Preliminary Testing for the Thermal Performance of Open-source Solar Cooker Designs Relative to Commercial Cookers

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Abstract

Solar cooking is an innovative development, harnessing solar energy for use in cooking food and pasteurization of water to make it safe for drinking; however, commercially available solar cookers are at times prohibitively expensive for many in the developing world. Furthermore, while open-source solar cooker designs are available, few have been tested for thermal performance according to international standards. This research represents the first attempt to investigate the cooking power of open-source solar cooker models in comparison with their commercial analogues. Testing was performed on two open-source solar cooker designs—Parvati (Pardeshi, n.d.) and Fun Panel (Tan, n.d.)—according to the ISO-recognized ASAE S580.1 (ASABE, 2013) protocol using Solar Cooker International's Performance Evaluation Process, and its results were compared with existing preliminary results for a selection of commercial solar cookers. The outcomes demonstrated that the Fun Panel cooker outperformed the estimated standardized cooking power (in Watts) of commercial reflective-panel solar cookers of similar size and design by 15.3%, while the Parvati cooker lagged behind its counterpart by 59.2%. The estimates were derived from commercial cookers tested to date.

Keywords: Cooking, Renewable

1. Introduction

The United Nations has announced a list of seventeen Sustainable Development Goals in order to combat socioeconomic issues such as poverty and world hunger; solar cooking encompasses aspects of all seventeen of these goals and can help combat these issues ("United Nations Sustainable Development Goals," 2018). A solar cooker is a device that harnesses solar energy for cooking and pasteurization of water. Such cookers can offer a practical solution to cooking-fuel challenges faced by those in developing nations; an inexpensive, well-designed cooker can supplement the cooking energy needs for millions as well as contribute to a reduction in deforestation and the use of fossil fuels and polluting fuels. The purpose of this study was to examine the viability of low-cost, open-source solar cooker designs as an alternative to commercial designs for use in emerging markets.

2. Materials & Methods

Both the Parvati and Fun-Panel cookers were constructed from recycled cardboard, aluminum foil, and liquid adhesive based on provided open-source design dimensions. The cookers were tested according to the ASAE S580.1 protocol automated by the Solar Cookers International (SCI) Performance Evaluation Process (PEP) test station in Nyack, NY in November of 2018 (Figure 1). Statistical analysis was performed in Microsoft Excel and the standardized cooking power (W) was determined for each solar cooker.

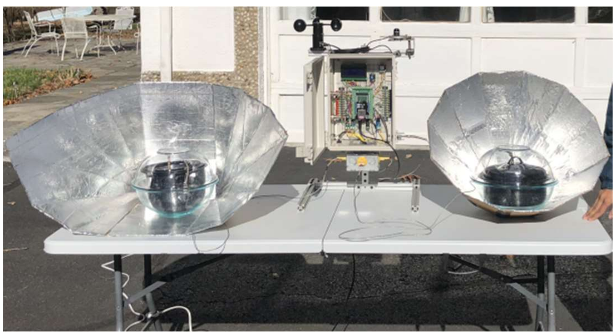

Fig. 1: Left: Fun-Panel; Center: PEP Test Station; Right: Parvati

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2.1. Test Equipment

The SCI standard PEP test station (Bigelow 2017a, Table 1) 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. Temperature and solar irradiance are the two climatic parameters which are associated with the thermal testing of solar cookers. Their accuracy impacts the final power measurement as per the ASAE S580.1 standard (TR-09.1, 2018; Purohit & Purohit, 2008). Test equipment was calibrated prior to testing to avoid inaccuracies in the measuring instrument. Data acquisition occurred over the course of one day. Recorded ambient temperature was lower than the recommended temperatures (between 20 and 35 degrees C) at an average of 17.22 degrees C during the test period.

Tab. 1: Test Equipment Comprising PEP Test Station

Electronics platform	Weather-proof enclosure contains: Arduino Mega open-source electronics, LCD, and removable SD card
Temperature	Type K thermocouples for measuring water and ambient temperatures. Typical reported accuracy of ± 2.2 degree C or ±.75% (whichever is greater)
Wind Speed	Anemometer (Adafruit, New York, New York, USA). Accuracy: Worst case 1 meter/s
Solar Irradiance	SP-215 amplified pyranometer (Apogee Instruments, Inc., Logan, Utah, USA) mounted to a horizontal, bubble-leveled plane, as suggested by the manufacturer. Sensitivity (4.0mV per W m^2), Calibration Factor (0.25 W m^{-2} per mV (reciprocal of sensitivity)), Calibration Uncertainty (± 5%)
Additional	Global Positioning System

2.2. Testing Procedure

The test procedure involves multiple steps. First, since the water load for a PEP test is dependent on the cooker's intercept area, it is necessary to calculate that area before the test begins. From the cooker's maximum intercept area and elevation angle, a trigonometric correction can be applied to determine the intercept area of the solar cooker for the sun elevation angle on a specific test date and location. Since those values for the solar cookers were unknown, a photographic approach was used to determine maximum intercept area. After determining the solar cooker elevation angle using the relationship, elevation angle = arcsin (footprint / hypotenuse) (Bigelow 2017b, Figure 2), photograph the solar cooker from a reasonable distance (to minimize spatial distortions) along a line parallel to the solar cooker elevation angle. Then, with a graphics program, such as Microsoft PowerPoint, superimpose and tile geometric shapes (with areas scaled according to size of cooker) over the entire intercept area and sum the areas of those shapes to obtain the maximum intercept area. Finally, apply a trigonometric correction for the average sun elevation angle for the test date.

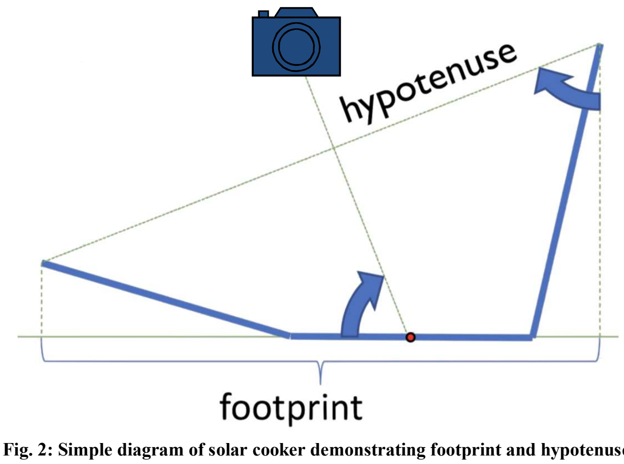

Fig. 2: Simple diagram of solar cooker demonstrating footprint and hypotenuse

Graniteware was selected as the cookware for the testing process as it is commonly available worldwide and often used for solar cooking. Feed-through thermocouple probes, each mounted to a hole drilled near the center of a cookware lid to reduce thermal leakage during a test, were used. A further step required for a PEP test, as recommended by the ASAE S580.1 testing standard, was to load 7000 grams of water per square meter intercept area using a scale to weigh the water load to the nearest gram. A leveling device was used to ensure a level surface for the test and a consistent tracking time interval, of 20 minutes was set.

The following steps were followed for the testing process:

- 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 electrical power to test station.
- Add pre-measured quantities of test water to cookers and cover with pot lids.
- Launch the program to automate PEP data acquisition
- Adjust cooker every 20 minutes to track the sun.

3. Results

Figures 3,4,5. show the wind speed, solar irradiance, and cooking and ambient temperature recorded during the test period, respectively. The test was conducted between 11:00 and 13:00 solar time over a period of two hours. In spite of the ambient temperature being below the recommended testing standard temperature, both cookers showed a strong rise in temperature. Figure 6. shows the preliminary results for the standardized cooking power of the two open-source cookers. The results for the Parvati cooker (*parabolic*) and Fun Panel cooker (*reflective-panel*) were found to be 16.4 and 43.5 W, respectively. For comparison, the estimated standardized cooking power for the selection of commercially available parabolic and reflective-panel cookers of similar size and design that have been PEP tested to date are 40.2 and 37.7 W, respectively ("View Test Results," 2017). The estimations were calculated by linearly extrapolating the standard wattage results relative to intercept area of commercial parabolic and reflective-panel type cookers.

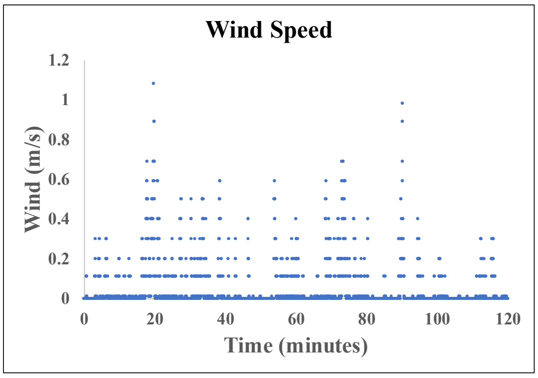

Fig. 3: Wind Speed Over Testing Time

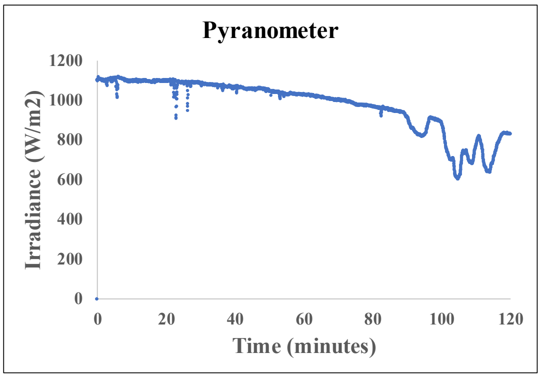

Fig. 4: Solar Irradiance Over Testing Time

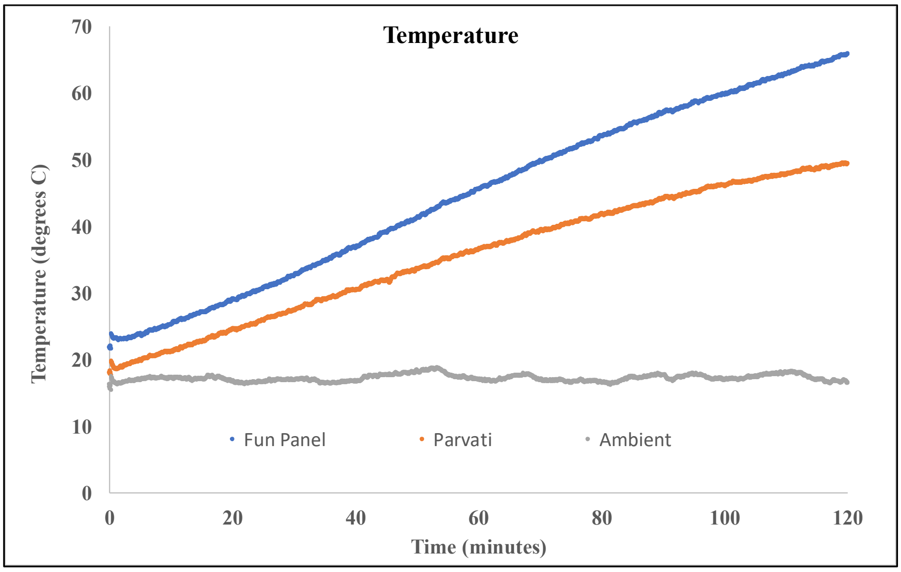

Fig. 5: Preliminary Test Results from November 8, 2018 – SCI/NYs

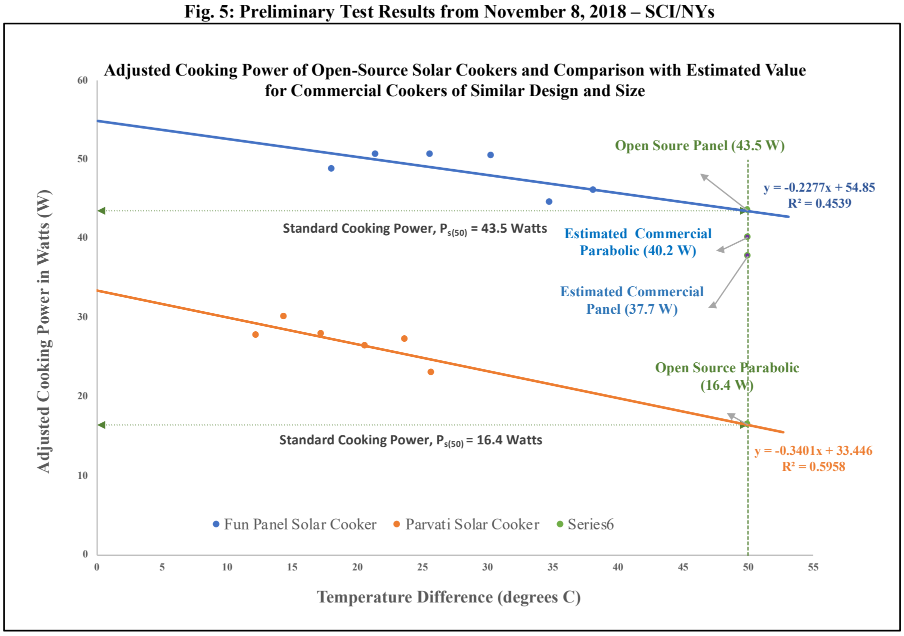

Fig. 6: Standardized Cooking Power of Open-source Solar Cookers

4. Discussion & Conclusion

The standardized cooking power for the open-source Fun Panel cooker was higher than that of the selected commercial solar cookers of similar design and size, indicating its competitiveness. The standardized cooking power of the Parvati cooker was found to be lower, suggesting that there exists possibility for design improvement. Moreover, since the testing was conducted in New York in November, when the ambient temperature was lower than the recommended range of between 20 and 35 degrees C, the preliminary results could have been impacted. Furthermore, testing of the cookers over at least three days, as recommended by the ASAE S580.1 protocol, would be necessary to improve the preliminary results of the standardized cooking power. Nevertheless, these preliminary results of open-source designs according to testing standards prove that they could be an inexpensive alternative to commercial solar cookers in emerging markets. The authors propose to extend the current study and also conduct tests on other open-source cookers.

5. Acknowledgments

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