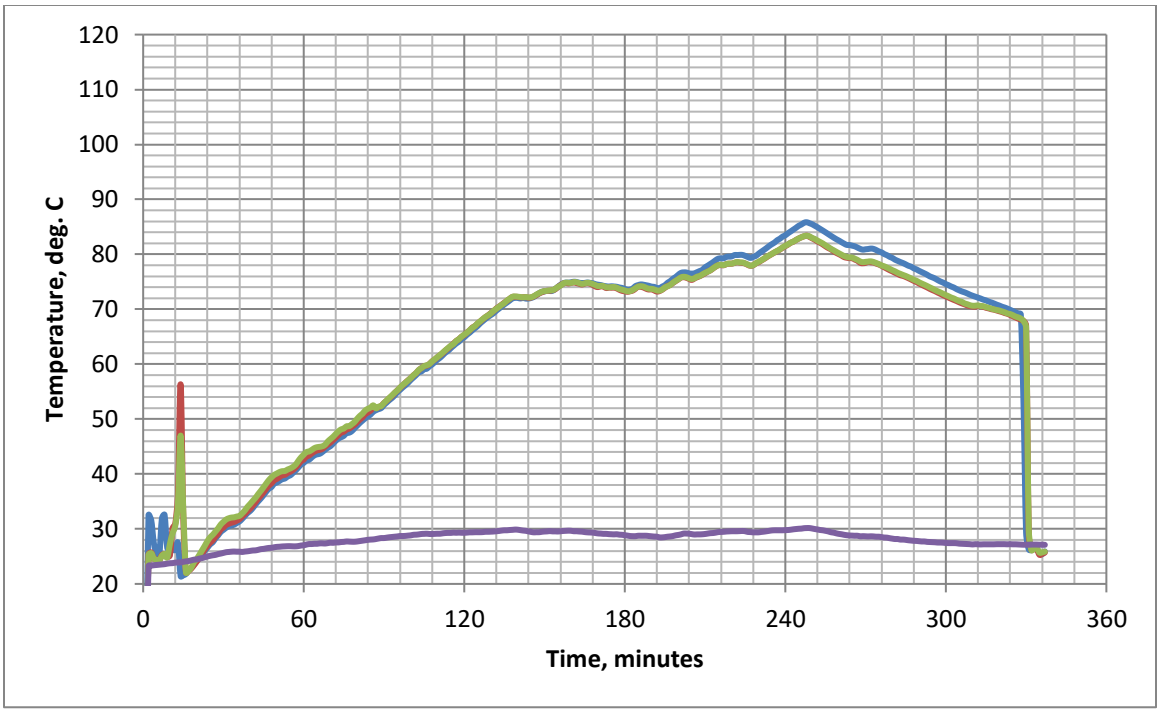
Data after about 424 minutes went to very high levels; a connection problem.

Sensor was in shade from trees for first hour.

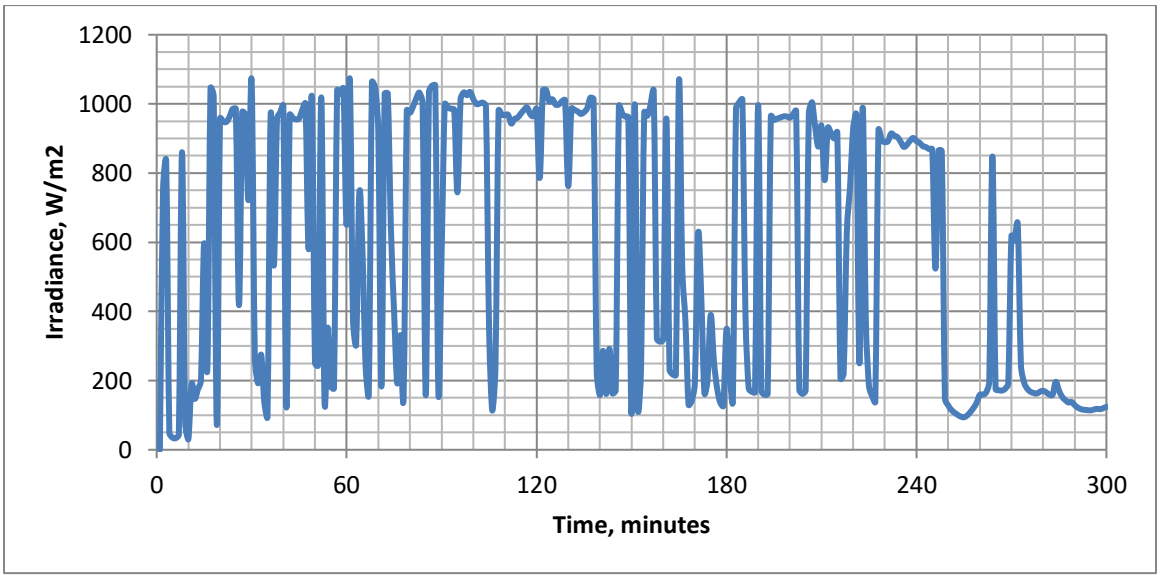


20160820

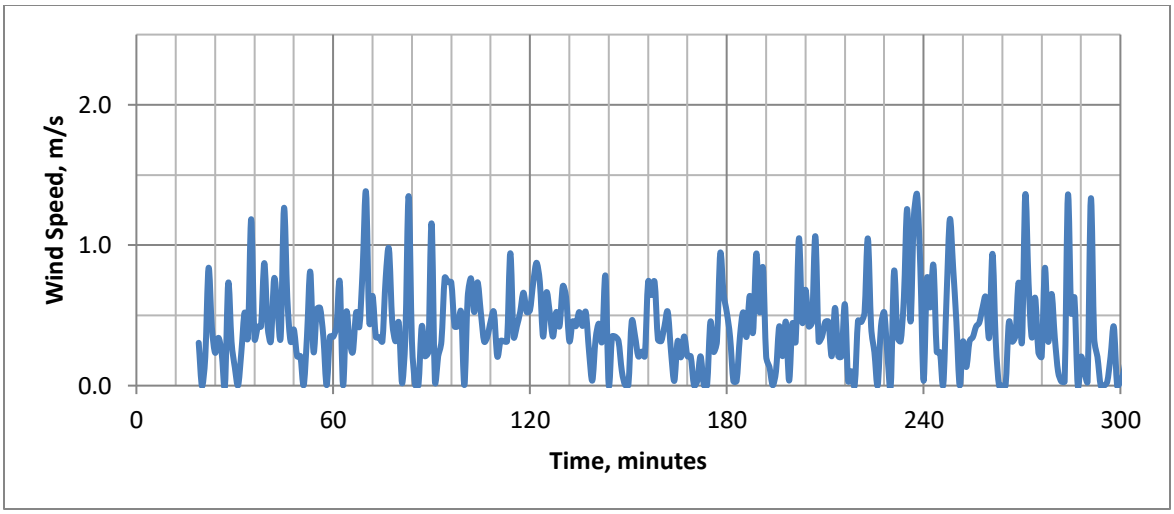
Wind was practically calm all day.



20160822 – B: Haines pot 2 with glass lid, G: Haines pot 1 with silicone lid. P: ambient.



20160822



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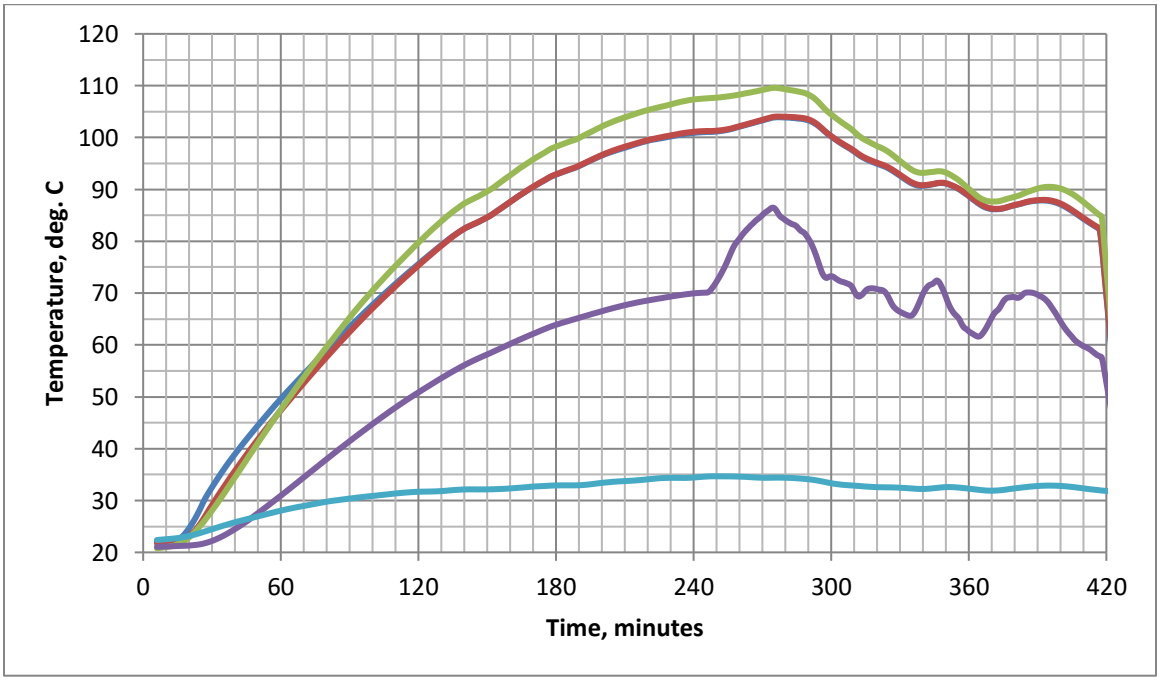
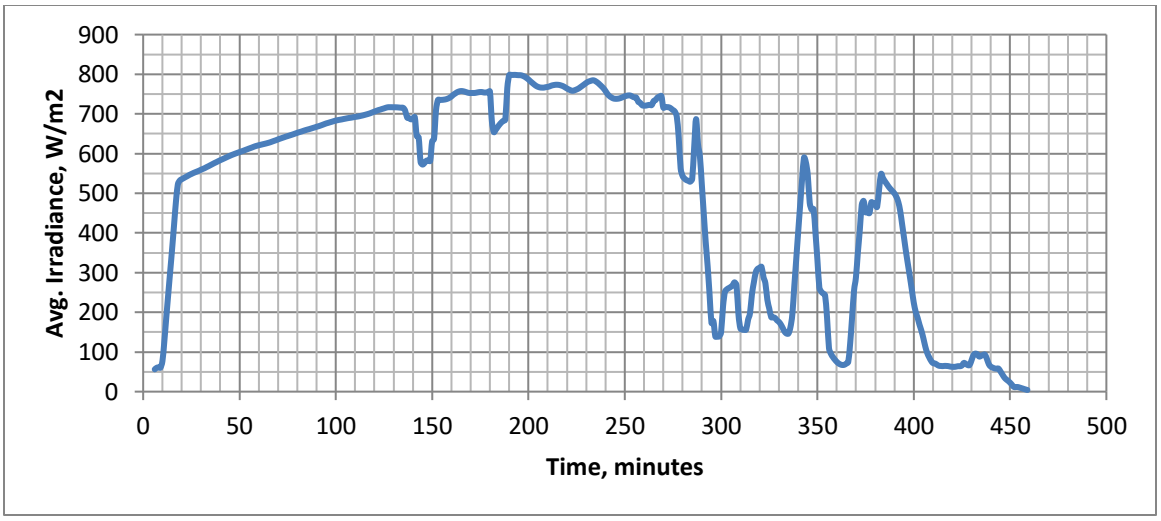


20160823 – B & R: Haines pot #2, G: Haines pot 1 with hole and silicone lid (load 2.45 l.); P: ASSC (load 2.37 l.) LB: ambient.



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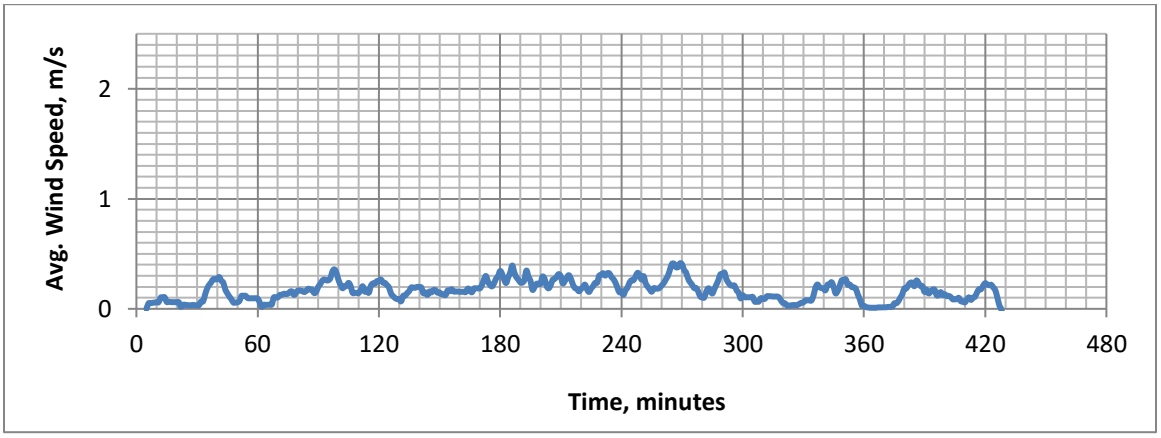

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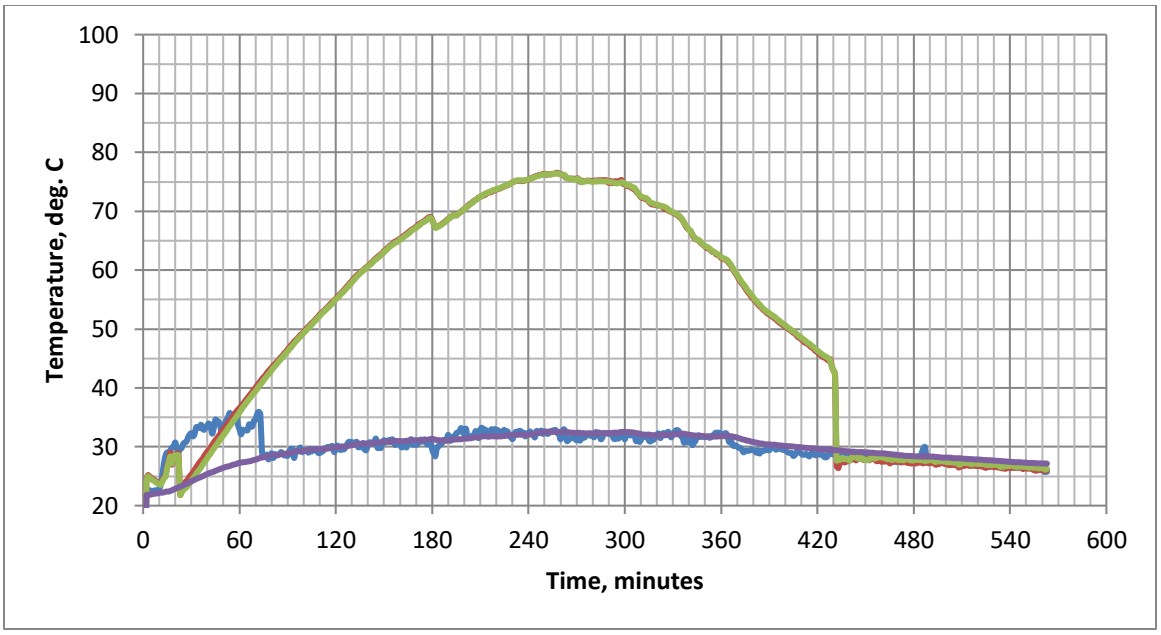
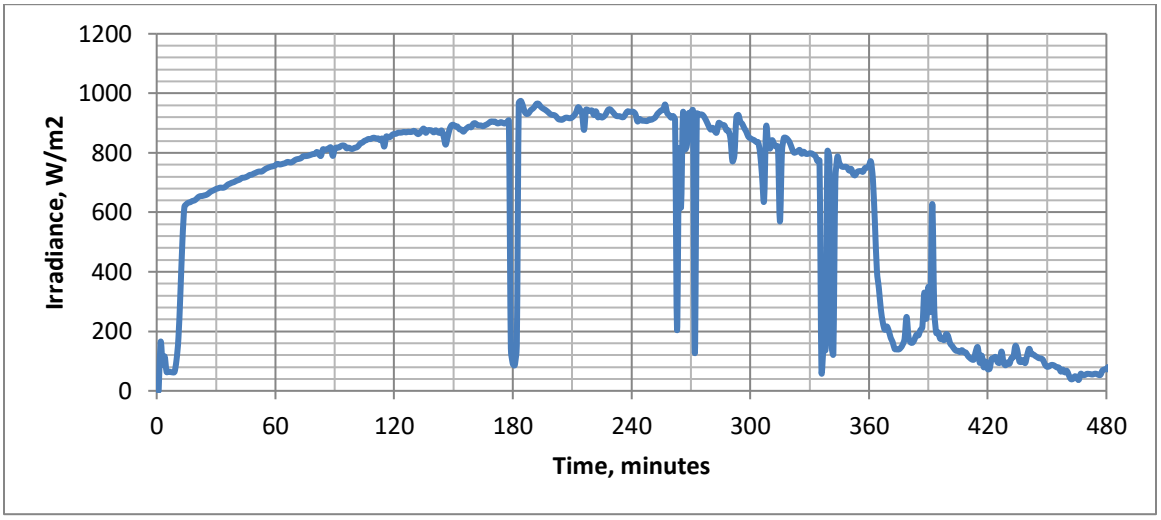


20160824

R&G: ASSC (All-Season Solar Cooker) with transparent cover.



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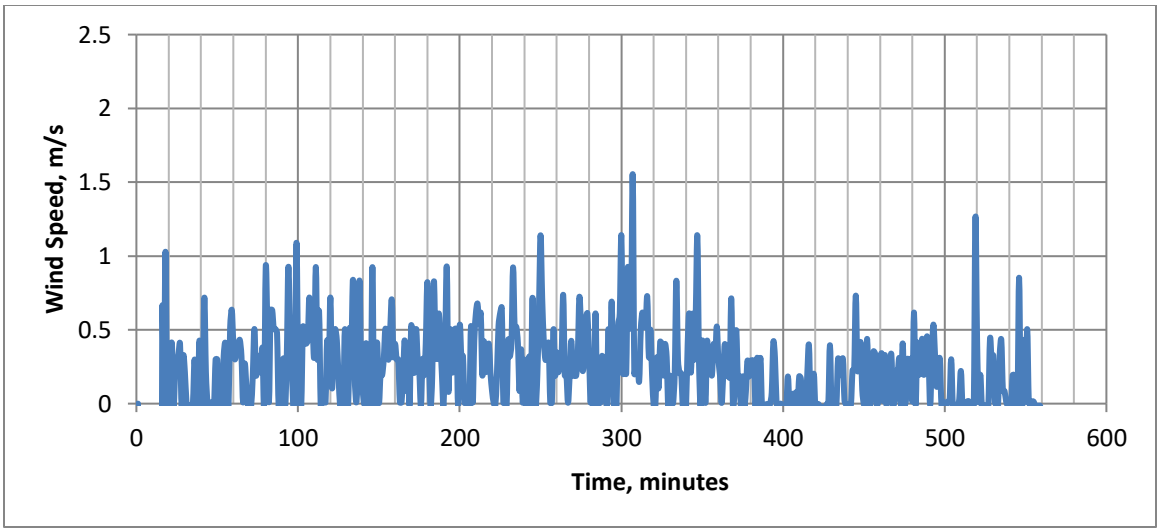

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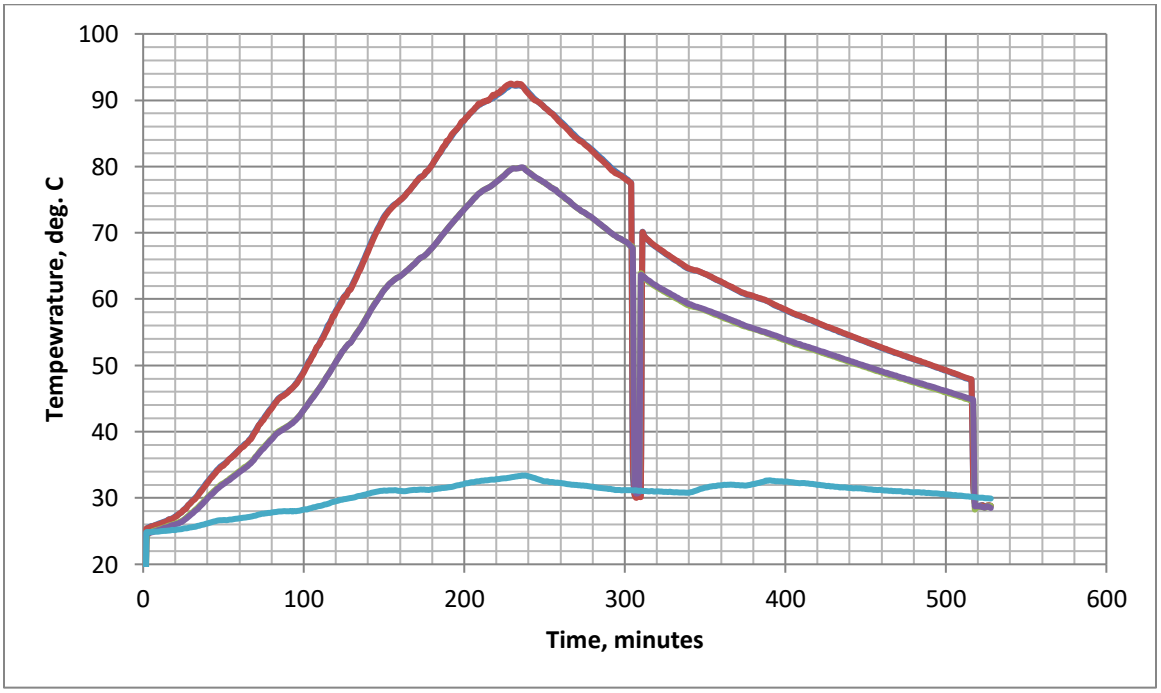


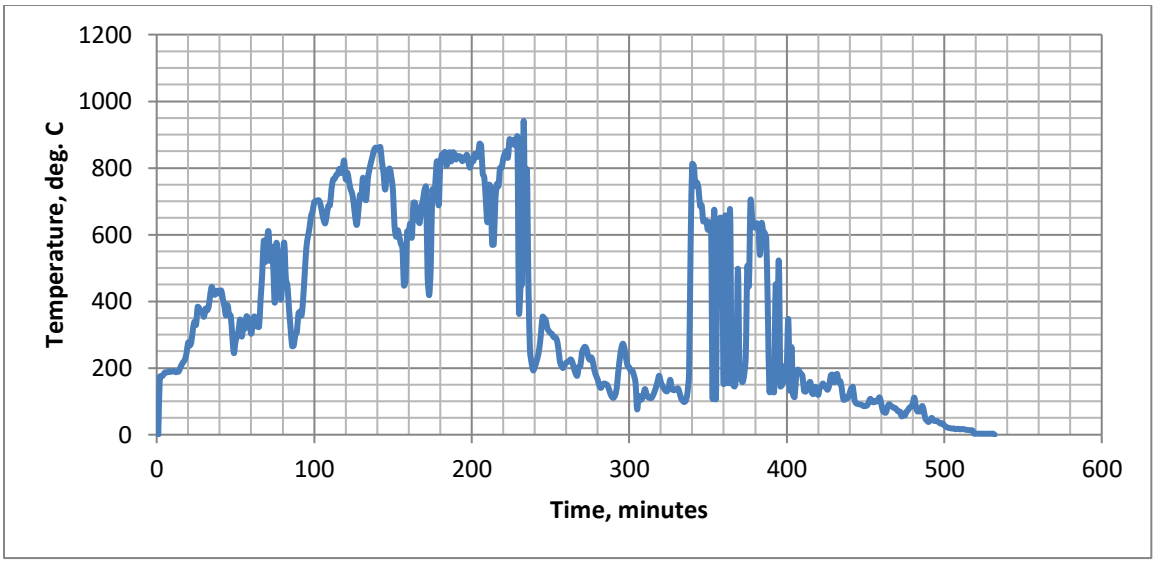
20160825

Comparison of Haines cookers

Red: Copenhagen reflectors

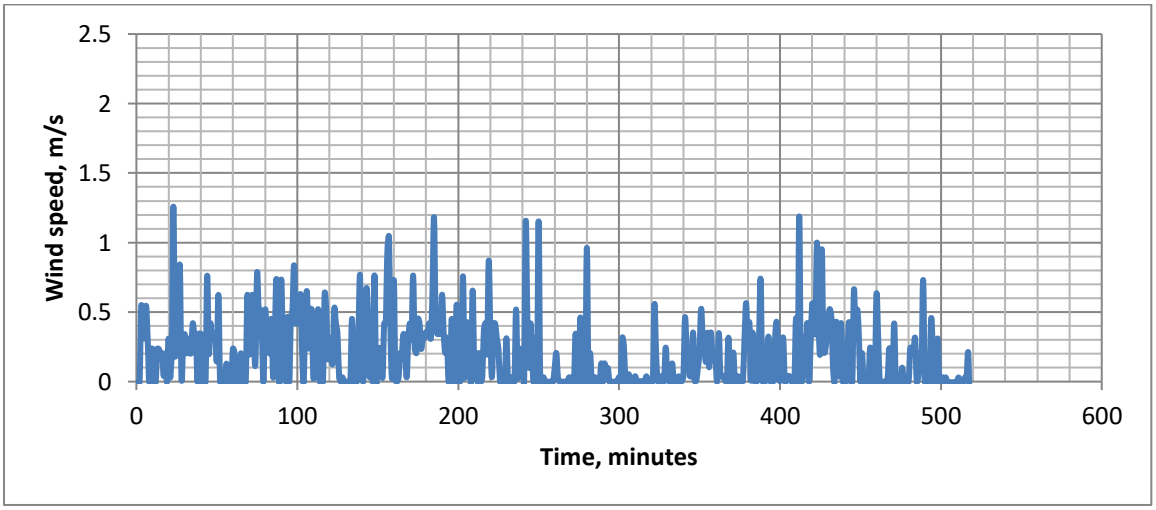
Purple: Haines reflector

Glitch: when lids were removed temporarily



20160825

20160825



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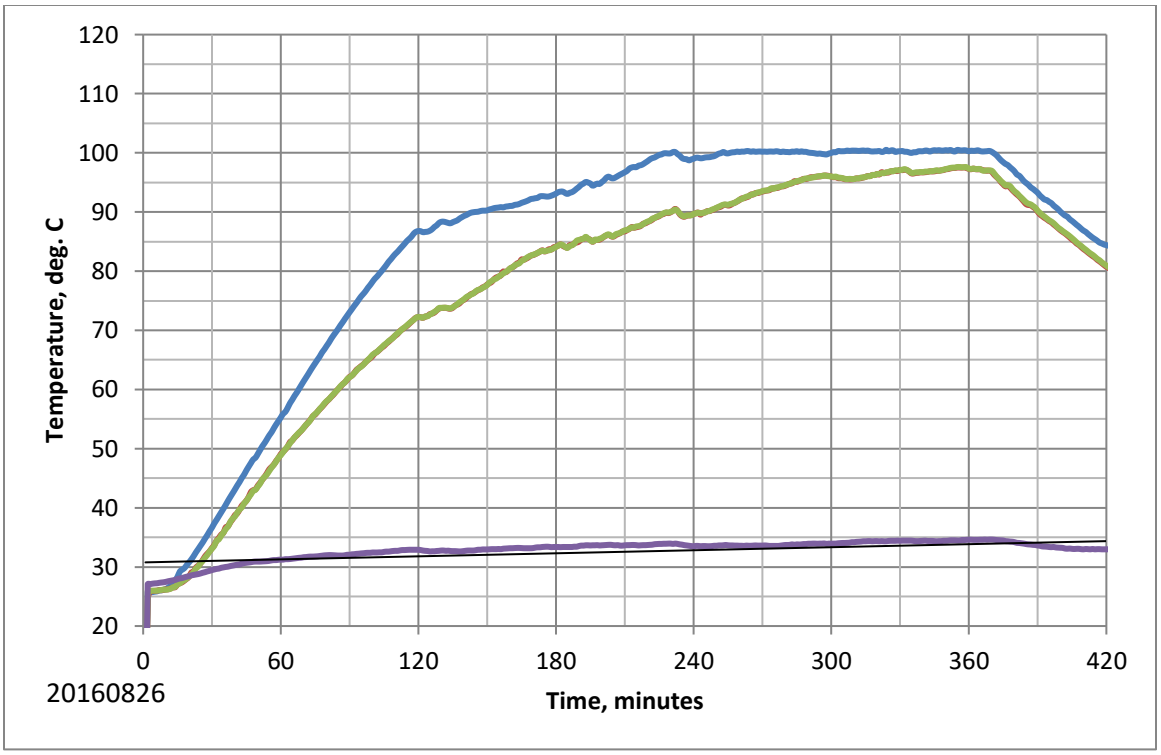
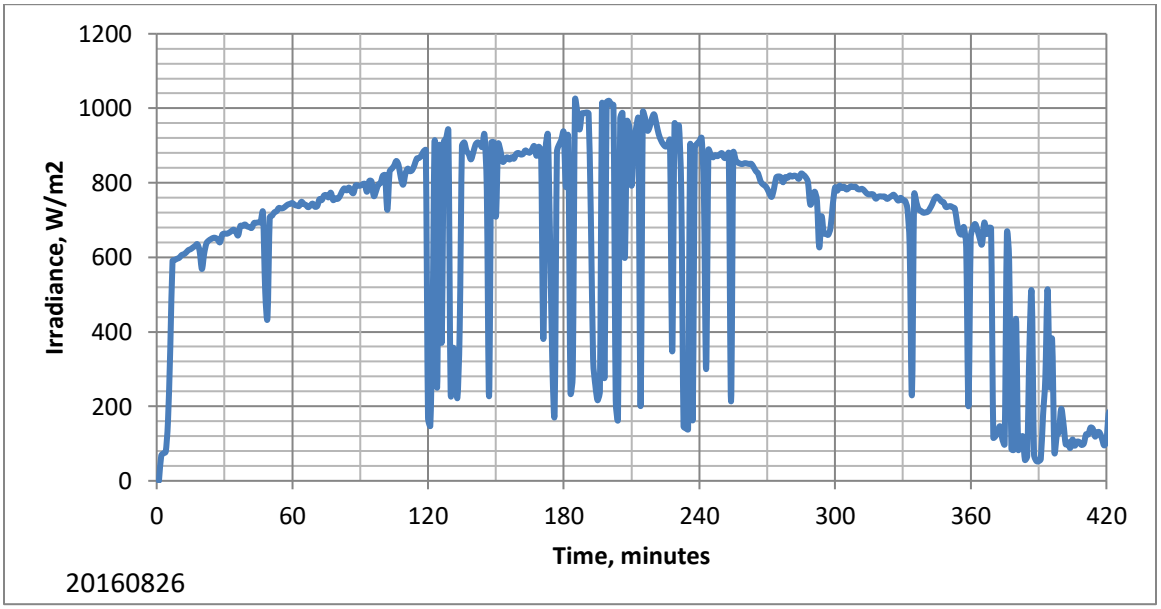
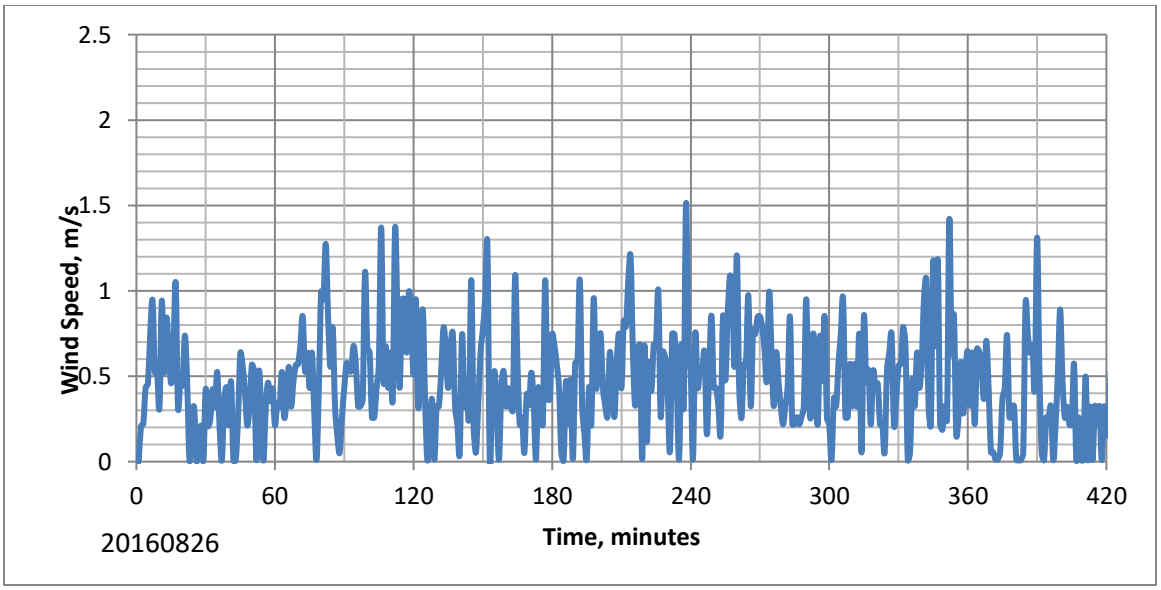
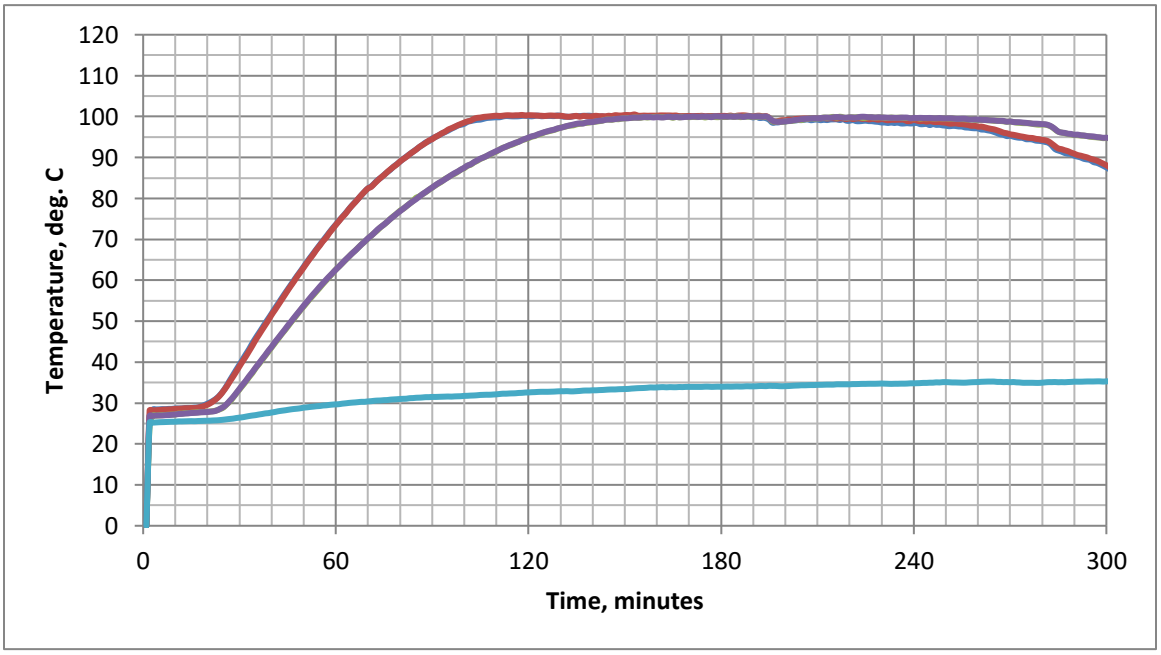


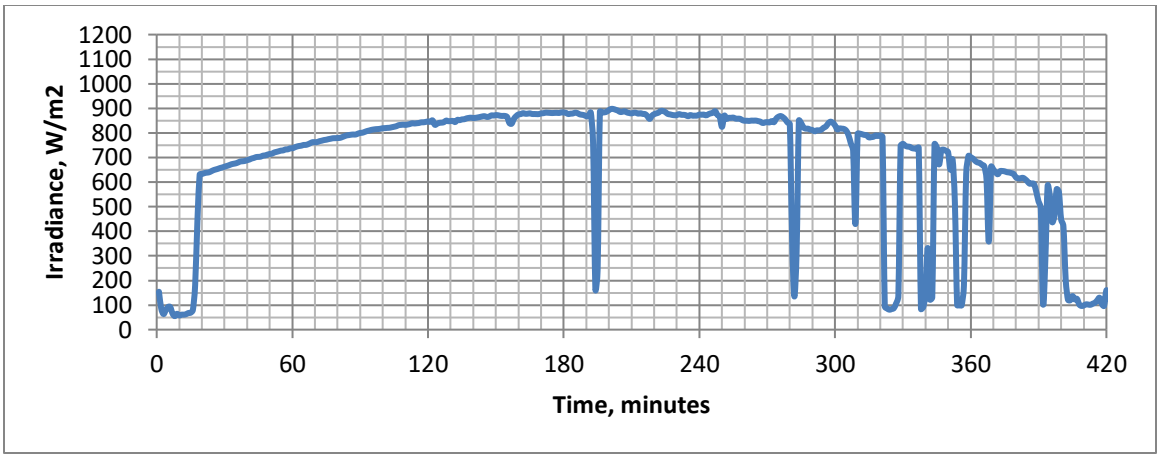
Repeat of 8/25 with better sky. B: Haines #1 with #2 reflector covered with smooth reflector material from Clausson. G: Haines #2 with #1 reflector. P: ambient.





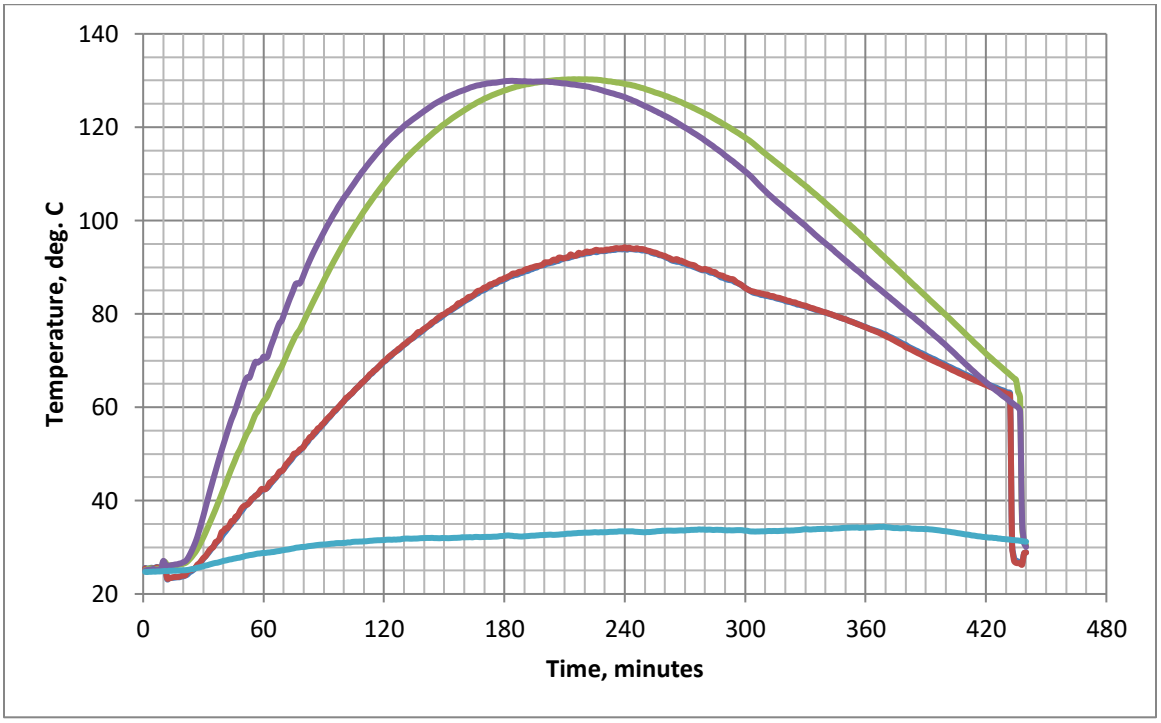


20160827 – R: Haines #1 with smooth reflectors; P: Haines #2. Load 1 liter water. LB: ambient.

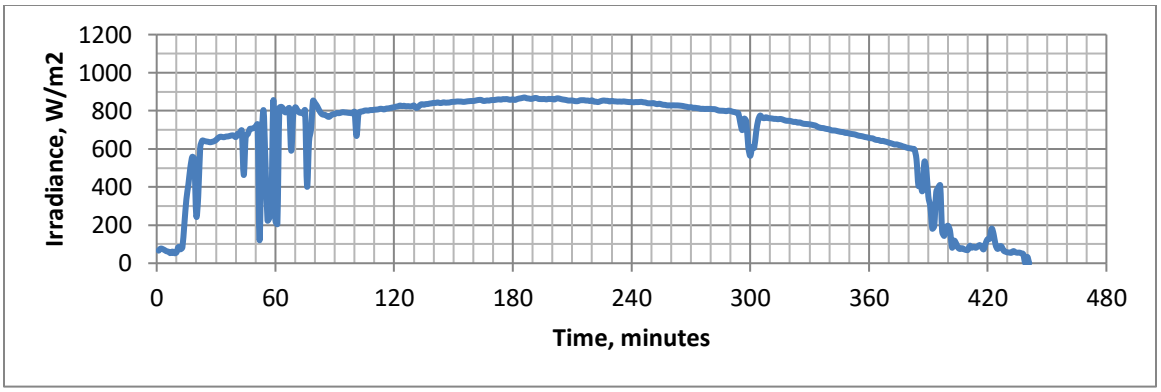


20160827 – very good sky.

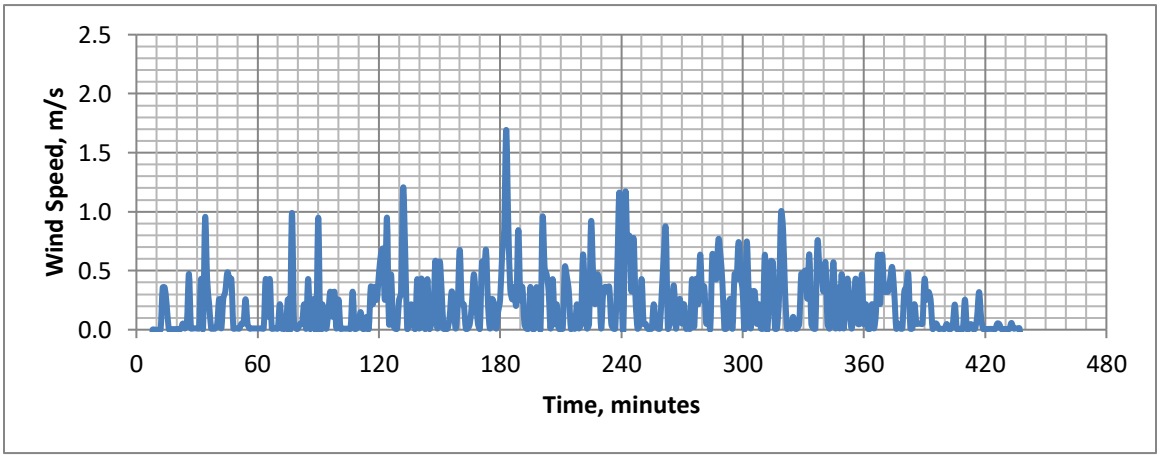
No wind speed data recorded (power off).



20160828 – R: Haines #1 with 2.45 l. water load; G & P: 3 kg copper blocks. LB:ambient



20160828



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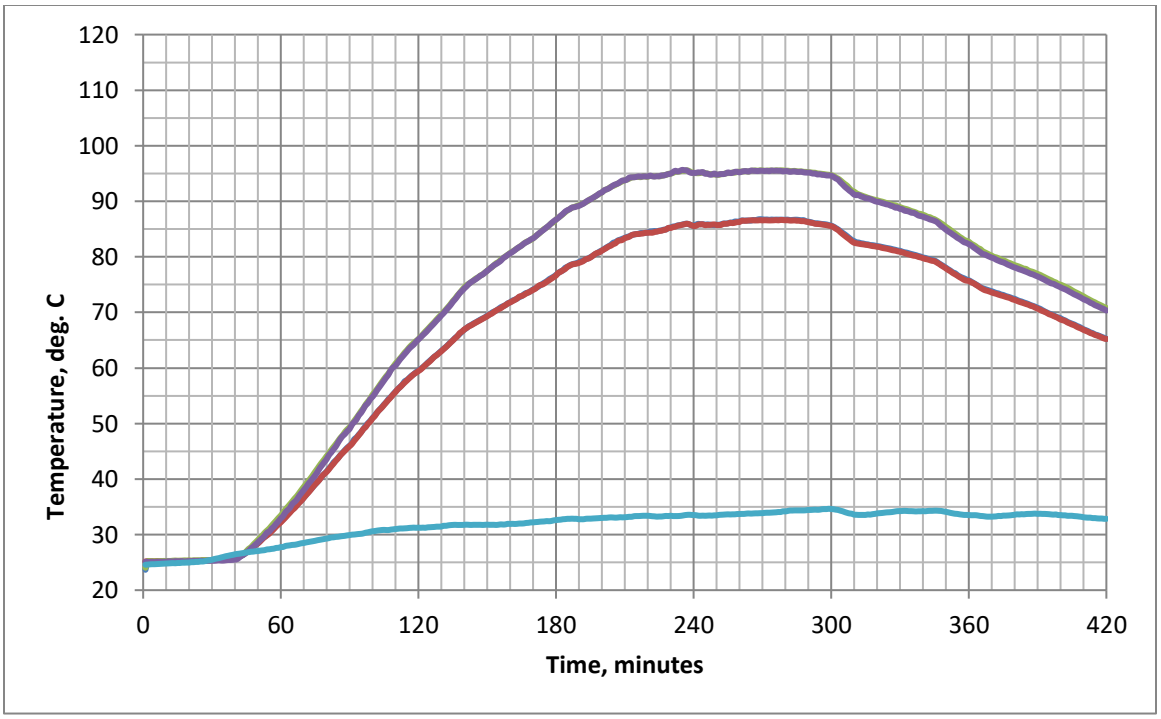
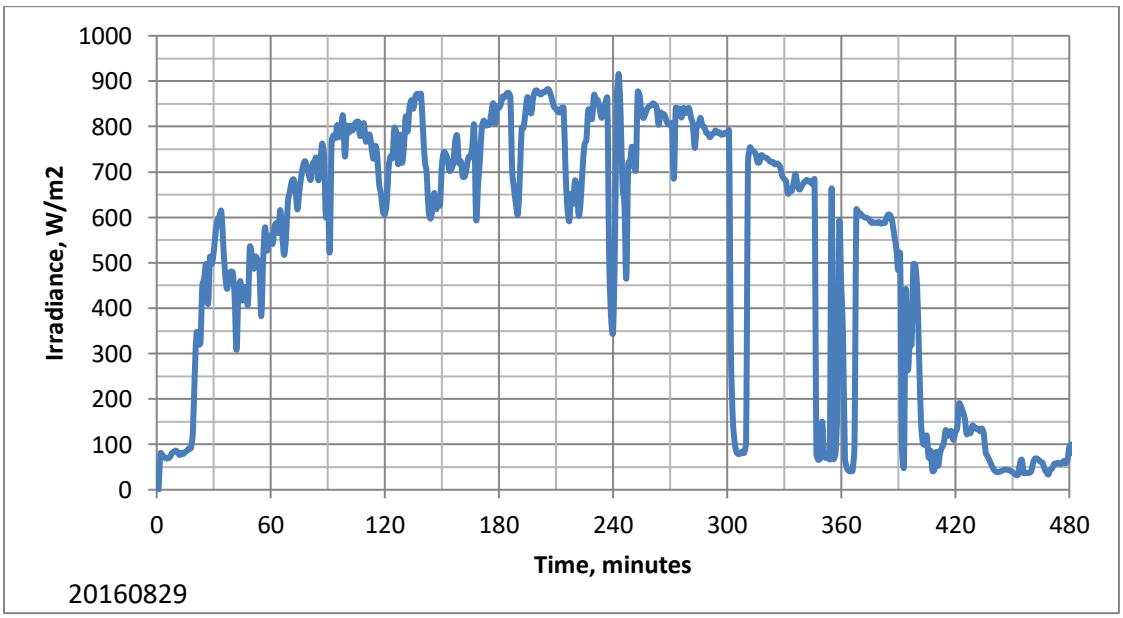
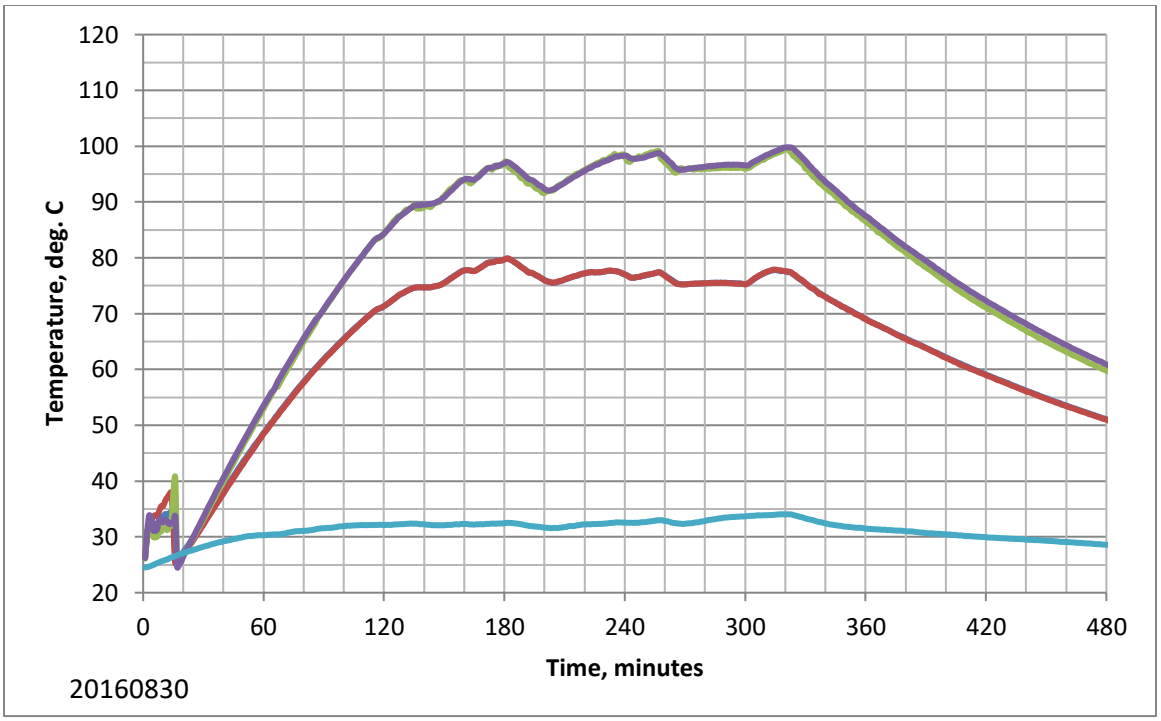


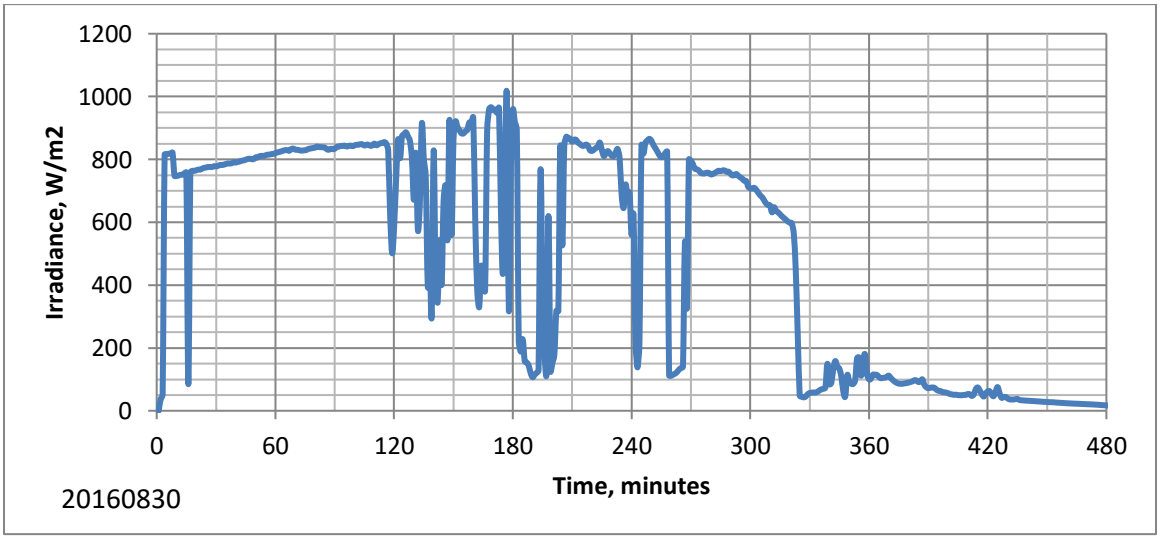
20160829 – Repeat of 8/25 with better sky. R: Haines. P: smooth reflectors. LB: ambient.

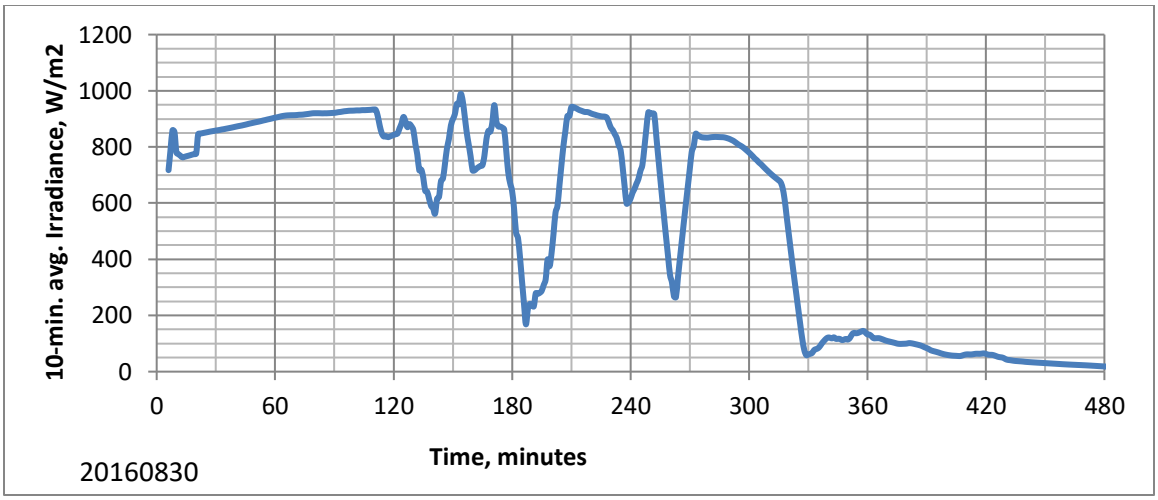


(No wind data)



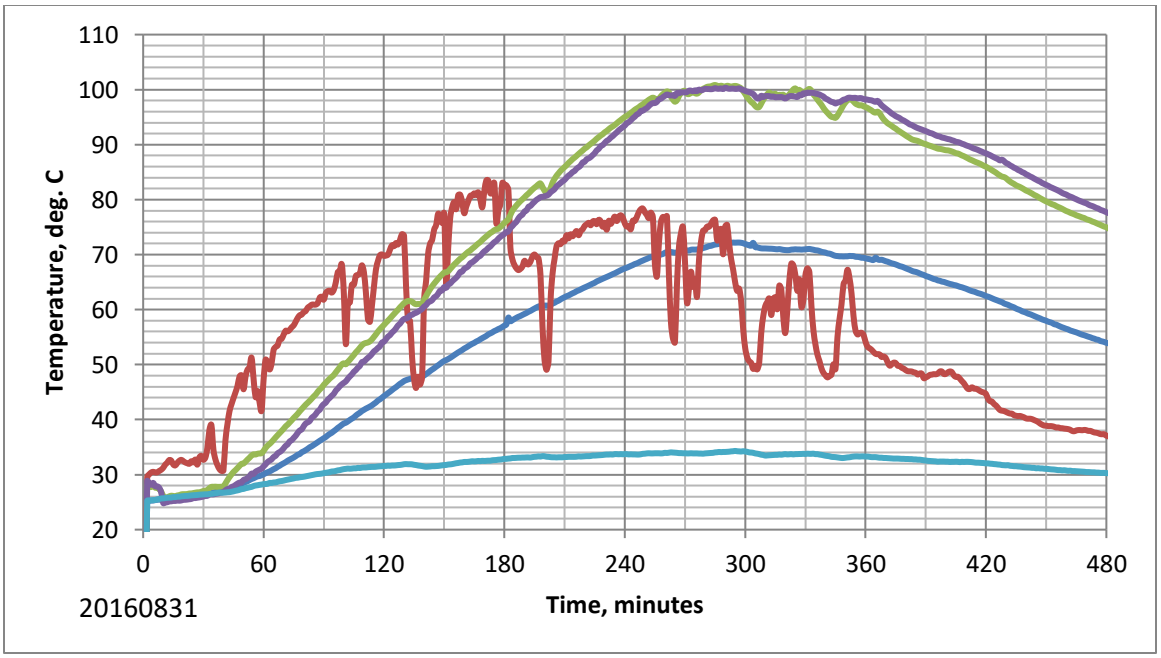
Repeat of 8/29. R: Haines #1. G & P: Haines #2 with smooth reflectors. LB: ambient.



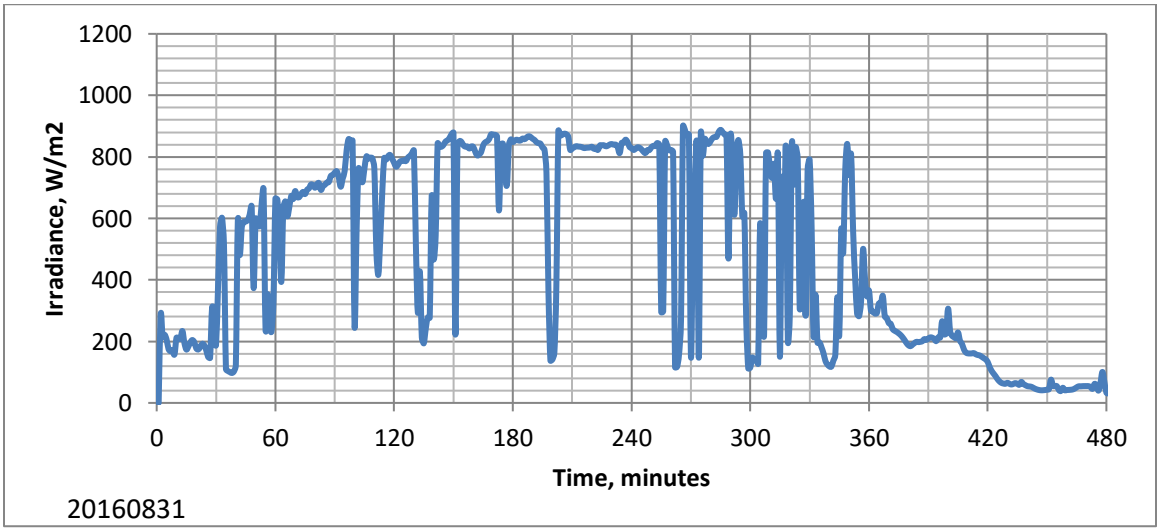


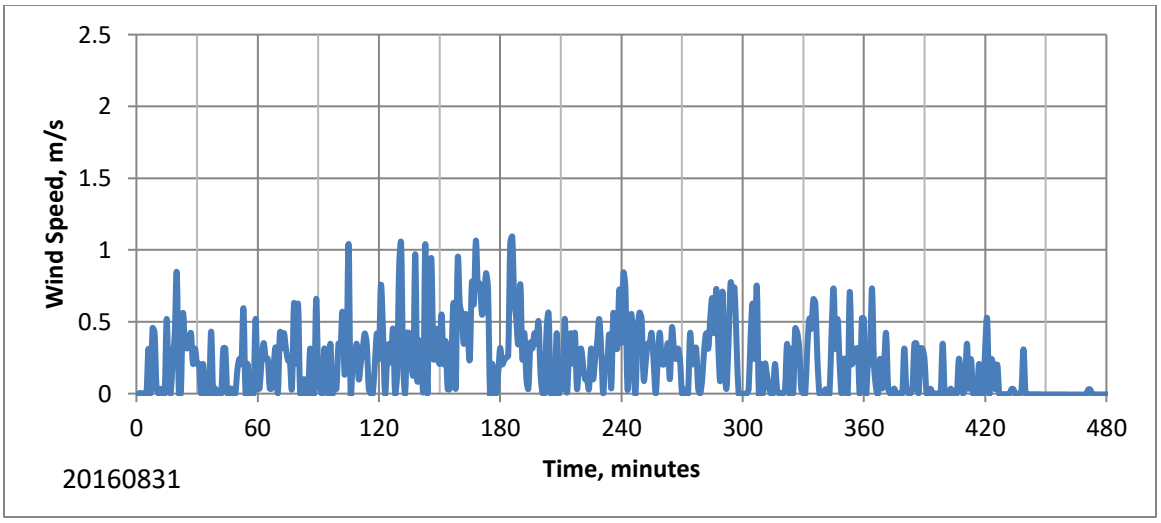
10-minute averaged data.

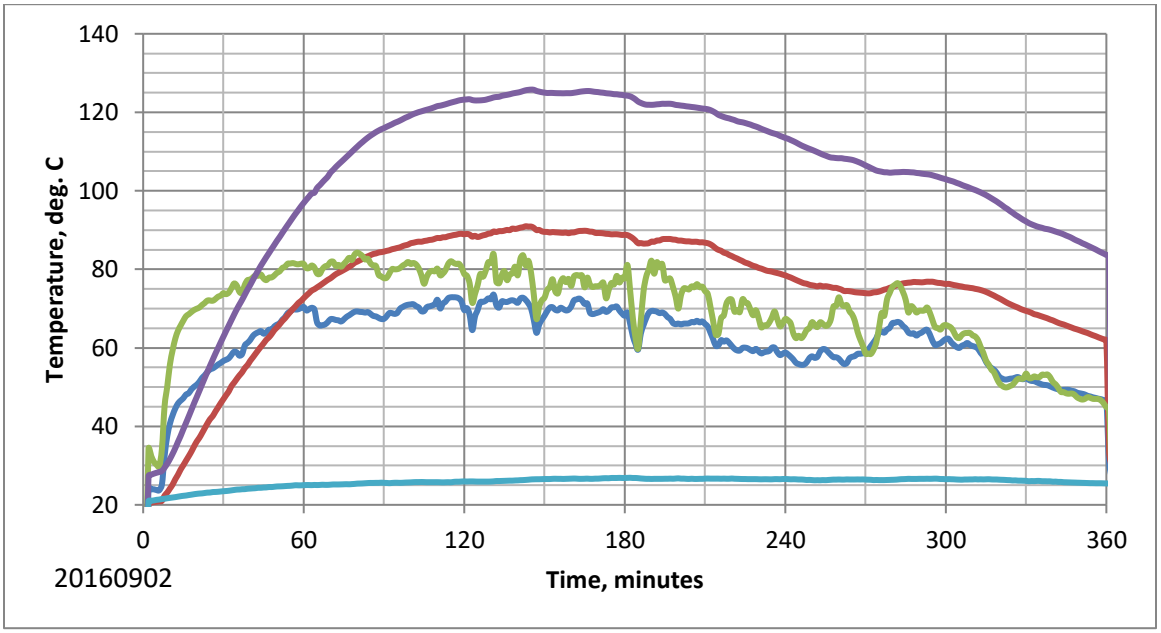
(no wind speed data)



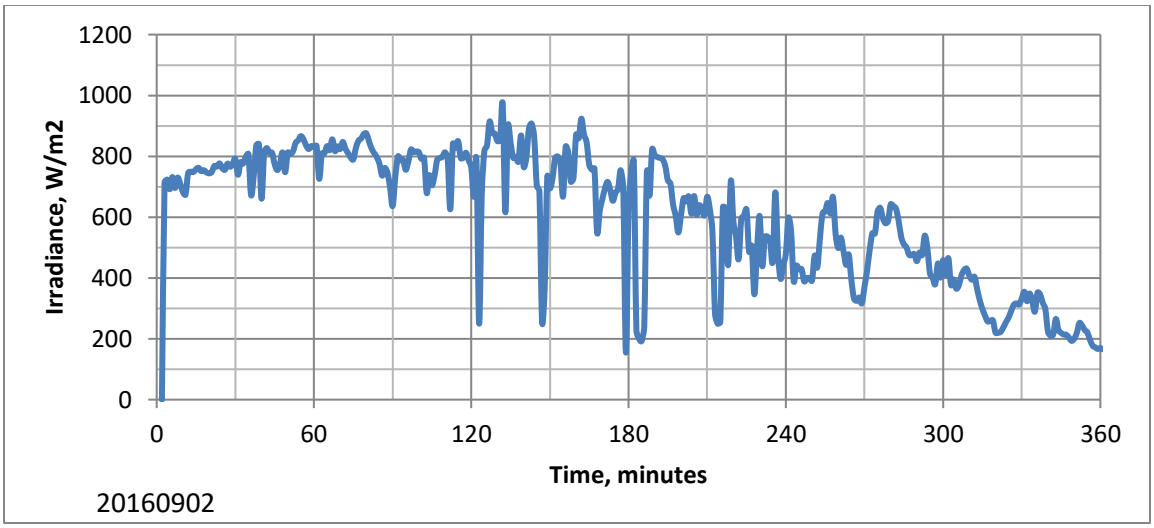
B: Internal temp. of black enamel pot in CooKit. R: Air inside bag around pot.
G: Sport with Haines pot (with silicone lid). P: Under Haines pot. Load: 3 liters each. LB: ambient.

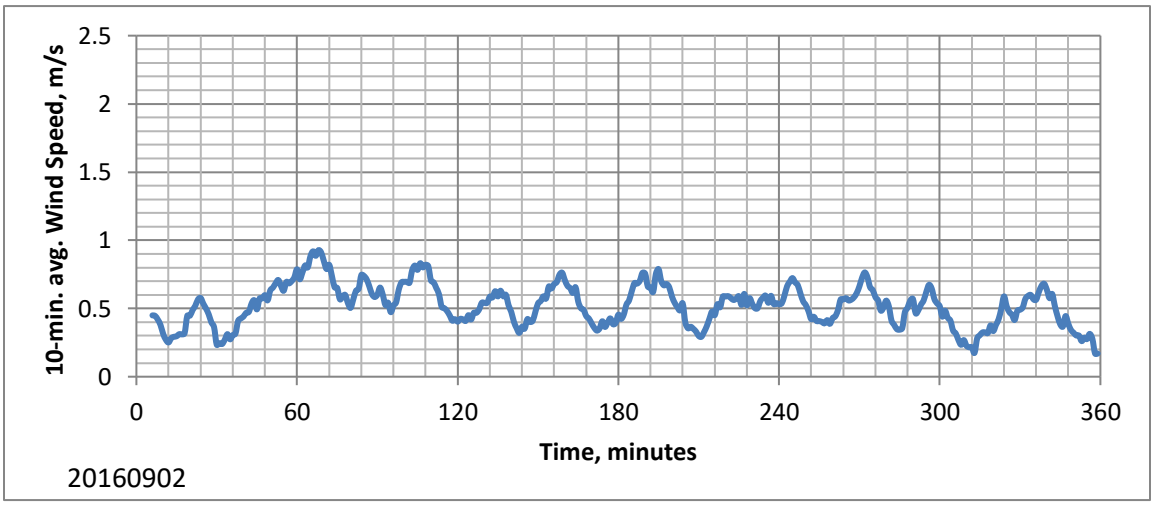


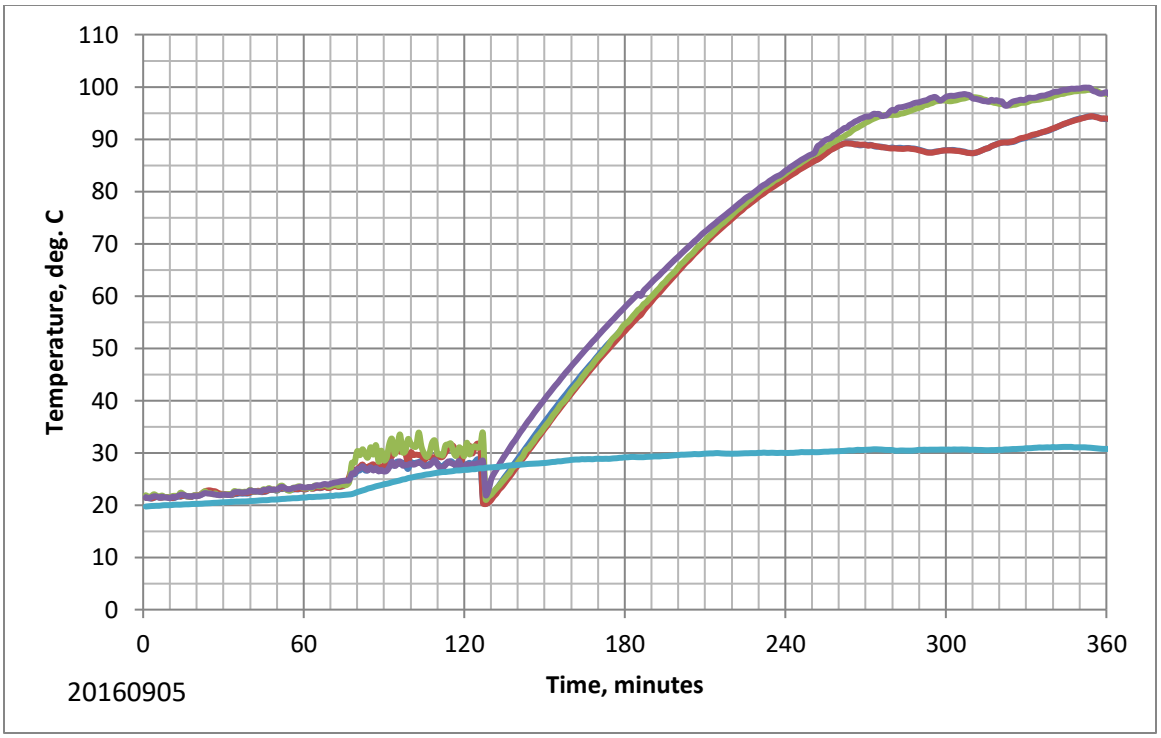




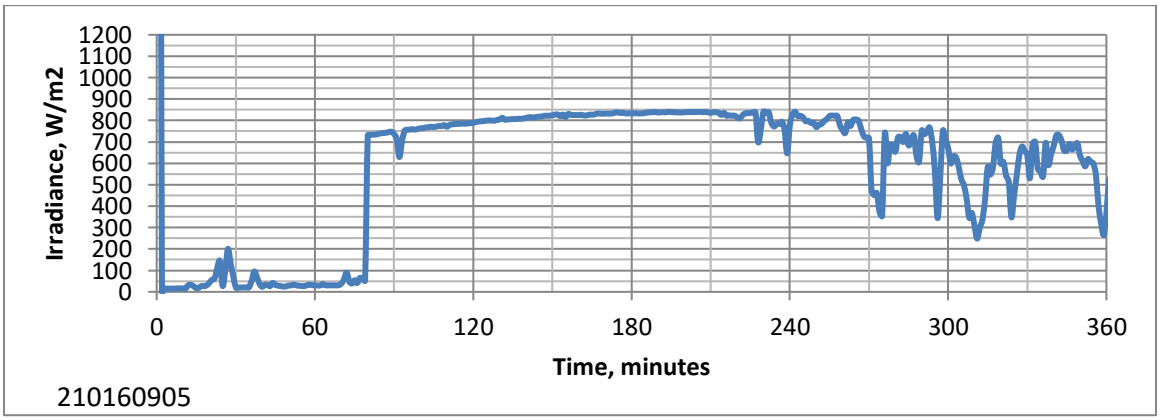
B: Haines #1 pot, under pot in air. R: in pot in water. Load: 1 liter water.
G: Haines #2 pot, under pot in air. P: in pot in water. Load: 3 kg copper blocks.
LB: ambient.
(The copper blocks heated up much faster than the water. To match the water, a much larger mass of copper would be needed.)


1200
1000
800
600
400
200
0
Irradiance, W/m2
0
60
120
180
240
300
360
Time, minutes
20160902

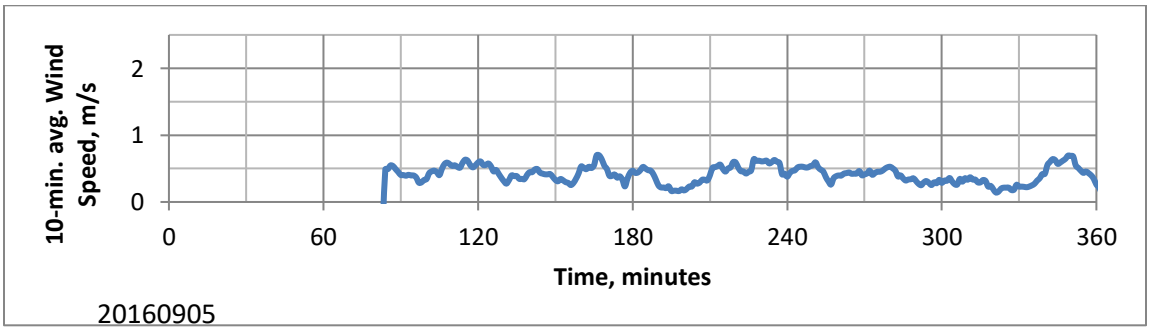

2.5
2
1.5
1
0.5
0
10-min. avg. Wind Speed, m/s
0
60
120
180
240
300
360
Time, minutes
20160902

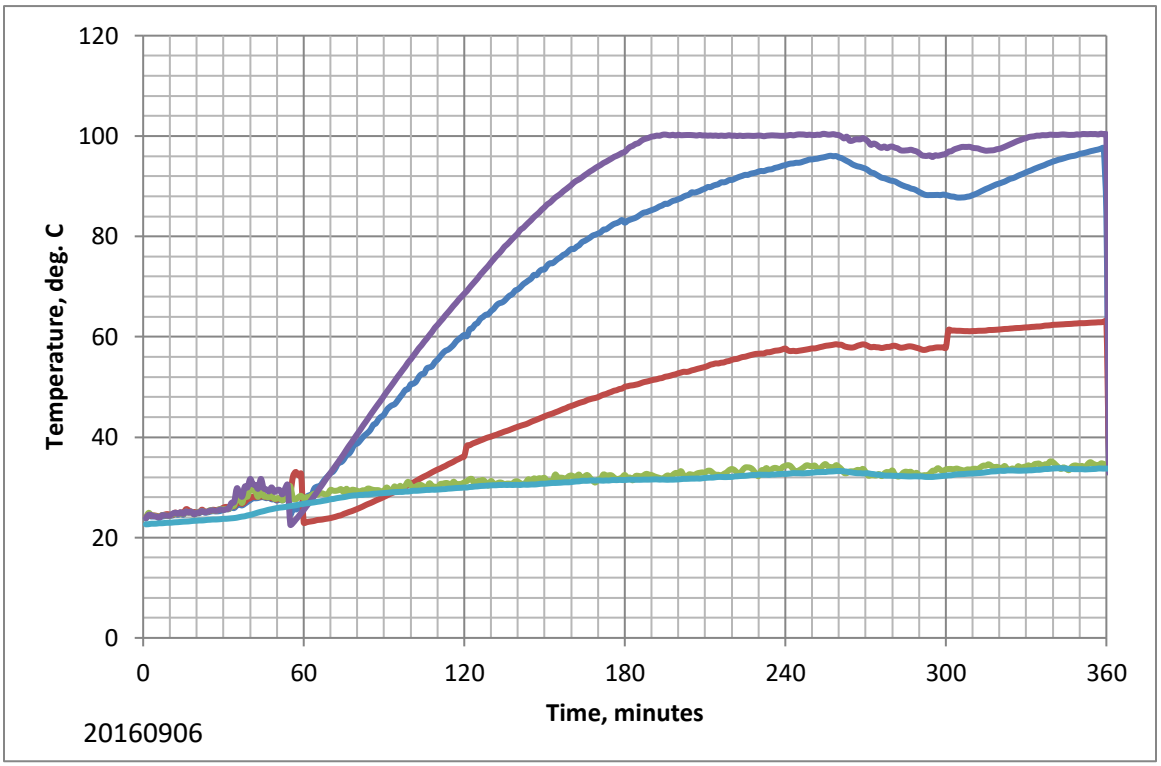


B&R: Haines #1 with smooth reflectors. G&P: Haines #2 with #3 reflector. The test started late, at about 130 minutes. LB: ambient.



The Stevenson box was placed in the sun at about 80 minutes.





Blue: Haines #1 with 2.45 l. water

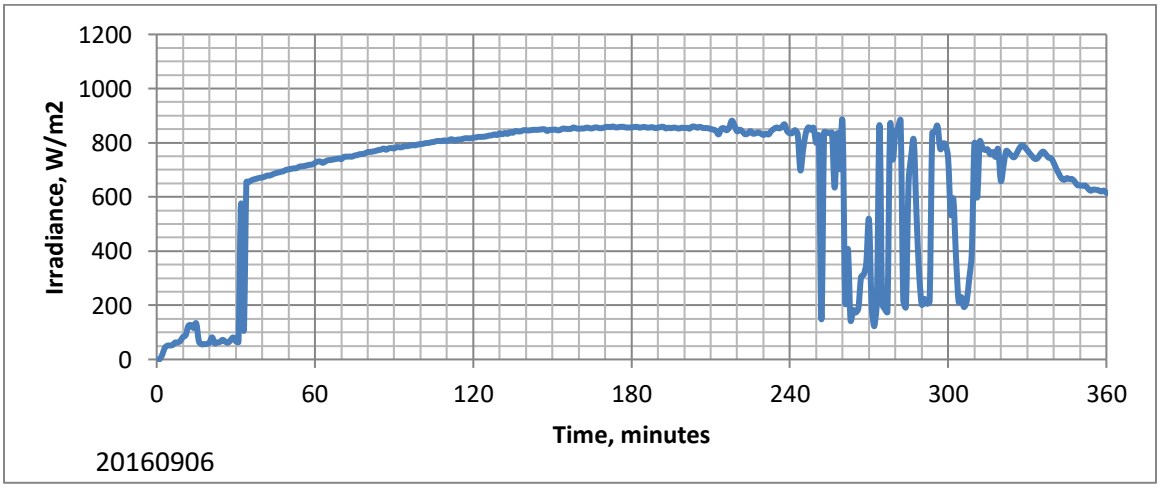
Red: ASSC with no cover, 2.37 l load

Green: ambient

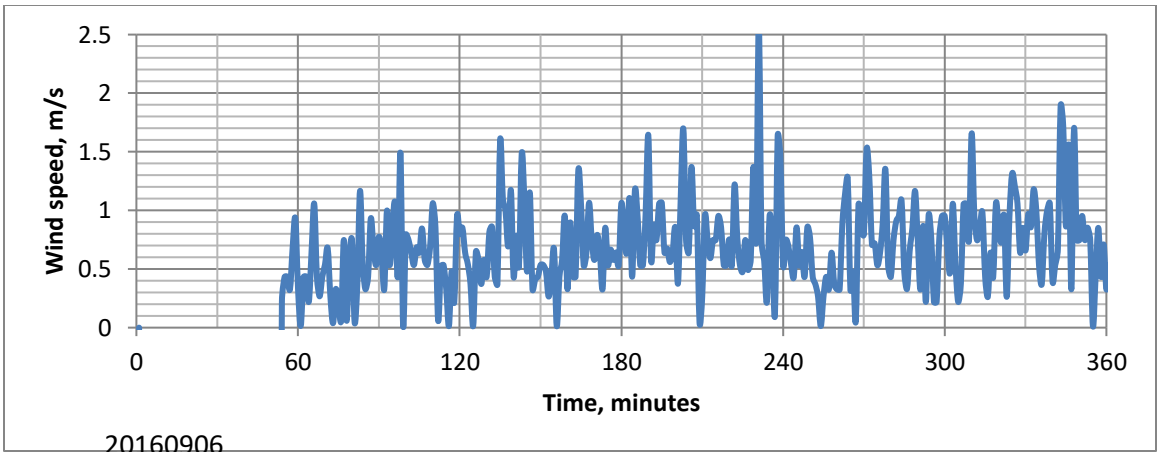
Purple: Haines#2 with smooth reflectors, 2.45 l

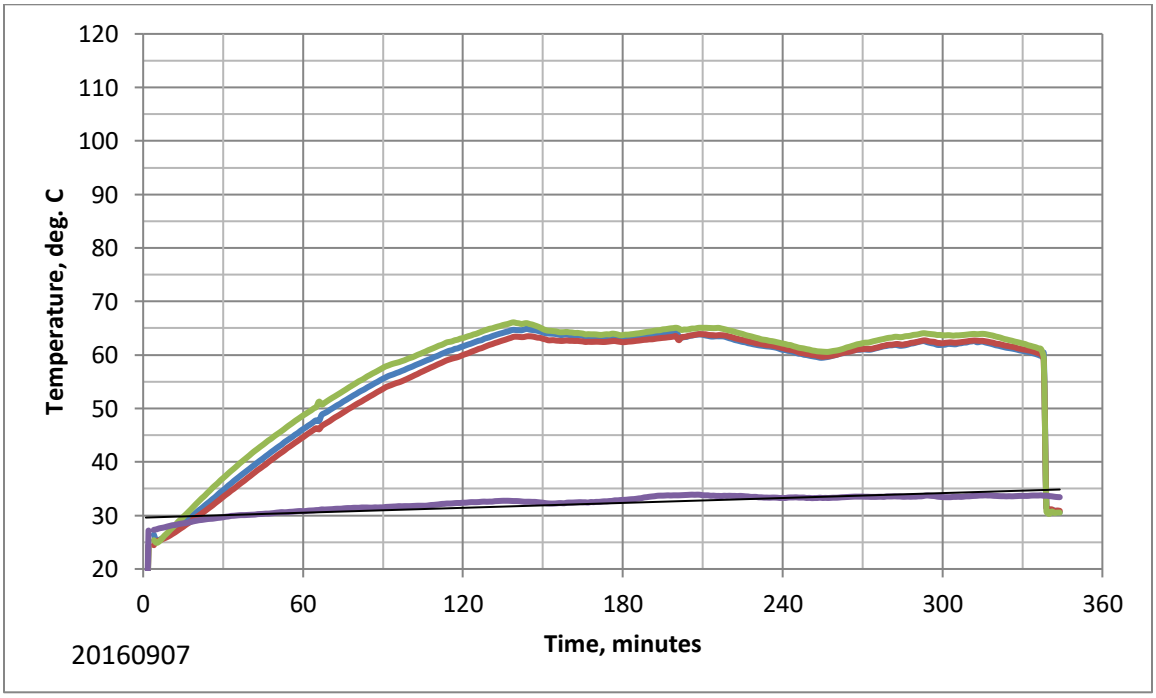
(Full boil – I have a video of this.)

LB: ambient

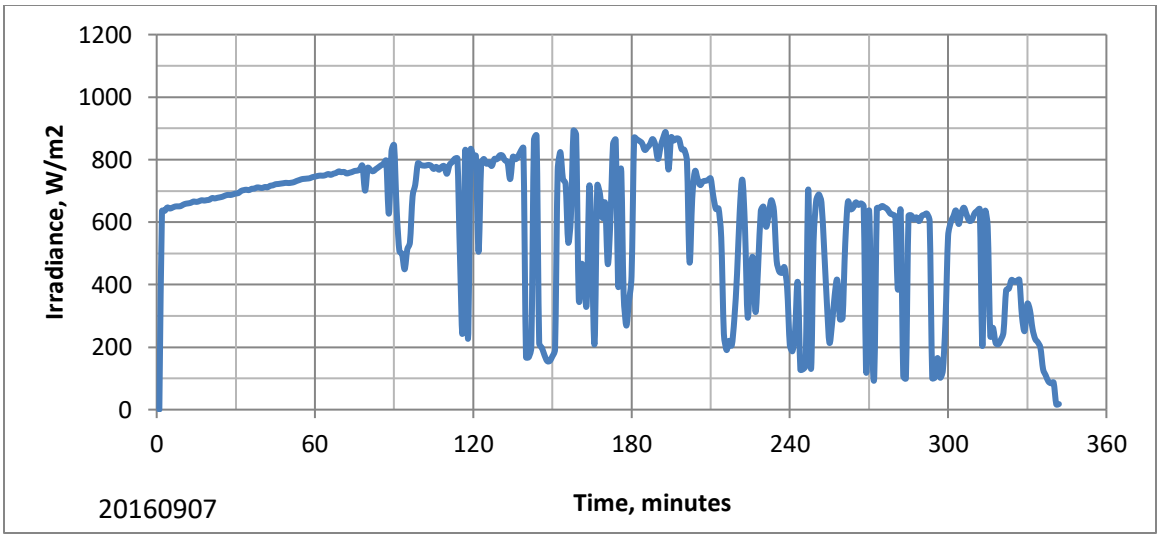


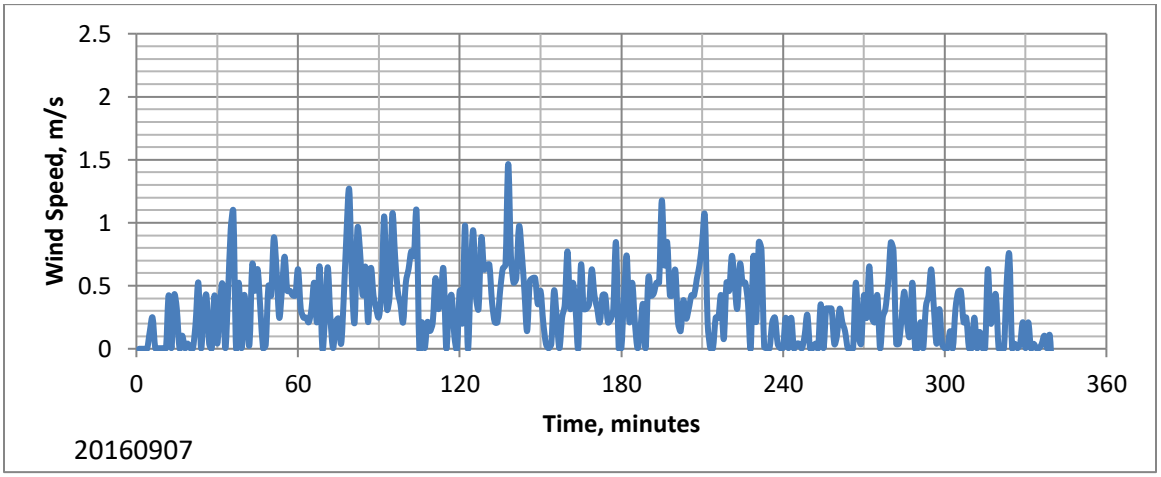
Best day so far this summer!

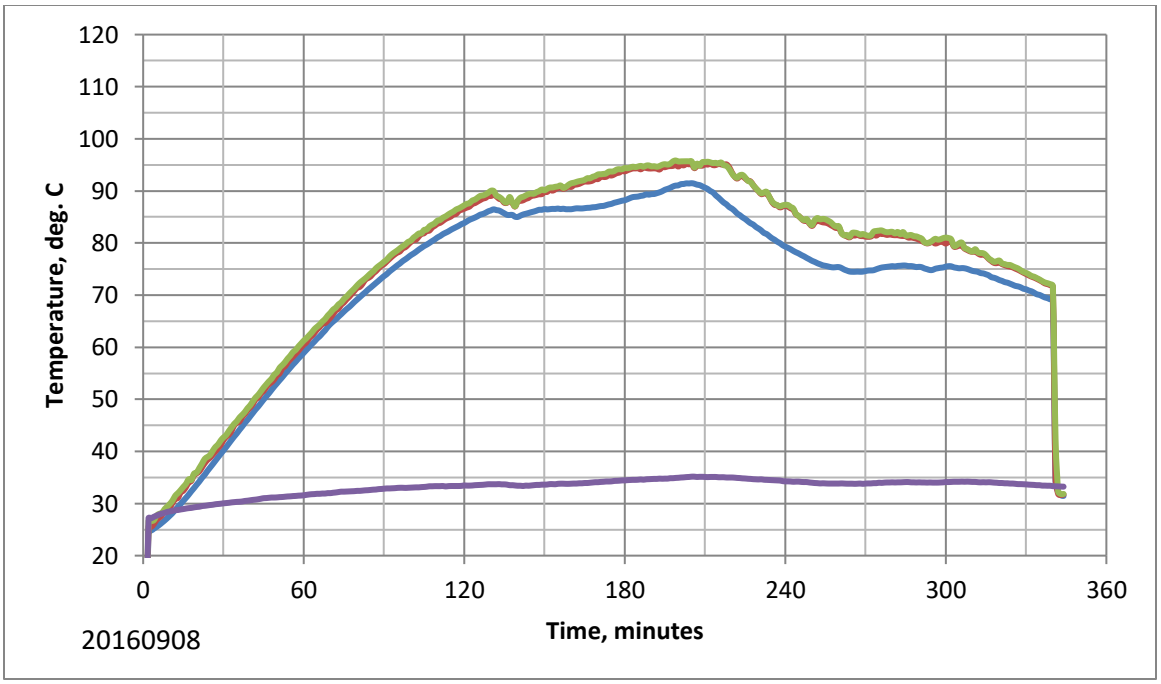




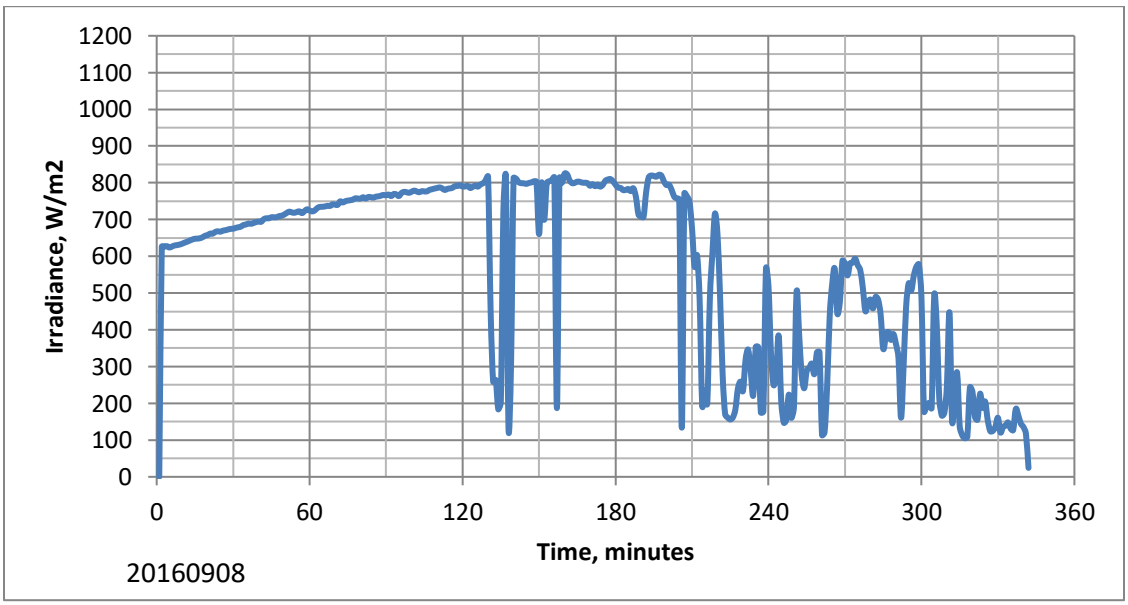
All 4 thermocouples in Granite Ware black pot in ASSC (All-Season Solar Cooker) P: ambient.

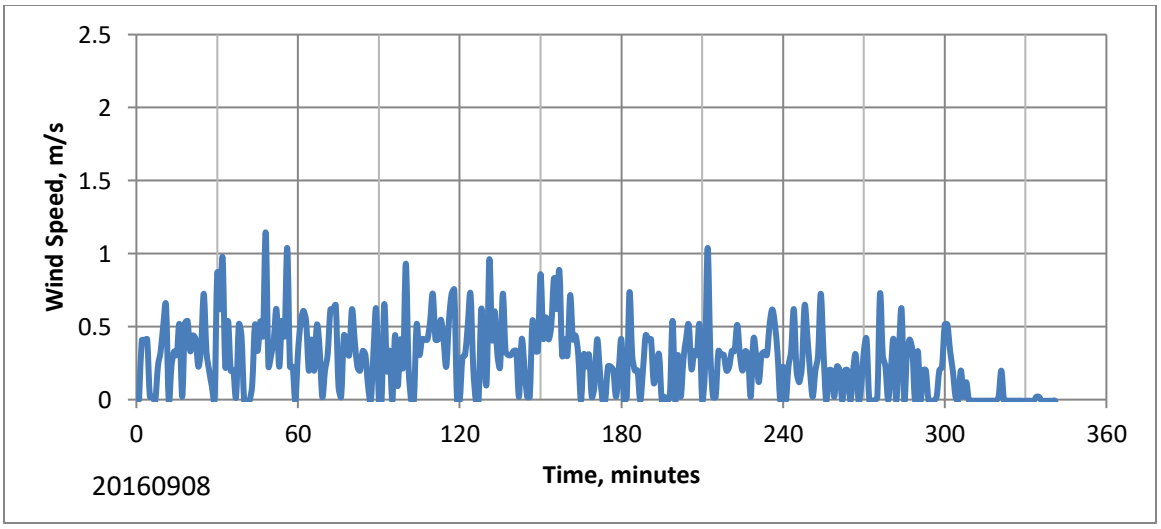

1200
1000
800
600
400
200
0
Irradiance, W/m2
0
60
120
180
240
300
360
Time, minutes
20160907

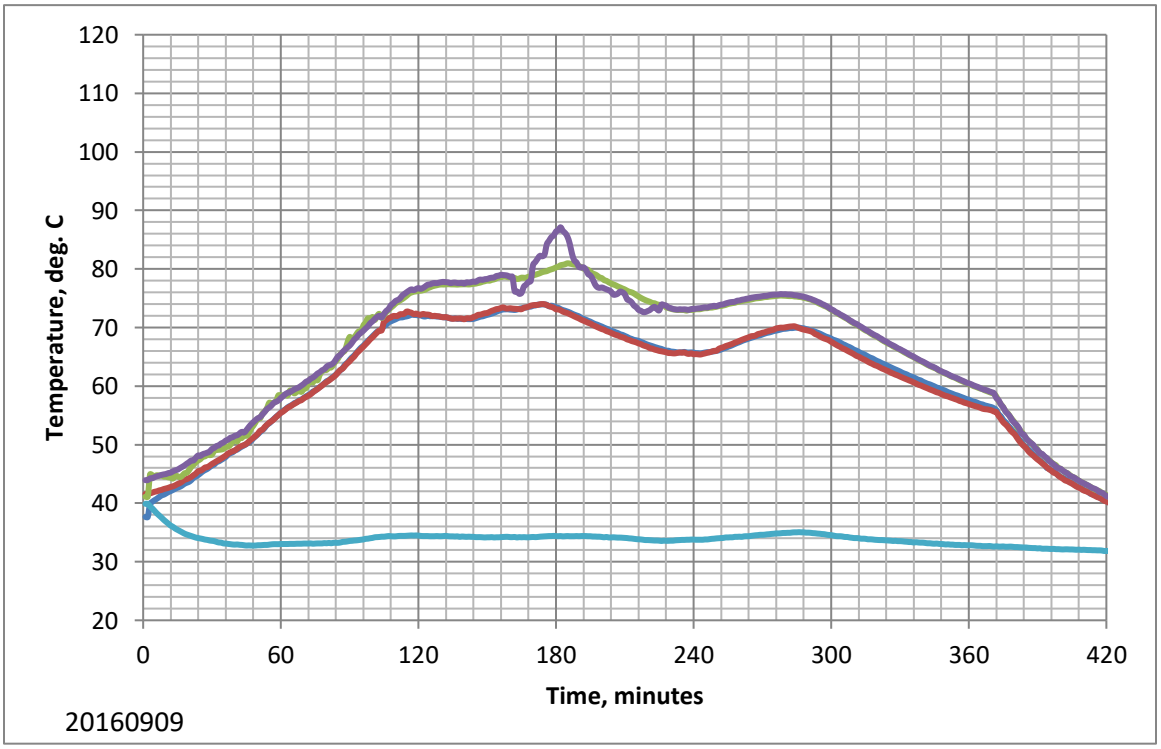

2.5
2
1.5
1
0.5
0
Wind Speed, m/s
0
60
120
180
240
300
360
Time, minutes
20160907



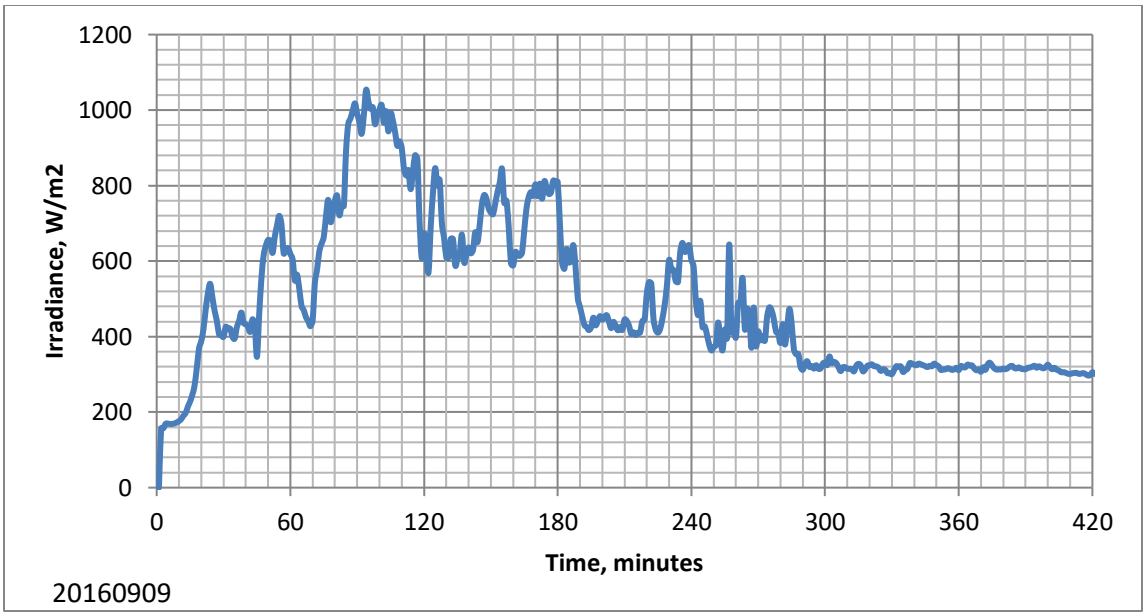
B: HotPot with Lid #1, sealed, load 2.32 liters water. R&G: HotPot with Lid #5, unsealed, load 2.32 liters. Lid#1 developed reflective condensation.



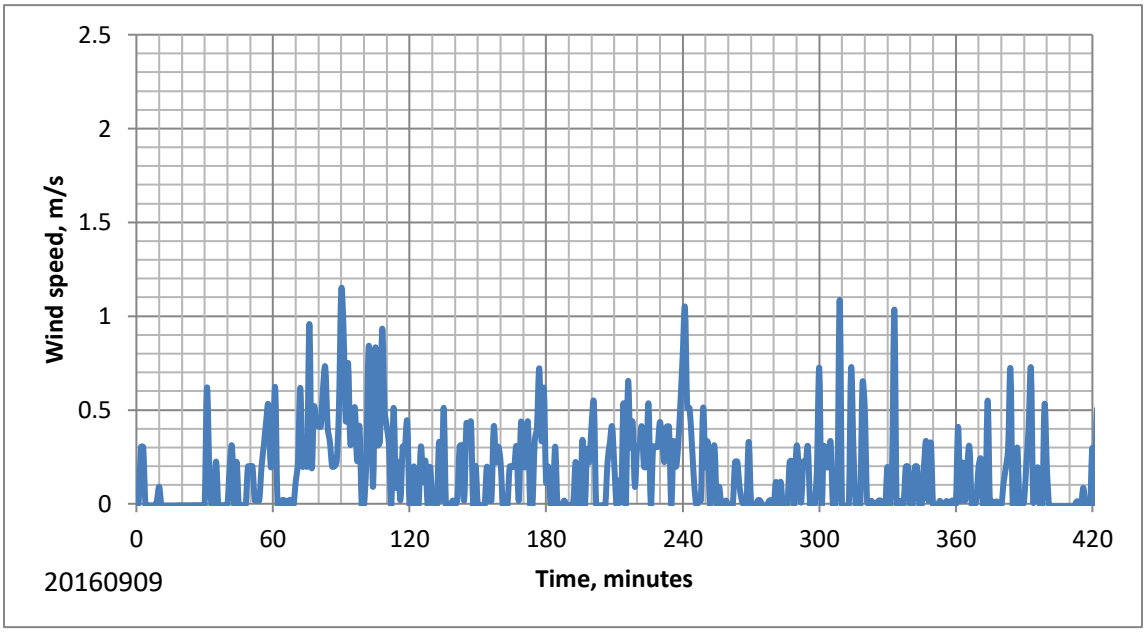


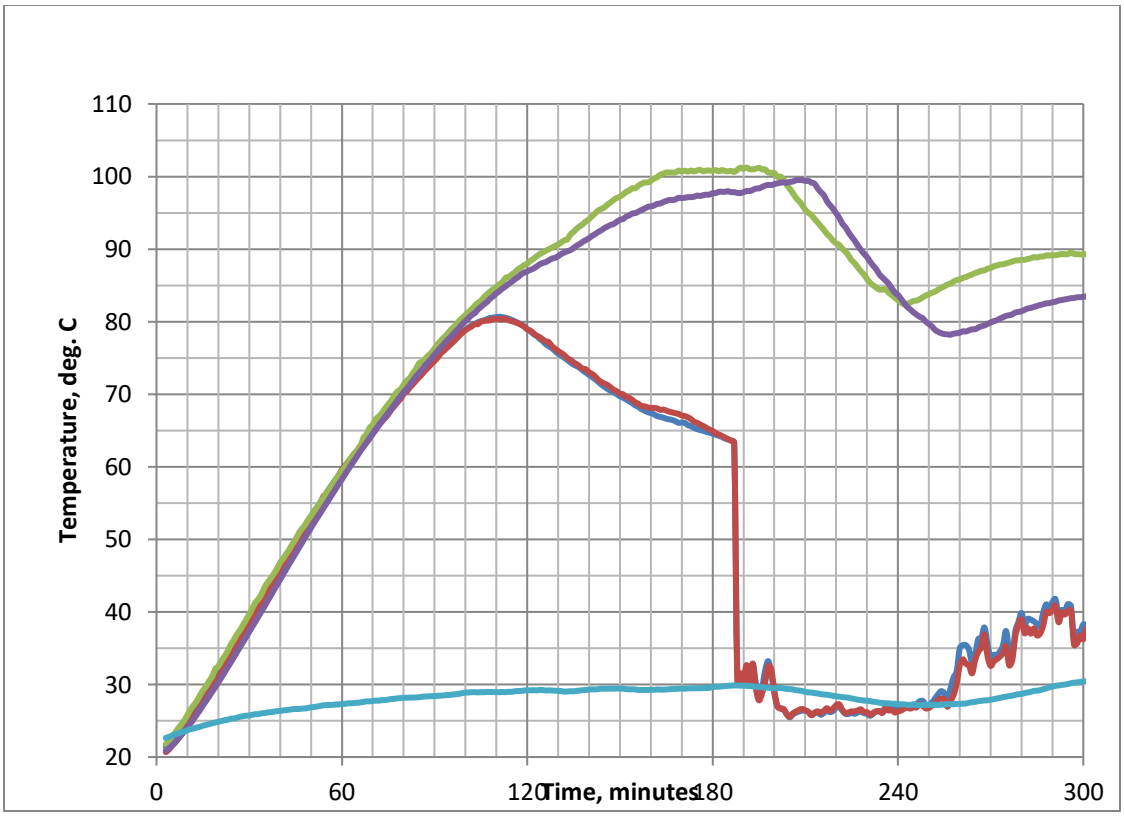


Repeat of 9/8 with cleaned pot lids. Load 2.32 liters.
B&R: HotPot Lid #5, sealed. G&P: HotPot #1, unsealed. (reverse of 9/8).
Sensor #4 (purple) was out of water for part of the time.



Weather was not as clear as on 9/8, so this test should be repeated.





20160912

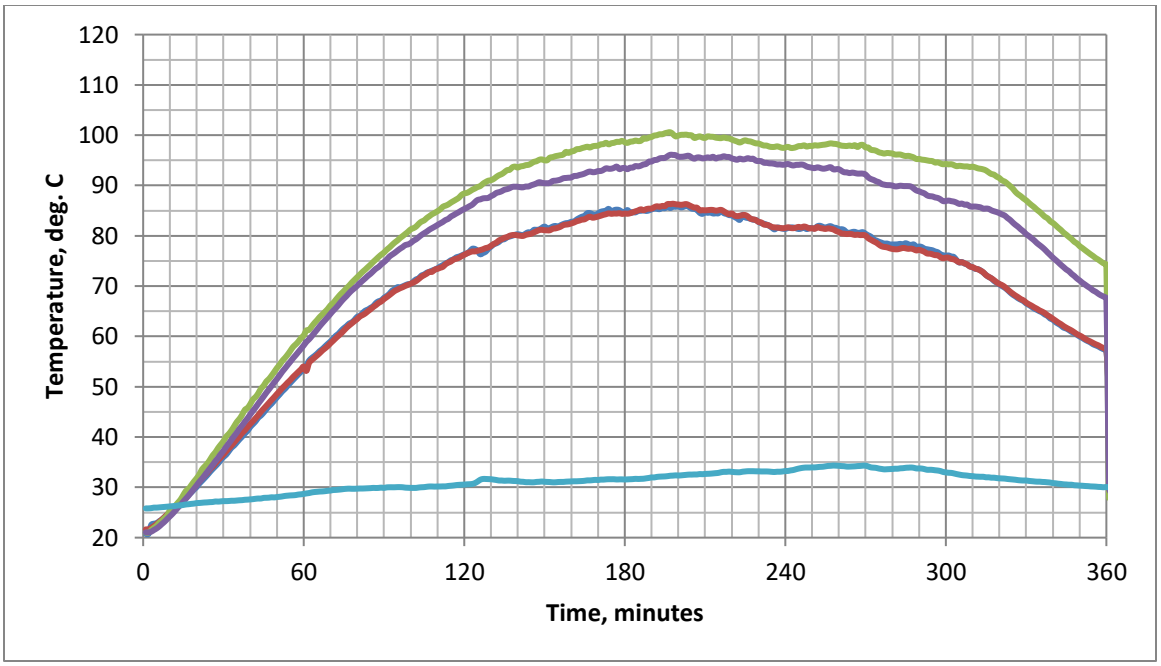
Blue-red: HotPot #1, sealed; shaded after 100 min.

Green: HotPot #2, sealed

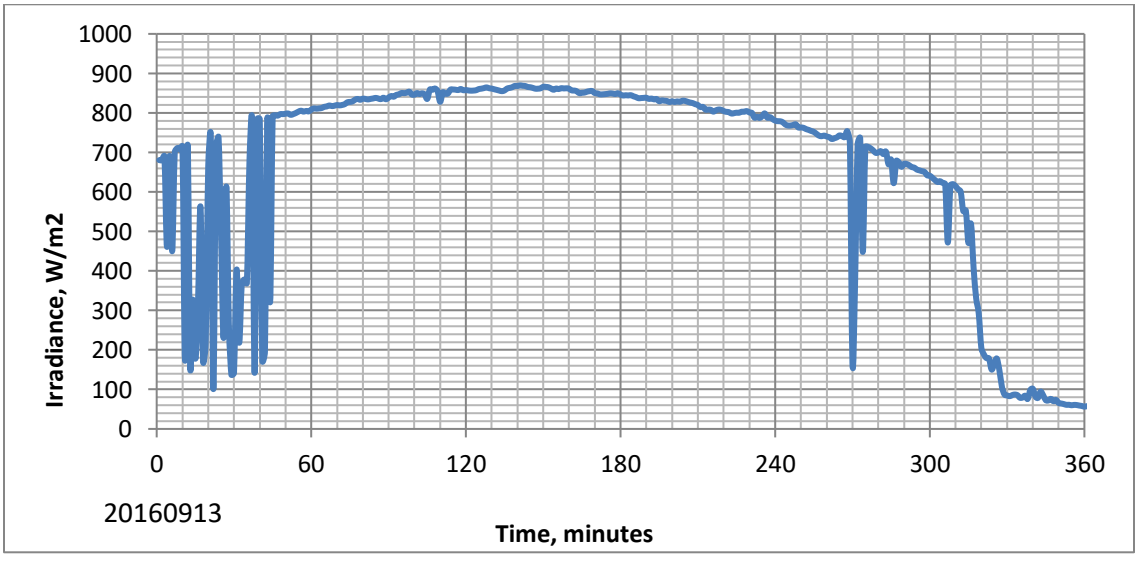
Purple: HotPot #5, unsealed

Sky clear but shaded after 180 min.

Pyranometer data not reported due to loose connection in cable.

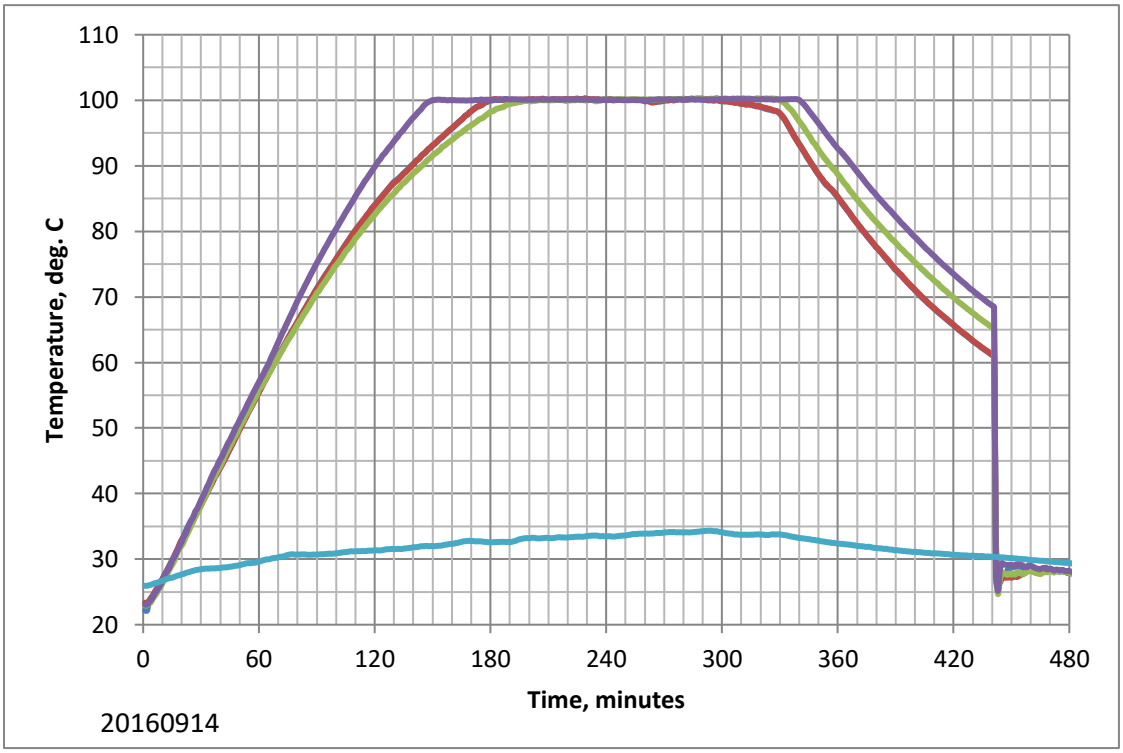


20160913
Blue & red: HotPot lid #1, sealed with silicone gasket
Green: HotPot #2, sealed with silicone gasket
Purple: HotPot #5, unsealed
Load 2.32 l in all pots
HotPot 2
best.
It appears to violate repeatability because two of the HotPots were sealed.
The lid gap seals could be different; the reflectors could be slightly different.
More testing is needed to establish repeatability of the notorious HotPot.

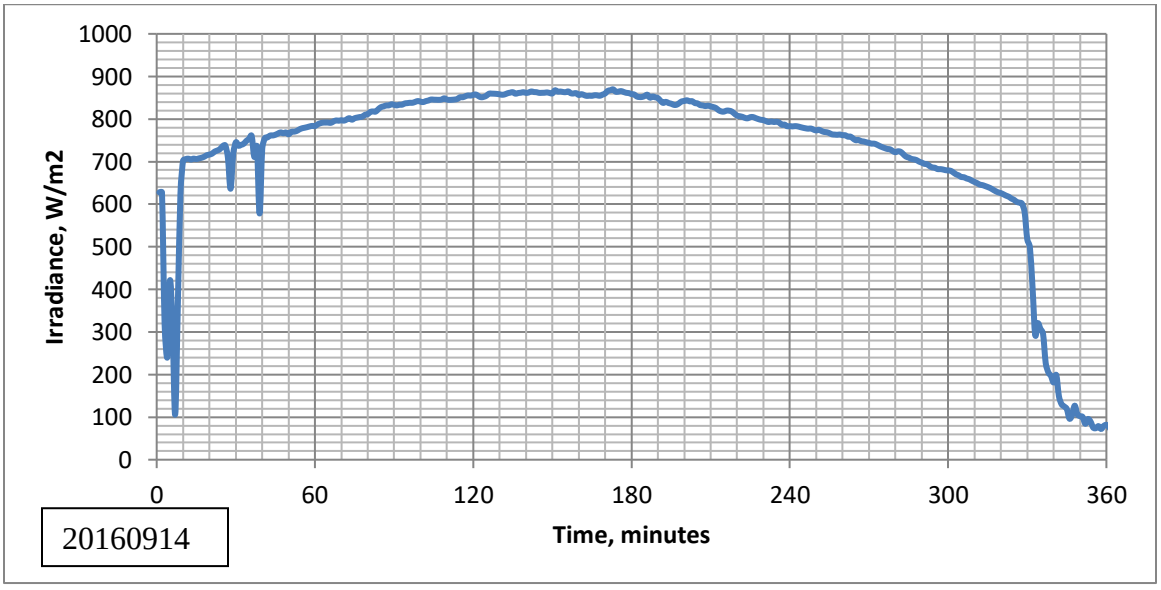


Nice day; clear all day but tree shadows in the morning. Sky was clear.

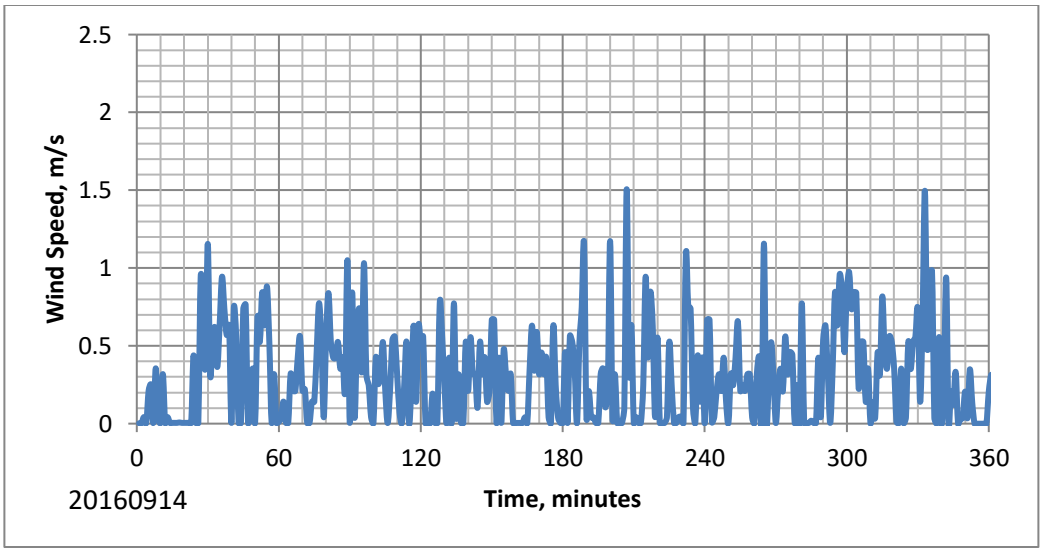
Wind speed data were not recorded on 9/13; logs show wind speed avg. 2 mi/hr.

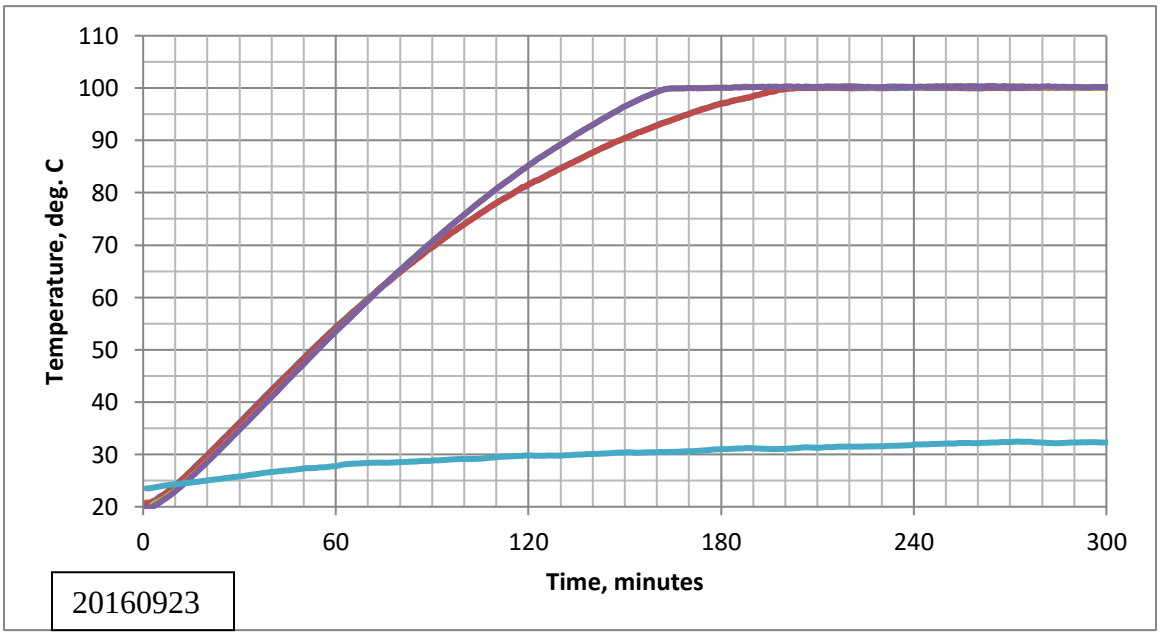


Comparison of 3 Haines reflectors with the same load, 2.45 liters water.
Blue & red: Morningstar reflector #2.
Green: Haines reflector #1
Purple: Haines reflector #3 with smooth cover.



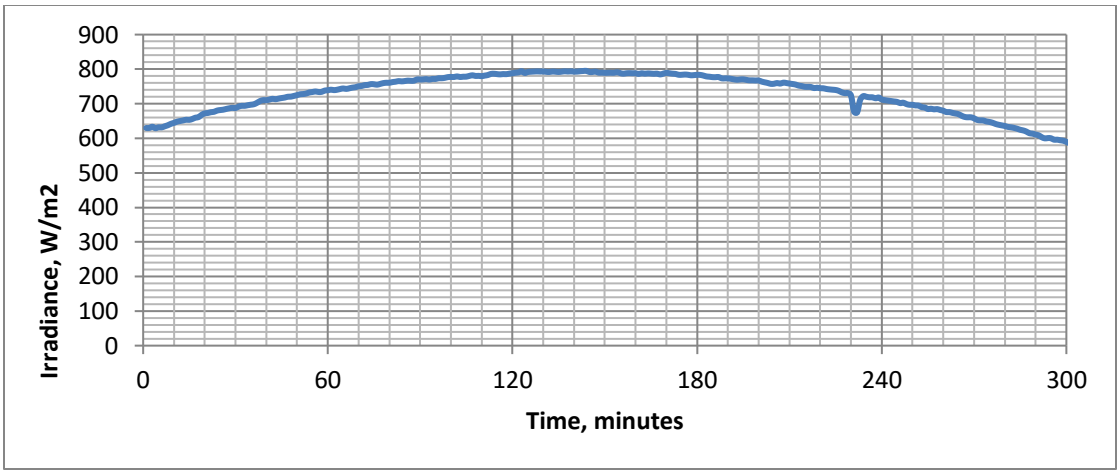
A bit of cirrus in the morning; the rest of the day very clear.



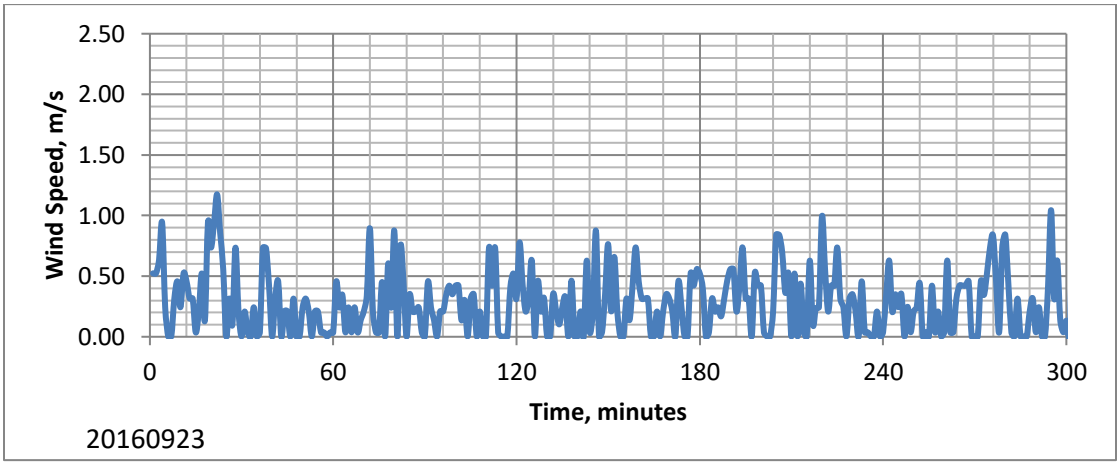


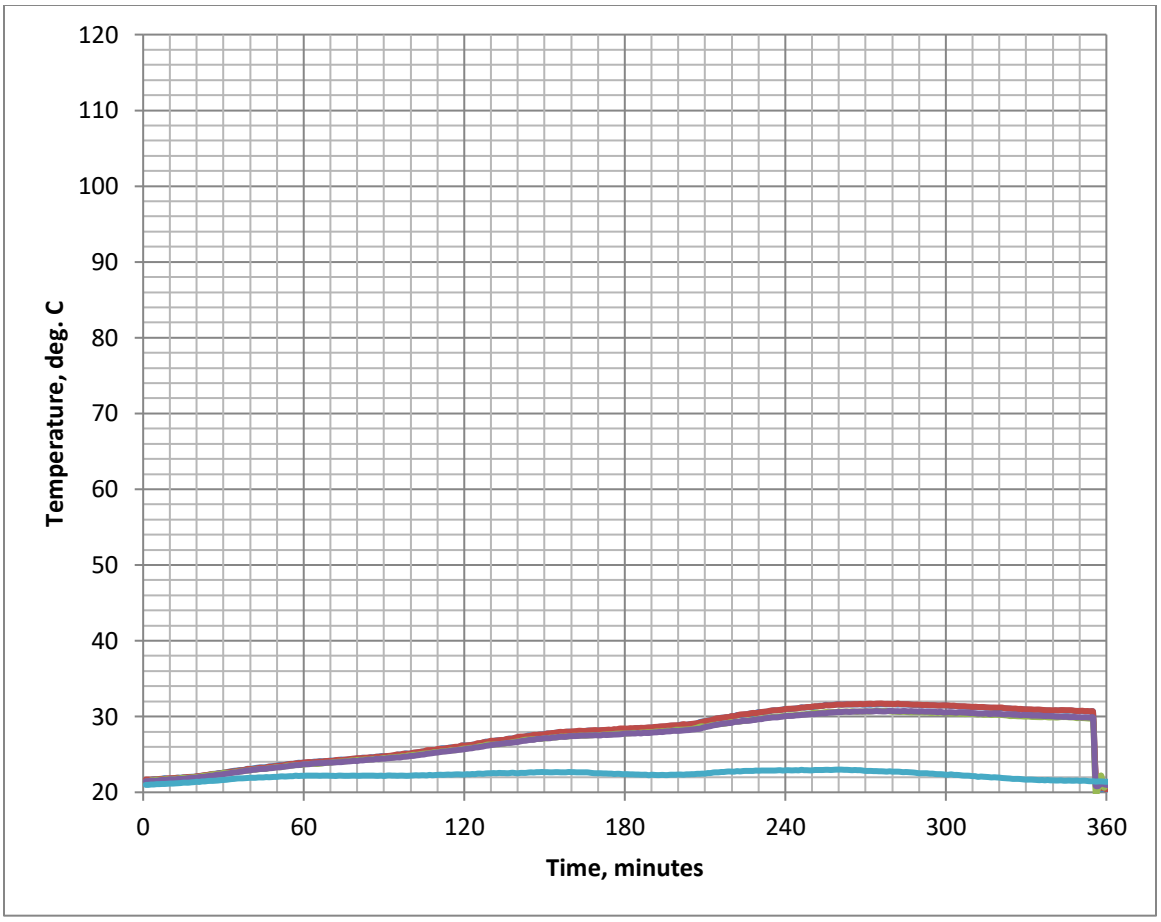
Blue & Red - Haines #1, painted Ultra black, refl. #1
Green & Purple - Haines #2 with reflector #3

Expected the ultra-black pot to heat faster, but it did not.
The reflectors could be a factor. The #1 appeared slightly duller.
Lid gaps could also be a factor.
Heating rate was nearly the same until near boiling.

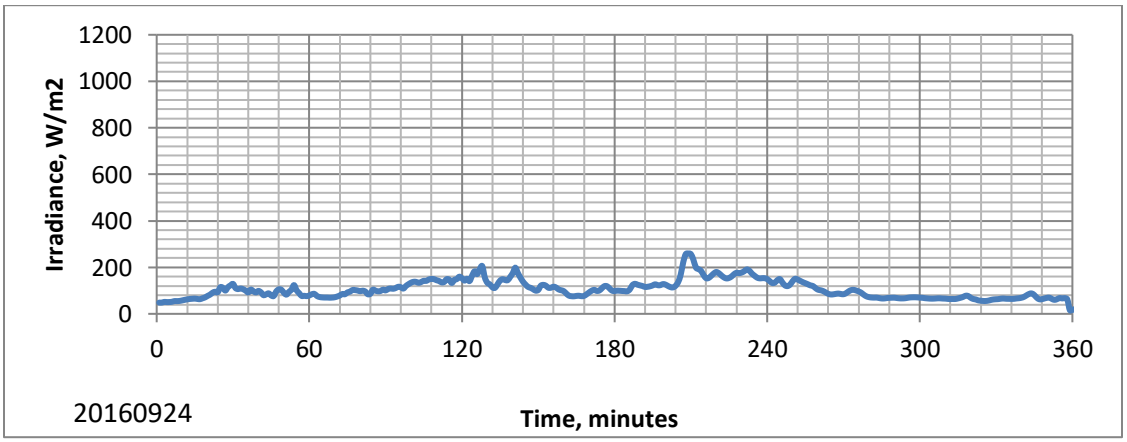


20160923 – Fabulous clear day.

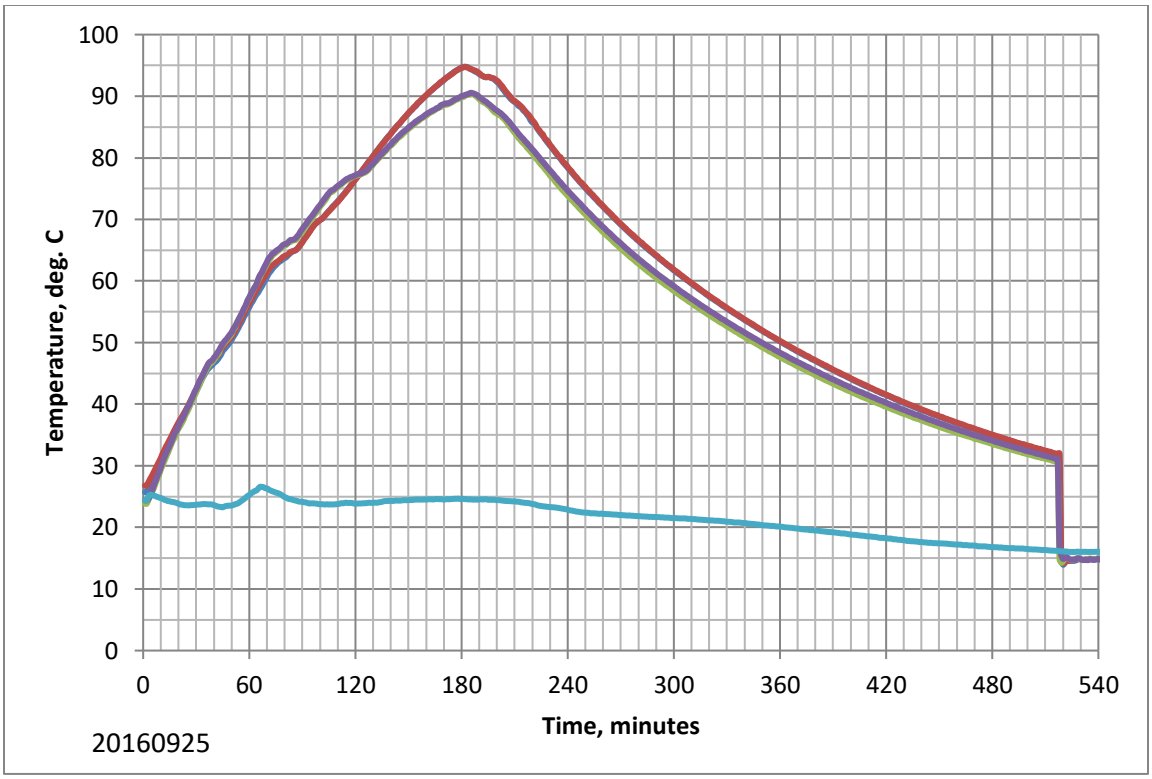




20160924 – To show what heating looks like on an overcast day.
Haines pots and reflectors. Reflectors do not work on cloudy days.



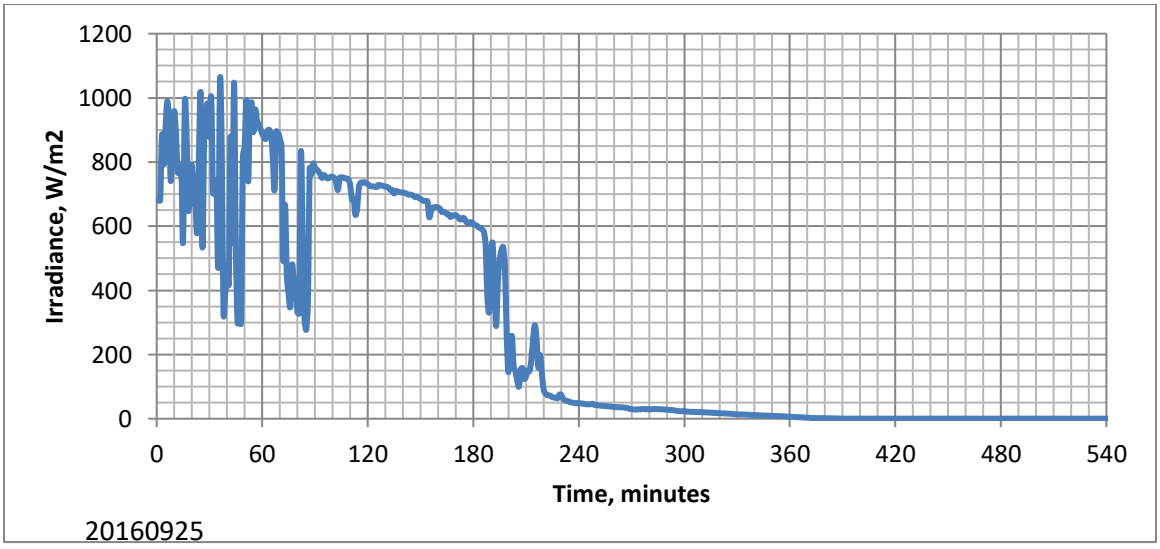
(No wind speed data, but log shows 1 mi/hr at start.)

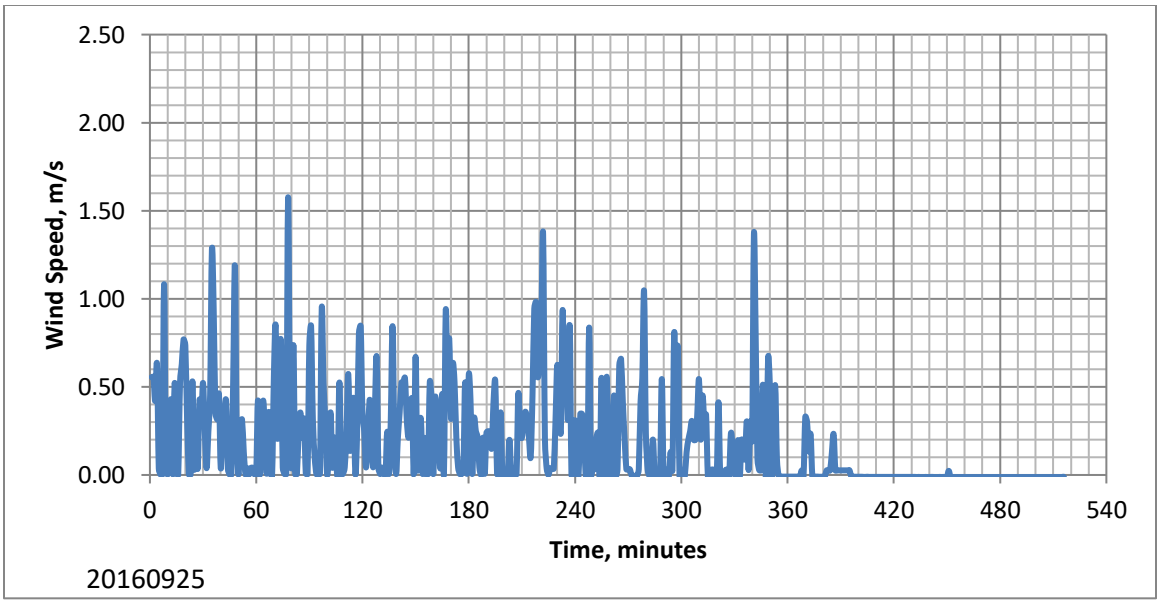


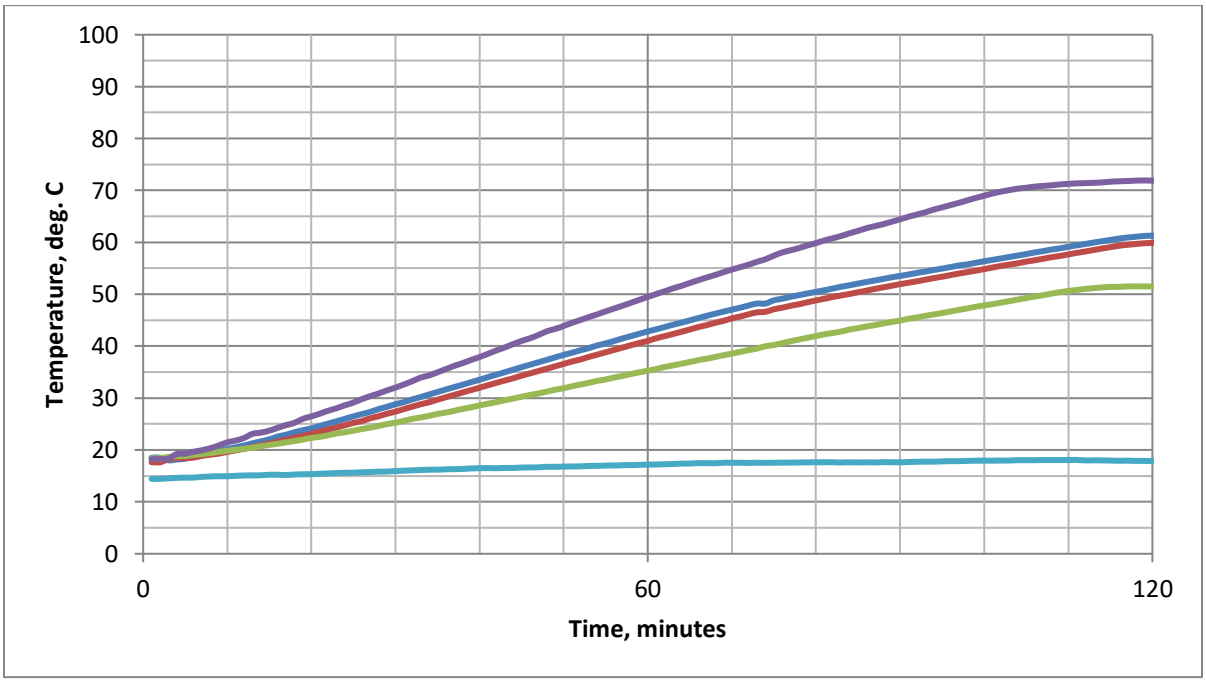
Blue-red: Haines pot #2, refl. #1

Green-Purple: Haines pot #1 ultra-black, refl. #3 (brighter)

Sun below trees at 180 min.



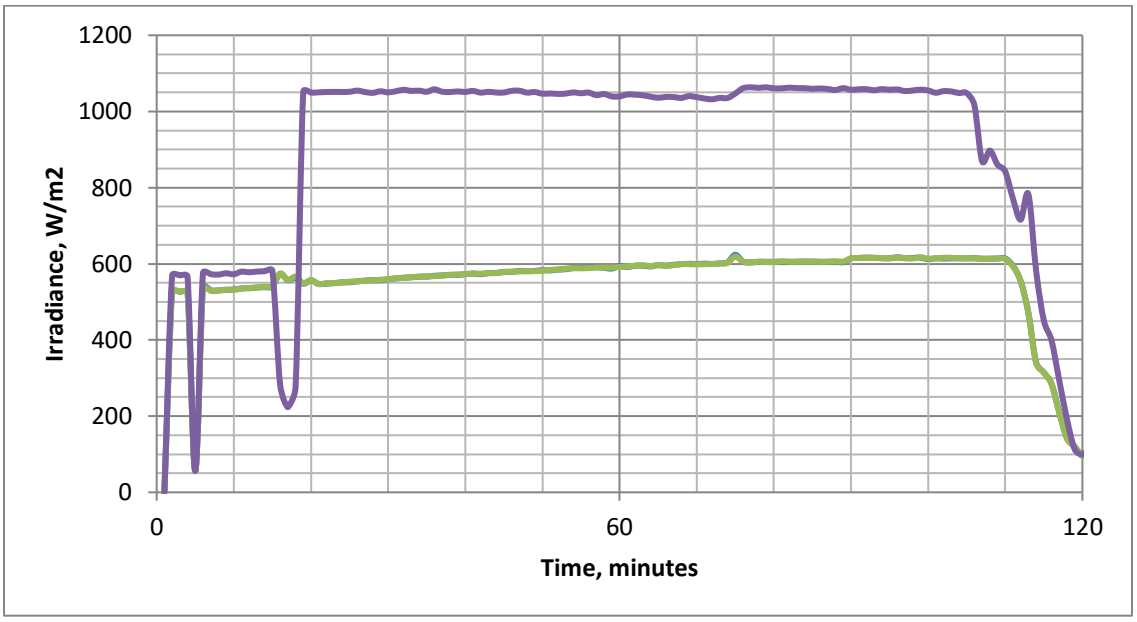




Red and blue: ASSC 2.0 with pot #1, 2.37 l. d. w.
Green: ASSC 1.0, pot #2, 2.37 l. d. w.
Purple: ASSC 3.0, pot #3, 2.89 l. d. w.
Lt. blue: ambient

ASSC 3.0 performed best. It was bigger and had a different shape.
However, the water load was also proportionately bigger.
ASSC 1.0 has a duller reflective surface than the others.

All cookers became shaded after 100 minutes. Repeat with longer time in clear sky.



20161105

Green: GHI pyranometer

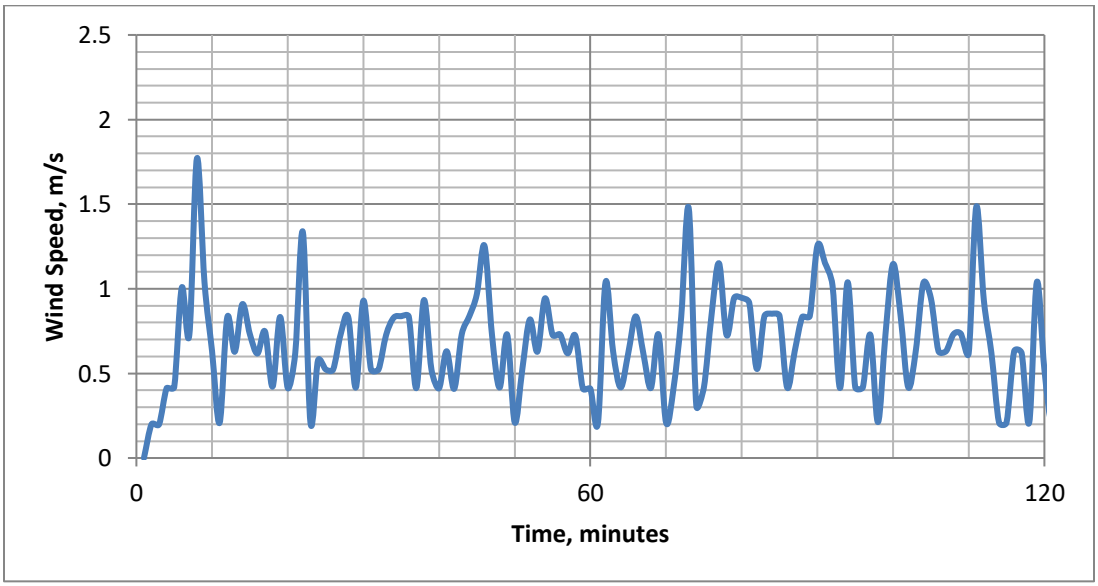
Purple: Apogee pyranometer. It was turned from vertical to direct (toward the sun) at 18 minutes, after some gaps for mechanical mounting.

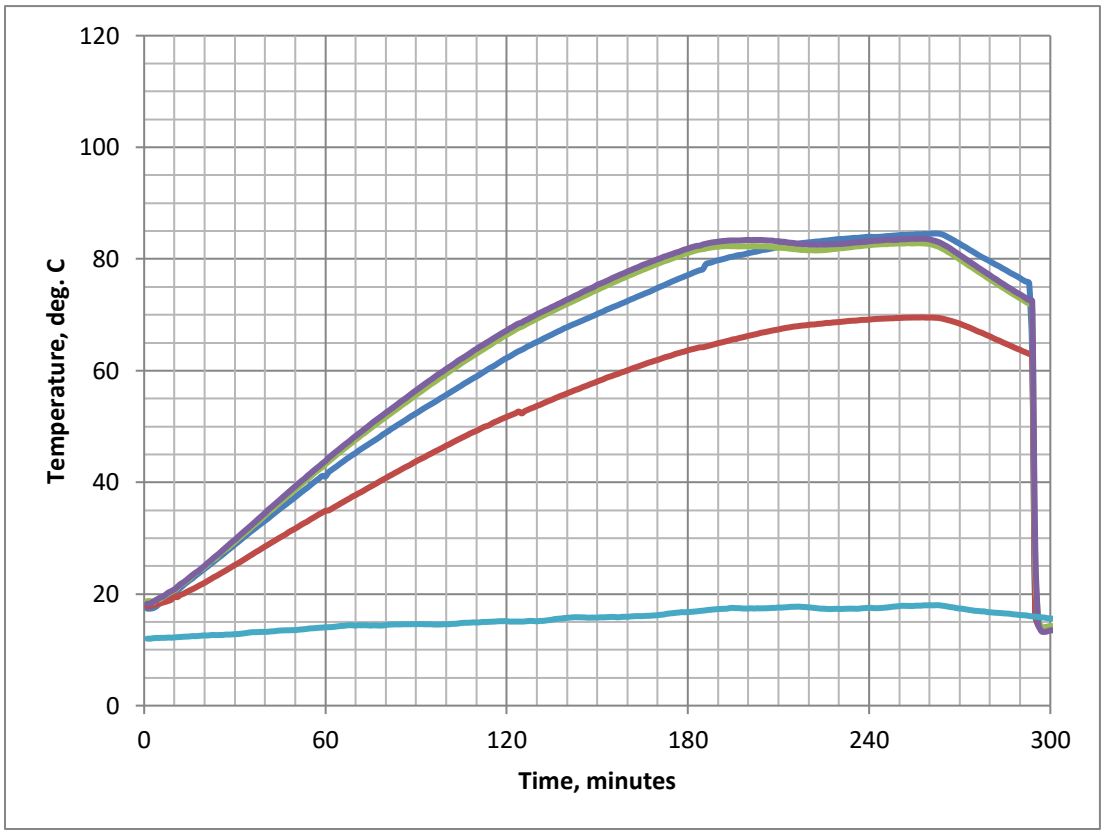
Sky was really clear, and sun angle was only 35 deg. at noon.

It almost reached 1100 W/m2, which S580 has as the reject limit.

(Why?)

The jump at 75 min. is due to turning the sensor toward the sun.



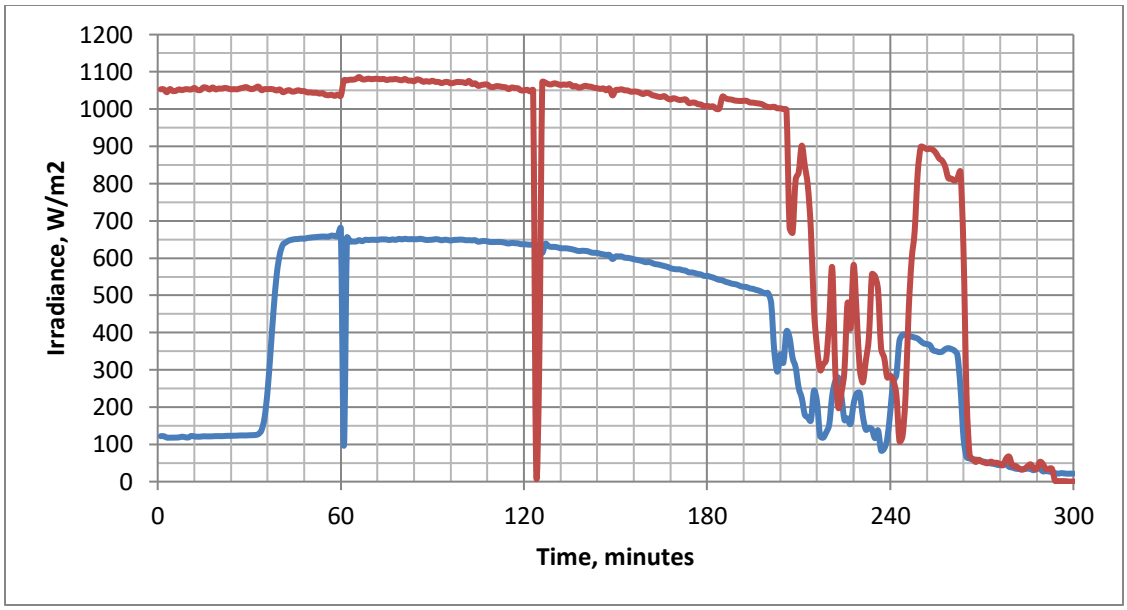


20161107

Blue: ASSC 3.0, 2.89 l. tap water, Haines Dutch Oven pot, roaster bag

Red: ASSC 1.0, 2.37 l. tap water, Haines DO pot, bag

Green & Purple: ASSC 2.0, 2.37 l. tap water, Haines DO pot, bag



20161107

Red: DTI Blue: GHI

The low values are dropouts due to temporary shadows when moving instruments.

The sky was basically clear all day with zero clouds. Shadows after 200 min.