Development and implementation of a Performance Evaluation Process (PEP) for solar thermal cooking devices

Alan W. BIGELOW*, Justin TABATCHNICK, Caitlyn HUGHES

Solar Cookers International, California, USA

alan.bigelow@solarcookers.org

Abstract

Solar Cookers International staff designed and built portable test stations for a performance evaluation process (PEP) for solar thermal cookers in response to a specific need expressed by the solar cooking sector that an independent, neutral agency develop a testing process for solar thermal cooking devices. The PEP test stations are based on commercially available components, including thermocouples, an anemometer, a pyranometer and Arduino hardware. The test station control software was designed to automate the American Society of Agricultural and Biological Engineers (ASAE) S580.1 protocol for Testing and Reporting Solar Cooker Performance; it measures temperature changes in an amount of water proportional to the intercept area of a solar cooker, while monitoring wind speed and solar insolation, for normalizing results.

keyword: Testing standards, Solar cookers, Sustainable development, Solar thermal cooking, Tier 4 cookstoves

1 Introduction

According to the World Health Organization, for the approximately three billion people cooking food by using biomass fuel such as firewood, charcoal or animal dung, smoke particulates from cooking indoors is linked to some 4.3 million premature deaths annually worldwide and is having negative impacts on the health of people, mostly women and children, regularly exposed to high levels of indoor air pollution [1]. Solar thermal cookstoves that convert solar energy directly into heat energy are viable options for clean sustainable cooking that are beneficial for all, including the most vulnerable populations.

Solar cooking devices harness free, solar energy for no-emissions, clean sustainable cooking. Solar cookers collect solar energy with reflectors, absorb solar energy with black surfaces to transform solar energy to heat energy, and retain heat using insulation. People can generally obtain a solar cooker by purchasing a commercial product, by building one using an open-source design, or by innovating and implementing a new design. Prices for commercial solar cookers range from tens to hundreds of US dollars. Shipping and import fees can increase the price. However, pricing can be reduced through local or regional manufacturing and assembly and/or bulk purchasing .

Types of solar cookers include the reflective-panel, box oven, parabolic reflector, evacuated tubes, Fresnel lenses and Fresnel mirrors. "Institutional solar cooking systems are another type of solar cooker; these systems can be mounted on rooftops to concentrate solar energy, heat water, and create steam, or heat a thermic fluid, such as oil, that is transferred to a kitchen inside the building." In India, for example, there are institutional solar cooking systems that power mega kitchens that can cook tens of thousands of meals per day [2].

Solar cooking has numerous benefits that can transform lives, particularly for women and girls in developing regions who are disproportionately exposed and impacted by harmful aspects associated with acquiring and using combustible cooking fuels such as firewood and charcoal. Solar cookers are suitable for nutritious meals, like legumes and pulses that are otherwise fuel intensive to cook. Furthermore, with solar cooking, less time is spent scavenging for firewood, freeing up time for education and micro enterprises; indoor air quality improves; deforestation is reduced; and family budgets for cooking fuel can be reduced [3]. Solar cookers can pasteurize water, killing water borne microbes (bacteria and viruses) [4]. Solar dryers heat their contents using solar thermal methods to dehydrate and preserve food, which adds post-harvest value and increases food security [5].

Solar cooking can make a positive impact on all 17 United Nations Sustainable Development Goals (SDGs) [6]. as elaborated on below; hence, solar cooking's potential for social, economic and environmental solutions suggests it for bold and transformative steps which are urgently needed to shift the world to a sustainable and resilient path for environmental and human preservation.

End poverty in all its forms everywhere 1.1. Energy costs proportionately more for vulnerable people. Access to free, no-emission solar thermal energy builds resilience. Solar technologies for cooking help end poverty.

End hunger, achieve food security and improved nutrition, and promote sustainable agriculture 1.2. With free solar thermal energy for cooking, families can cook all quantities and types of traditional and highly nutritious foods. Solar energy reduces demand for biomass and fossil fuels, improving soil and water quality. Using dung as fertilizer instead of fuel can increase crop production, and solar drying increases food security.

Ensure healthy lives and promote well-being for all at all ages 1.3. Women and their young children experience the highest exposure to household air pollution, the number one cause of disease. Solar thermal cookers do not produce flames, so burn risk is greatly reduced, particularly for women and children.

Ensure inclusive and equitable quality education and promote life-long learning opportunities for all 1.4. Freed from the time-intensive tasks of gathering biomass fuel for cooking fires by solar cooking, vulnerable persons, including the indigenous, those with disabilities, and children, can have more time for education and study.

Achieve gender equality and empower all women and girls 1.5. Cooking with solar energy reduces women's and children's exposure to violence when gathering biomass fuels. "women's and children's exposure" to violence when gathering biomass fuels.Women and children can gain up to 5 hours/day for education, empowering them for leadership roles.

Ensure availability and sustainable management of water and sanitation for all 1.6. Sustainable management of drinking water supplies for all will rely on decentralized pasteurization of local water sources. Solar thermal cookers can make water safe to drink, addressing water scarcity and reducing diarrheal disease.

Ensure access to affordable, reliable, sustainable, and modern energy for all 1.7. Solar thermal energy is clean, efficient, and sustainable. It does not need to be gathered or purchased, and is available in all regions on all continents. Enough solar energy reaches the Earth every hour to power all human activity for one year.

Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all 1.8. Cooking with free solar energy reduces household fuel costs and helps break the cycle of energy poverty.

Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation 1.9. Solar technologies reduce the need for centralized energy infrastructure and increase resilience for all. Many innovative solar cookers can be made using locally-sourced materials.

Reduce inequality within and among countries 1.10. Free solar energy is accessible to all people, irrespective of age, sex, gender, disability, ethnicity, origin, religion, or economic or other status.

Make cities and human settlements inclusive, safe, resilient and sustainable 1.11. Solar energy can be used in urban settings where biomass fuels are less available. Solar energy use reduces competition and conflict for energy.

Ensure sustainable consumption and production patterns 1.12. Free solar-thermal energy reduces environmental costs of fuel production and delivery. Solar energy is renewable and contributes to sustainable patterns of household energy consumption and production.

Take urgent action to combat climate change and its impacts 1.13. No-emission solar energy reduces production of climate-change forcing agents, such as greenhouse gases and black carbon produced by combustion of fossil fuels and biomass fuels.

Conserve and sustainably use the oceans, seas and marine resources for sustainable development 1.14. Healthy biomass helps soil absorb water, reducing pollutants and fertilizers in the oceans. Preserved forests sequester carbon which could lessen the burden on oceans to absorb excess carbon that warms the seas.

Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss 1.15. Cooking and pasteurizing water with solar energy preserves forests, and curbs land degradation and desertification.

Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels 1.16. Access to solar energy achieves our human right to cooked food and safe water. Solar energy reduces human conflict over scarce fuels.

Strengthen the means of implementation and revitalize the global partnership for sustainable development 1.17. Solar cooking technologies strengthen and empowers community members, particularly women, to change agents for revitalized, resilient and sustainable development.

Solar Cookers International (SCI) is a non-profit organization whose mission is to improve human and environmental health by supporting the expansion of effective carbon-free solar cooking in world regions of greatest need. SCI leads through advocacy, research, and strengthening the capacity of the global solar cooking movement. SCI is a convener that connects 500+ collaborators in 135 countries and hosts the Solar Cooking Wiki . that has over 1,700 pages of information about solar cooking, including open-source design plans [7].

SCI is an independent and brand-agnostic international agency. Because of its objective leadership status and expertise, SCI was well-positioned to respond to the solar cooking sector's request for an independent organization to develop a platform for evaluating solar cookers according to existing testing standards. The outcome is SCI's development and implementation of the Performance Evaluation Process (PEP) for testing the thermal performance of solar cookers. PEP implementation is poised to boost the solar cooking sector and enhance the impact from use of solar cookers. More specifically, PEP is benefiting the solar cooking sector by assisting customers in selecting solar cookers; building credibility and verification for the solar cooking sector; encouraging manufacturers to develop superior products; and guiding project managers in selecting appropriate solar cookers for their projects.

In developing the PEP, SCI has established a standard testing platform for measuring the thermal performance of no-emissions solar cookers. SCI is included on the list of Regional Testing and Knowledge Centers (RTKCs) posted by the Clean Cooking Alliance[8]. In addition to SCI's testing locations in California, USA and New York, USA, SCI has provided instrumentation and training to two other RTKCs (Center for Rural Technology, Lalitpur, Nepal; and University of Nairobi, Nairobi, Kenya), which now have the capacity for PEP testing of solar cookers in their respective regions.

Theoretical framework 1.18. There are multiple ways to evaluate a solar cooker, such as these existing approaches for evaluating the thermal performance of solar cookers:

1) ASAE S580.1 Testing and Reporting Solar Cooker Performance [9].

2) The Indian Standard: Solar Cooker Box Type Specification [10].

3) The Focusing Solar Cooker [11].

After reviewing those approaches, SCI chose to base its testing platform on the ASAE S580.1 protocol. The ASAE S580.1 protocol was initiated in January 1997; has received further evaluation [12,13] and is specified by the International Organization for Standardization (ISO) as a normative reference for measuring standardized cooking power for solar cookers in the ISO 19867-1:2018 standard for laboratory testing of cookstoves [14] and in the ISO 19869:2019 standard for field testing of cookstoves [15]. Furthermore, the solar cooking sector agreed that ASAE S580.1 was the most suitable protocol for evaluating solar cookers,(6th SCI World Conference, January 2017) and it has recognition at the Clean Cooking Alliance. SCI's PEP automates the ASAE S580.1 protocol to determine a performance metric according to the ISO standards mentioned above. Those ISO standards include protocols for durability and safety metrics that apply to solar cookers[16].

The ASAE S580.1 protocol for evaluating solar cookers provides a single measure of performance: the standardized cooking power, Ps(50), expressed in watts. This value for standardized cooking power is evaluated when the cooking temperature is 50 "ﬂC" above ambient temperature, at a temperature relevant to the onset of cooking. Standardized cooking power is derived from measurements of temperature change in an amount of water proportional to a cooker's intercept area (7000 g/m2); hence, it is a measure of the uptake of power in water that is within a cooking vessel and can be interpreted as a heating rate for a given quantity of water. Standardized cooking power results are normalized using incident solar radiation, allowing comparable results independent of testing date and location, and the testing protocol includes constraints on ambient temperature and wind speed values to limit heat loss due to those factors.

SCI added several refinements in applying the ASAE protocol to improve solar cooker evaluations. These steps are described further in the methodology section below and include using an automated data acquisition platform, on-board and post-processing routines, Global Positioning System (GPS), horizontal pyranometer positioning with trigonometric evaluation of irradiance values, a trigonometric correction of the solar cooker intercept area, default cookware, feed-through thermocouples and a thermocouple calibration routine, and emphasis on using a level surface while testing.

To summarize the ASAE S580.1 protocol, it first calculates the cooking power for a solar cooker during successive 10-minute intervals using the following equation (eq. 1), where, for each ith 10-minute interval, Pi is the cooking power (W); T1 is the initial temperature "(flC)"; T2 is the final water temperature "(flC)"; M is water mass (kg); and Cv is heat capacity of water (4186 J/(kg "flC)").

Pi=[(T2-T1)MCv]/[600 s] (1)

Adjusted cooking power, P_s, for each 10-minute interval is corrected and normalized to a standard insolation of 700 W/m^2 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.

Ps=Pi[(700 W/m^2)/I_i] (2)

Adjusted cooking power values are then graphed with respect to temperature difference between the water and the ambient air a miminum of 30 adjusted cooking power values (observations) are required. Standardized 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 crosses the temperature-difference value of 50 °C, as shown in the example below.

2 Methodology

With the ASAE S580.1 available as an internationally-agreed-upon standard for testing solar cookers, a corresponding need was for standard instrumentation with consistent components for automating the protocol. A standard test platform with consistency in instrumentation and post-processing routines can provide uniformity in data acquisition. SCI therefore developed a common test platform to facilitate consistent data collection and analysis. SCI self-imposed the following design requirements when developing PEP test stations: the instrumentation should be robust, relatively inexpensive, and the design should become an open source and available to all. SCI met these requirements. The PEP test station is robust: it is portable (fits inside carry-on luggage), easy to set up, powered at the test site, and able to withstand most test environments. The PEP test station is relatively inexpensive and open source: PEP design plans are available at the SCI website (www.solarcookers.org) allowing users to assemble their own test station. These test stations are designed to include Arduino electronics, and require minimal software programing skills. SCI has designed and created such PEP test stations that:

1) Automate the ASAE S580.1 protocol for evaluating solar cookers

2) Satisfy all the design requirements.

Hardware 2.1.

After considering the cost advantages from a do-it-yourself approach, each PEP test station (Figure 1) was built using commercially available components with a total parts cost of less than 1,000 USD. Test station hardware includes an Arduino Mega open-source electronics platform, GPS, liquid crystal display, three type K thermocouples, an anemometer (Adafruit, New York, New York, USA), and an SP-215 amplified pyranometer (Apogee Instruments, Inc., Logan, Utah, USA). Electronics are housed in a weather-proof enclosure and data are stored on a removable SD card; see Figure 2. The pyranometer mounts to a horizontal, bubble-leveled plane, as suggested by the manufacturer. While this positioning differs from the sun-angle alignment suggested in the ASAE protocol, trigonometric corrections to SCI solar irradiance measurements give accurate results within instrument tolerance, for solar irradiance incident on solar cookers being tested. The system is expandable and can accommodate up to eight thermocouples and Bluetooth connectivity.

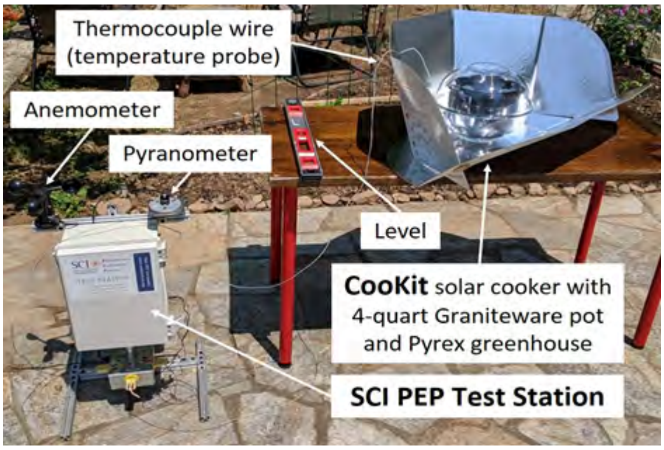

Figure 1. Picture from 2 July 2020 of an SCI PEP test station while evaluating the thermal performance of an SCI CooKit, a reflective-panel cooker, using Pyrex bowls as a greenhouse.

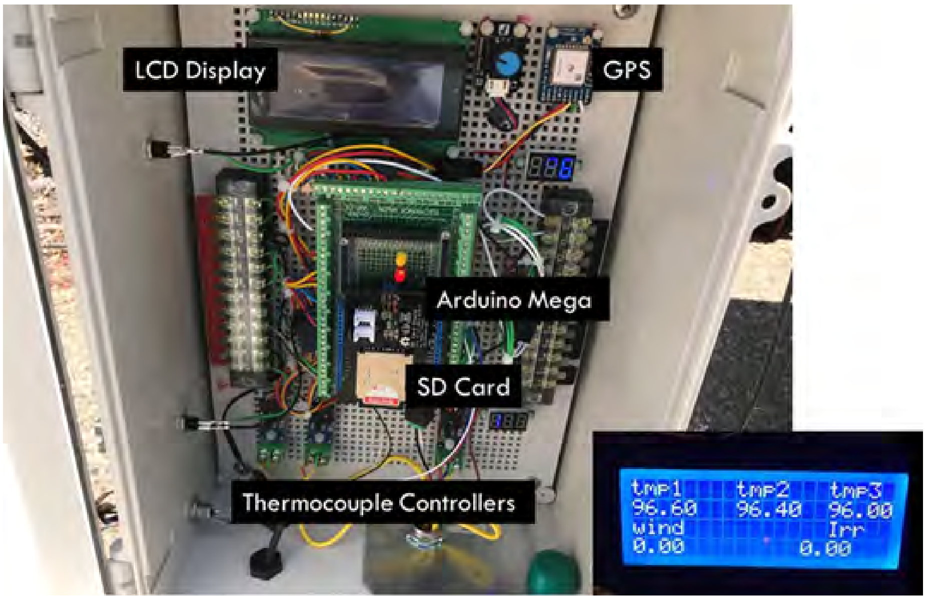

Figure 2. Picture showing the electronics layout for an SCI PEP test station with a close-up of the LCD display (lower right corner).

Software 2.2.

Control software for the PEP test stations was written in-house using C++. The software accepts user input listed in a config.txt file with parameters, such as duration of evaluation, duration of observation intervals, average sun elevation during the test, and water load values. Data is stored on an SD Card as a space delimited text file. This approach automates data acquisition from all sensors. Raw data is post processed by an external program written in C++, including bounded Adjusted Cooking Power calculations according to the ASAE S580.1 protocol. It also applies a 2-point calibration correction to the thermocouple sensor channels to ensure accurate temperature readings. After a solar cooker evaluation, the user can open the resulting data and post-processed files into Microsoft Excel, for example, to inspect the data and prepare graphs for a PEP results report.

Testing 2.3.

SCI's PEP requires several set-up steps. First, since the water load for a PEP test is proportional to the intercept area of a solar cooker, one needs to determine that area prior to the test. If the maximum intercept area and the elevation angle for the solar cooker are known, one can apply a trigonometric correction with respect to the sun elevation angle to determine the effective intercept area of the solar cooker for a specific test date and location. When those values are unknown, one can use a photographic approach to calculate the applicable aperture area of a solar cooker for a specific sun elevation angle [16]. This approach can also be used to determine the maximum intercept area. After determining the solar cooker elevation angle using the relationship, elevation angle=arcsin (footprint/hypotenuse), photograph the solar cooker from a reasonable distance (about 5 meters; to minimize spatial distortions) along a line parallel to the solar cooker elevation angle, as shown in Figure 3. Then, load the picture into a computer program for Binary Large Object (BLOB) analysis or into a computer application, such as Microsoft PowerPoint, where one can 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.

PEP results apply to an entire solar cooking system, which is the solar cooker and the cookware or cooking pot. Since cookware and cookware material can impact PEP results, it is important to use the same type of cookware consistently throughout each test. When conducting PEP tests, SCI prefers to use cookware provided by a solar cooker manufacturer; however, while some manufacturers include cookware with their solar cookers, others do not. SCI chose Graniteware as default cookware for PEP for solar cookers that do not include cookware. Graniteware is commonly available worldwide and often used for solar cooking. SCI testing centers in California, USA and New York, USA both have a set of Graniteware pots and select a best match of pot size to the amount of water needed for the PEP.

The SCI testing centers favor using a feed-through thermocouple probe mounted to a hole drilled near the center of a cookware lid to reduce thermal leakage during a test. Further steps required for a PEP test are to load 7000 grams of water per square meter intercept area. One should use a scale to weigh the water load to the nearest gram. Also, the PEP test operator should use a leveling device to ensure a level surface for the test and use a consistent tracking time interval, such as 20 minutes.

Figure 3. Schematic of a solar cooker side view, in blue, and reference lines, in gray, for determining the solar cooker elevation angle (gray arrows).

PEP results apply to an entire solar cooking system, which is the solar cooker and the cookware or cooking pot. Since cookware and cookware material can impact PEP results, it is important to use the same type of cookware consistently throughout each test. When conducting PEP tests, SCI prefers to use cookware provided by a solar cooker manufacturer; however, while some manufacturers include cookware with their solar cookers, others do not. SCI chose Graniteware as default cookware for PEP for solar cookers that do not include cookware. Graniteware is commonly available worldwide and often used for solar cooking. SCI testing centers in California, USA and New York, USA both have a set of Graniteware pots and select a best match of pot size to the amount of water needed for the PEP.

The SCI testing centers favor using a feed-through thermocouple probe mounted to a hole drilled near the center of a cookware lid to reduce thermal leakage during a test. Further steps required for a PEP test are to load 7000 grams of water per square meter intercept area. One should use a scale to weigh the water load to the nearest gram. Also, the PEP test operator should use a leveling device to ensure a level surface for the test and use a consistent tracking time interval, such as 20 minutes.

3 Findings and Discussion

Numerous tests across different types of solar cookers conducted since 2017 using the SCI PEP test stations at SCI testing centers in California, USA and in New York, USA indicated that results are repeatable with close correlation between the two locations, thus validating the test platform prior to SCI officially launching its PEP testing program for solar cookers.

Presented here are PEP results acquired at the SCI testing location in New York, USA during 26 May, 8 June, and 2 July 2020 for the following solar cooking system: CooKit reflective-panel solar cooker with a 4-quart Graniteware cooking vessel placed in a Pyrex greenhouse. The PEP test station recorded temperatures, solar irradiance, wind speed and GPS location to a space delimited file on an SD card for later post-processing. Graphical versions of data acquired by the SCI PEP test station include temperature profiles shown in Figure 4 and irradiance and wind speed profiles shown in Figure 5. Adjusted cooking power values are shown in Figure 6 along with the standardized cooking power.

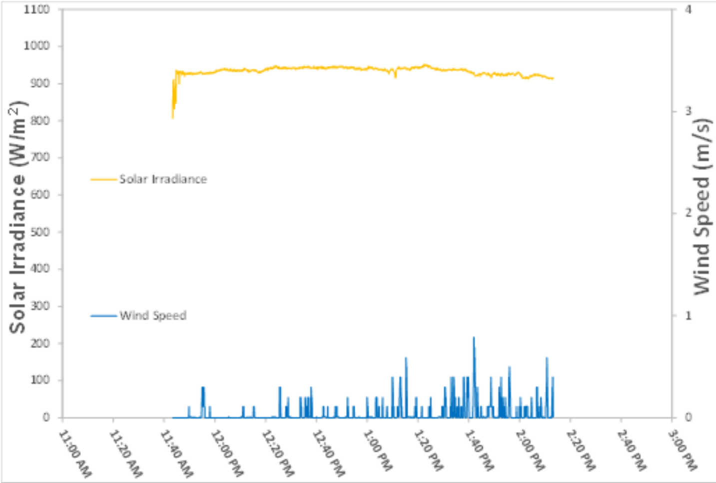

Figure 4. Temperature profile of 3.256 liters of water (in red) and ambient air (in blue) recorded by an SCI PEP test station on 2 July 2020 while monitoring a CooKit reflective-panel solar cooker with a 4-quart Graniteware cooking vessel placed in a Pyrex greenhouse.

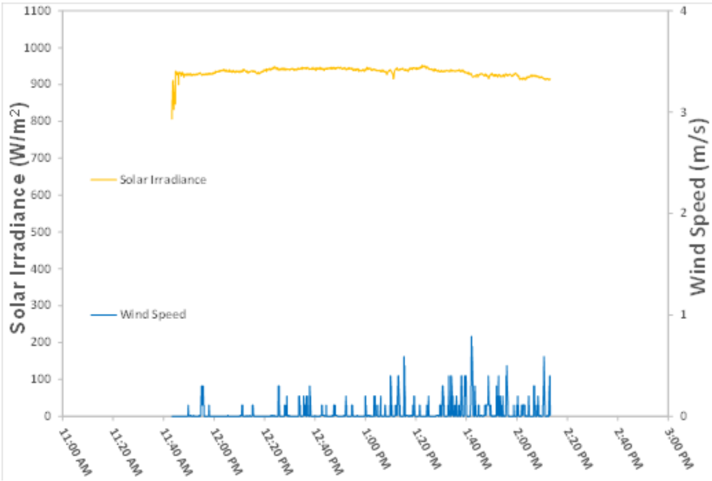

Figure 5. Solar irradiance and wind speed recorded by an SCI PEP test station on 2 July 2020.

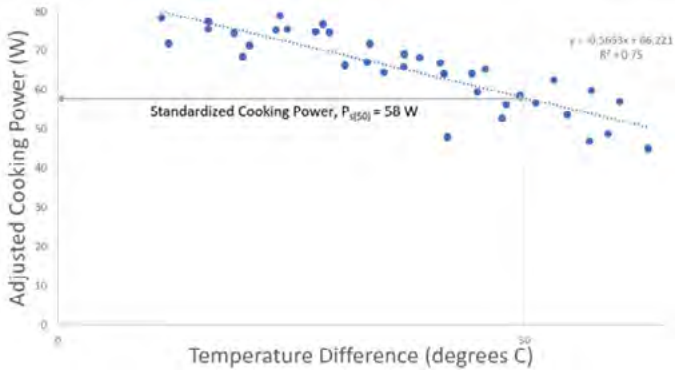

Figure 6. Adjusted cooking power recorded by an SCI PEP test station during 26 May, 8 June, and 2 July 2020. These results from three non-consecutive days of testing produced 37 observations (exceeding the 30 observations required by the ASAE protocol) and demonstrate reproducibility and that the standardized cooking power of a CooKit with a Pyrex greenhouse is 58 watts.

The linear regression fit to the adjusted cooking power values results in a linear equation that can be evaluated for any temperature difference. In the example shown in Figure 6, the regression line equation y=-0.5653x+86.221. When the regression line for this example is evaluated for x at a temperature difference of 50 degrees C, the resulting standardized cooking power is 58 W, which is the uptake of power into the medium being heated (water). The fundamental definition of power can be expressed as energy per time, and since heat is a form of energy (thermal energy), the standardized cooking power can be interpreted simply as a heating rate for the specified amount of water used during the test, when the temperature difference is 50 degrees C.

SCI PEP results for which manufacturers have given written permission for SCI to publish on the SCI website are summarized in Table 1 [17]. The PEP results presented here were current at the time of authoring this manuscript (January 2021). Manufactures may improve products or develop new products, and arrange for follow-up PEP tests with SCI. Additionally, other manufacturers may agree to PEP testing at any time. Updated and most current PEP results are available on the SCI webpage for PEP results [17].

Table 1. Summary of SCI PEP results for solar cookers

Solar Cooker Type	**Solar Cooker Name**	**Manufacturer**	**Standardized Cooking Power (watts)**
Reflective panel	Haines 1	Roger Haines	41
	CooKit with oven bag greenhouse	Solar Cookers International	46
	CooKit with Pyrex bowl greenhouse	Solar Cookers International	58
	Haines 2.0	Haines Solar Cookers	82
Box oven	SunFocus	Sun BD Corporation	52
	UGLI	Sun BD Corporation	61
	StarFlower	Solar Chef International, LLC	117
Evacuated tube	Glenergy Solar Cooker	Glenergy	85
	Fornelia Mini	Fornelia LTD.	93
	GoSun Sizzle	Glenergy	99

In obtaining the standardized cooking power, the regression line also provides two additional aspects of the solar cooker: 1) the heat loss coefficient (the slope), and the initial cooking power (the y-intercept). These values suggest the insulation quality and there is potential for correlating these values with different types of solar cooker [12]. These values are provided in all SCI PEP reports via the regression equation, which can also provide guidance for solar cooker designers and manufacturers to meet their goals.

In obtaining the standardized cooking power, the regression line also provides two additional aspects of the solar cooker: 1) the heat loss coefficient (the slope), and the initial cooking power (the y-intercept). These values suggest the insulation quality and there is potential for correlating these values with different types of solar cooker [12]. These values are provided in all SCI PEP reports via the regression equation, which can also provide guidance for solar cooker designers and manufacturers to meet their goals.

In addition to measuring standardized cooking power (in watts), PEP results suggest design-based aspects that can improve performance: 1) use a larger collector for gathering more incident solar energy there is a general trend that standardized cooking power scales with intercept area, and 2) give attention to cookware and greenhouse material, as they are a part of the entire solar cooking system being PEP tested. Regarding greenhouse material, for instance, it may be desirable to use a clamshell of two 4-quart Pyrex bowls instead of a plastic bag as a greenhouse for reflective-panel solar cookers such as the CooKit. The transmission spectrum for Pyrex [18]. shows that it has high transmission for visible light it lets sunlight in and poor transmission for infrared light emitted from a hot black-body irradiator it blocks heat radiation from a cooking pot from escaping [19] While transparent plastic bags can also have optical spectra favorable for solar cooking, surface topology and material overlap for plastic-bag greenhouses can reduce incident sunlight transmission. Furthermore, designers should evaluate aspects about materials regarding sustainability, durability, expected lifetime, insulation quality, ease of use and transport, cost, and availability. For example, plastic bags are banned in some countries. PEP results can also help inform consumers and users to choose design characteristics suitable for the types of food and the desired cooking times that they would like.

SCI generated its first official PEP results reports during 2019 and SCI's testing program has been gathering momentum along several fronts: with manufacturers, with national policymakers and with solar cooks. The steps for completing a PEP testing cycle involve: 1) manufacturer arranges for PEP testing by SCI with a signed agreement; 2) SCI conducts PEP testing of a like-new model of the manufacturer's solar cooker at one of SCI's testing locations; 3) SCI prepares a PEP results report and sends it to the manufacturer; 4) pending manufacturer approval of the PEP results report, manufacturer signs an agreement with SCI for SCI to publish their PEP results; and 5) SCI publishes the PEP results and manufacturer gains use of SCI's PEP tested label, shown in Figure 7. Furthermore, SCI showcases PEP-tested solar cookers as part of its advocacy efforts for example, at the United Nations, which dovetails with SCI's efforts in strengthening the capacity for solar cooking worldwide.

Figure 7. The SCI PEP tested label, which solar cooker manufacturers can associate with their PEP-tested products and gain recognition for having product tested by an independent organization and according to ISO standards.

4 Conclusion

SCI has developed, built and implemented four PEP test stations for acquiring data to measure the thermal performance of solar cookers according to ISO standards at SCI testing centers in California, USA, in New York, USA, in Lalitpur, Nepal, and in Nairobi, Kenya. SCI developed several refinements in applying the ASAE S580.1 protocol, including using an automated data acquisition platform, on-board and post-processing routines, GPS, horizontal pyranometer positioning with trigonometric evaluation of irradiance values, a trigonometric correction of the solar cooker intercept area, default cookware, feed-through thermocouples and a thermocouple calibration routine, and emphasis on using a level surface while testing. SCI posts PEP results and reports on its website following approval and permission by respective solar cooker manufacturers.

Manufacturers are encouraged to have their solar cookers PEP tested by SCI. PEP results can have a role in design optimization and product improvements. SCI also suggests that manufacturers post PEP results in terms of the standardized cooking power (in watts) as performance specifications for their products. Standardized cooking power values can help consumers, project leaders and national policy makers decide which solar cookers to invest in. SCI also encourages individuals, organizations and governments to invest in solar cooking, which can increase cooking-energy independence and food security. Investment in solar cooking can also help with climate change mitigation and adaption, and it can be particularly beneficial with overcoming social stressors linked with global pandemics and internal displacement.

SCI hosts a global evidence base for solar cookers that can be viewed as a map of the worldwide distribution of solar cookers [20] the map is interactive, where a user can obtain details such as number of cookers, implementing organization, and location. SCI encourages the solar cooking sector to post its distribution data quantity, type, and approximate location to further this evidence base. SCI shares this evidence with policy makers and the public to demonstrate the advantages of solar cooking. This information has also informed the creation of SCI's Economic Impact Summaries, a country-by-country analysis of the estimated to-date and potential environmental, health, and economic benefits of solar cooking on SCI's website [20].

PEP results have potential to add another dimension to this evidence base, which is to produce a global distribution of installed solar cooking capacity (in watts) per nation. A map view of the installed solar cooker capacity could inspire more innovation and competition among nations to increase their solar cooking capacity.

Furthermore, PEP results increase the accountability and the credibility of the solar cooking sector. Solar cooking is an innovative, inclusive, and cross-cutting solution that helps to achieve all 17 United Nations SDGs. It is an affordable, accessible, clean and sustainable cooking solution for reducing "CO_2" and black carbon emissions; hence, solar cooking is a readily available approach that national leaders can include in their plans to reduce emissions, such as their Nationally Determined Contributions (NDCs), which are part of the Paris Agreement within the United Nations Framework Convention on Climate Change. In the context of global efforts, such as those at the United Nations level, PEP results for solar cooker performance specifications can help unlock funding pathways for large-scale solar cooking opportunities that can enhance the economic impact from solar cooking at the national level [21].

5 Acknowledgements

Solar Cookers International would like to thank all of its current and previous donors, volunteers, board members, and staff who have supported and encouraged SCI's PEP development and implementation including former SCI Executive Director Julie Greene. SCI thanks SCI Global Advisor Paul Funk for his role in authoring the ASAE S580.1 protocol and for continuing to share his expertise in applying the ASAE protocol. The authors had productive exchanges with Paul Arveson at Solar Household Energy, which helped move this work forward. SCI thanks Ranyee Chiang, who, from her former role at the Global Alliance for Clean Cookstoves (now the Clean Cooking Alliance) suggested that SCI develop testing protocol that harmonized with ISO standards. SCI thanks James Jetter at the Environmental Protection Agency for his contributions to solar cooker evaluations and for his leadership at the ISO Technical Committee 285, which has developed standards for evaluating clean cookstoves. SCI also thanks Peter Schwartz and his students at Cal Poly San Luis Obispo who worked one summer for SCI in efforts to develop a precursor to the PEP. Approval and support were expressed by participants at SCI meetings, such as the 6th SCI World Conference held at the Muni Seva Ashram in Gujarat, India in January 2017. SCI thanks the SCI Associates, manufacturers, and collaborators worldwide who understand the importance of measuring impact and contributing their valuable insight to increase global understanding of the positive impact of solar cooking for all.

6 References

1. World Health Organization, Burning Opportunity: Clean Household Energy for Health, Sustainable Development, and Wellbeing of Women and Children. Geneva: World Health Organization, (2016).
2. A.R. Eswara, Solar energy in food processing-a critical appraisal. J food sci technol, 50(2013),209-27.
3. A. Bigelow, M. Fox, C. Hughes, Solar cooking for a sustainable planet. Aspenia international 89-90 "Green life matters", (2020),160-5.
4. D. A. Ciochetti, R. H. Metcalf, Pasteurization of Naturally Contaminated Water with Solar Energy. Appl. Environ. Microbiol. 47(1984) 2: 223-8.
5. A. R. Eswara, M. Ramakrishnarao,. Solar energy in food processing—a critical appraisal. J. Food Sci. Technol, [50](2013)2: 209-27.
6. United Nations Sustainable Development Goals,(2021).
7. Solar Cookers International, Distribution of Solar Cookers, Retrieved from (2021).
8. Clean Cooking Alliance,Centers, (2021).
9. American Society of Agricultural and Biological Engineers.. ASAE S580.1 Testing and Reporting Solar Cooker Performance. St. Joseph: American Society of Agricultural and Biological Engineers,(2013).
10. Bureau of Indian Standards.,ndian Standard. New Delhi: Bureau of Indian Standards. (2000)
11. Ministry of Agriculture of the People's Republic of China. Focusing Solar Cooker. Ministry of Agriculture of the People's Republic of China. 20(2003),2.
12. P.A. Funk, Evaluating the international standard procedure for testing solar cookers and reporting performance. Solar Energy, (2000),1-7.
13. S. M.Ebersviller, J. J Jetter, Evaluation of performance of household solar cookers. Solar Energy, 208(2020),166-72.
14. International Organization for Standardization. ISO 19867-1:2018 Clean cookstoves and clean cooking solutions - Harmonized laboratory test protocols - Part 1: Standard test sequence for emissions and performance, safety and durability. Geneva: International Organization for Standardization. (2018)
15. International Organization for Standardization. ISO 19869:2019 Clean cookstoves and clean cooking solutions — Field testing methods for cookstoves. Geneva: International Organization for Standardization, (2019).
16. B. S. Muller, Explanations of the aperture area,(2014).
17. Solar Cookers International,(2021).
18. Prazisions Glas Optik, (2017)
19. Wikimedia Commons
20. Solar Cookers International. (2021).
21. Solar Cookers International. (2021).