

Radiation distribution uniformization by optimized halogen lamps arrangement for a solar simulator

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Abstract

Solar simulator plays a vital role in the research and development of solar photovoltaic, solar thermal and builds environment. Producing uniformity in spatial, temporal and spectral radiation distribution are the key parameters when developing a solar simulator so the sun radiation is matched as closely as possible in the laboratory environment. This paper presents a development of a solar simulator for education and research purpose. The objective is to achieve a uniform spatial distribution of radiation from a set of halogen lamps. The simulator was built with eight 500W halogen lamps powered by typical domestic 220 V source. The lamps are connected in two parallel four-in-series arrangement and placed perpendicularly from each other about halogen bulb axis. The distance between lamp reflectors edge was varied and total radiation measured by a pyranometer at various distance from the lamp. The findings showed that the optimal distance between reflector edges is 0.15 m which produced good spatially uniform radiation between 500 and 1100 W/m² at distance between 0.20 and 0.40 cm within the test area of 0.4 m².

Keywords: Irradiance; solar photovoltaic; solar thermal; indoor testing;

1. Introduction

Utilization of solar energy in its optimized form is the ultimate solution for energy crisis. Ever increasing demand for energy, particularly electrical energy will surpass the current energy production in a foreseeable future. Many efforts are ongoing to improve solar energy conversion specially to reach a significant breakthrough in photovoltaic technology. Solar PV technologies have been adopting various materials including monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide [1]. New emerging technologies such as perovskite to replace the expensive crystalline silicon which can reach nearly 20% efficiency. Development of photovoltaic cells requires reliable and precise irradiance control to avoid intermittent sun radiation if tested outdoor. In this regard, developing test environment to provide appropriate lighting conditions is crucial. The solar simulator is the most effective way to simulate natural sunlight in a controlled way within laboratory space. The solar simulator is a device to imitate sun radiation to provide controllable indoor lighting for testing photovoltaic cells, sunscreen, plastic and other devices. It is also used to imitate sunlight in architectural illumination studies of model building [2]. With many applications requiring solar simulator, the needs to produce a reliable and standard-conforming device is vital. There are two common standards used to classify solar simulator used for photovoltaic testing: IEC 60904-9 Edition 2 and ASTM E927-10 standards which are a common specification for solar simulators [3]. The light from a solar simulator is should produce an acceptable range of spectral content, spatial uniformity and temporal stability. Each dimension is classified in one of three classes: A, B, or C. For each class, the specification is listed in Table 1. The solar simulation spectrum is specified by irradiance across wavelength intervals ranging between 300 and 1400 nm. Details of this can be found in ASTM.

Table 1 ASTM class specification

	Spectral Match, Each Interval	Irradiance Spatial Non-Uniformity	Temporal Instability
Class A	0.75–1.25	2%	2%
Class B	0.6–1.4	5%	5%

Class C	0.4–2.0	10%	10%
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Solar simulators provide artificial illumination either in continuous, flashed, and pulsed mode. The continuous solar simulator mainly used in low-intensity testing, from less than 1 sun up to several suns. In this context, 1 sun is full sunlight intensity on a bright clear day on Earth, which measures 1000 W/m^2 . Continuous simulators can consist of several different lamp types combined to extend the spectrum far into the infrared. The flashed simulator is like flash photography and uses flash tubes. The pulsed simulator, which uses a shutter quick block or unblocks the light from a continuous source providing pulsating illumination to the test subjects. The light sources for solar simulator comes from various types of light. The most common are Xenon arc lamp: mainly used for continuous and flashed solar simulators [4]. These lamps offer high intensities and an unfiltered spectrum which matches reasonably well to sunlight. But Xe spectrum produced by Xenon lamp is less desirable for some spectrally sensitive applications. Metal Halide arc lamp possesses high temporal stability and daylight color match advantageous in solar simulation [5, 6]. Quartz tungsten halogen lamps offer spectra closely match black body radiation, but with a lower color temperature than the sun [7, 8]. The light-emitting diodes can produce spectrally tailored artificial sunlight at high energy efficiency [9, 10]. In this paper, a development of a low-cost solar simulator is described. The simulator is meant for education and research purpose, mainly in the development of solar hot water system. Halogen light is used to provide irradiance for its price competitiveness and reasonable power requirement.

2. Methodology and experiment

2.1. Evaluation of single lamp radiation

The development of solar simulators started with the evaluation of three different lamp types. The lamps are two halogens and one LED. They were tested with respect to radiation strength and spatial distribution. The first step in the study was to determine which lamp produced the best radiation distribution for the solar simulator within the range of 800 and 1000 W/m^2 . Figure 1 illustrates the selected lamps for the experiments. The comparison of the three lamps with respect to power requirement, radiation strength, heat generated and the cost is shown in Table 2.



Fig. 1. (left) 500 w halogen; (middle) 1000 w halogen; (right)150 W LED.

Table 2. Characteristics of three different lamps.

Lamp	150 W LED	500 W Halogen	1000 W halogen
Power consumption	Low	Medium	High
Radiation strength	Weak	High	Too High
Heat dissipation	Low	Medium	Too High
Unit cost	High	Low	Medium

With a view to find the optimum lamp radiation for the application, a single lamp was investigated to measure the radiation strength three times to avoid any experimental error. The lamps were subjected to a vertical radiation test in which a pyranometer was used to measure the total radiation distribution using pyranometer sensor with logger lite software. The varied lamp heights were 10, 20, 30, and 40 cm and the distances were 10,15, 20, and 25 cm. Figure 2 illustrates the schematic of the radiation measurement set up and light distribution layout. The study proved that the LED lamp was very poor in producing heat with 400 W/m^2 as the maximum radiations. The optimum reading was

detected from the 500 W halogen at 15 cm distance between lamps and with 40 cm height. Figures 3, 4 and 5 reveal the distribution of each lamp radiation tested.

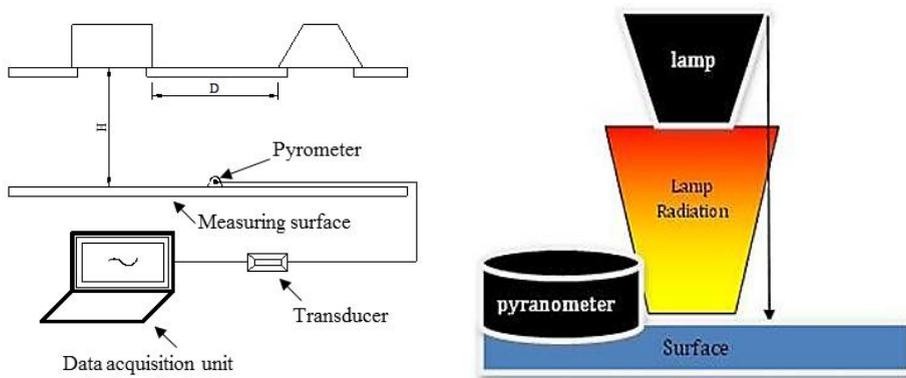


Fig. 2. (left) Schematic of radiation measurement set up; (right) light distributions layout

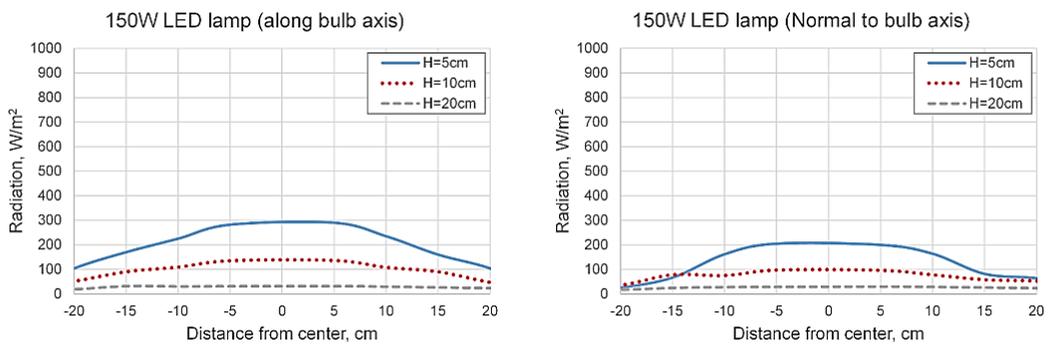


Fig. 3. Distribution of 150 W LED lamp radiation.

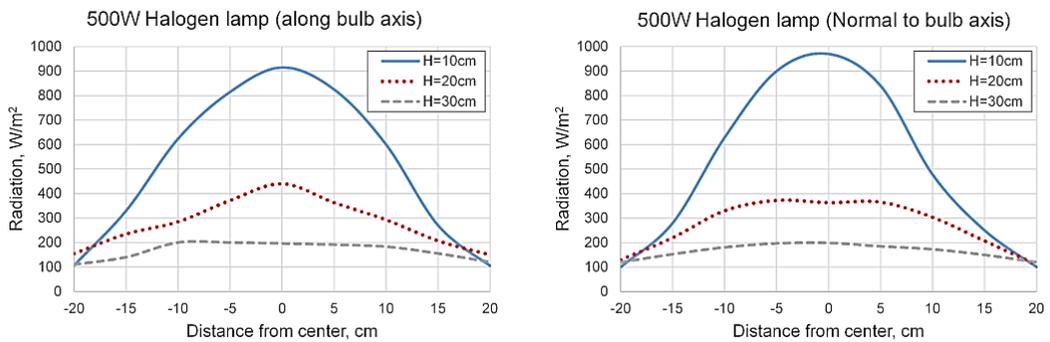


Fig. 4. Distribution of 500 W halogen lamp radiation.

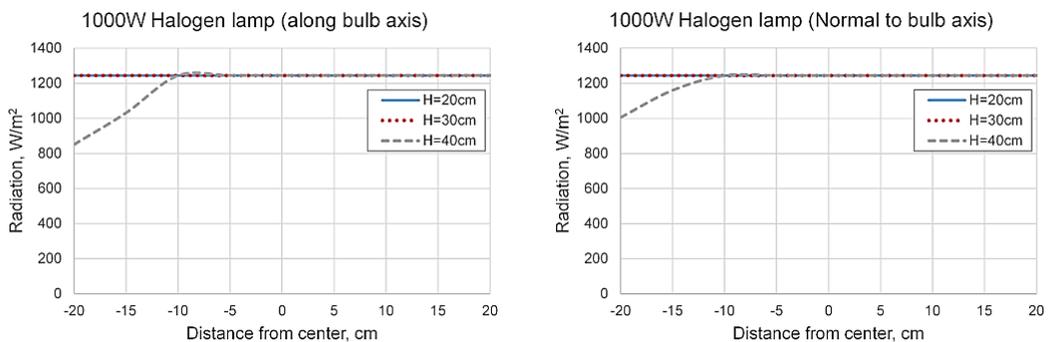


Fig. 5. Distribution of 1000W halogen lamp radiation.

2.2. Effects of lamp arrangement on radiation distribution

The second stage of the development was to determine the optimum arrangement and distance of the four lamps. To cancel out the uneven distribution found along the two axes with respect to lamp centerline, the four lamps were arranged perpendicularly as shown in Figure 6. The distances between the edges were varied to obtain the best balance between radiation spatial uniformity and area of coverage compared to the literature.

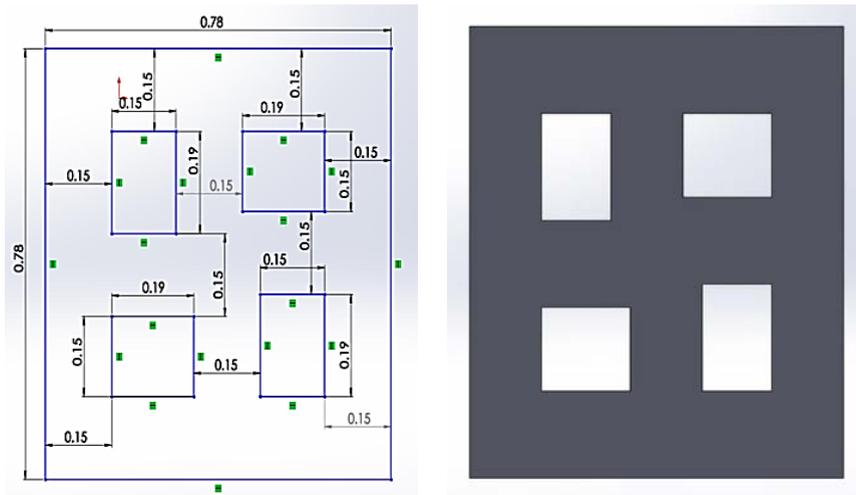


Fig. 6. Arrangement of lamp on the board

3. Results and discussion

As per the experimentation on the lamp to get the best arrangement, the final step was to design the structure of the stand to fit the lamps and electrical connections as shown in Figure 7. The frame provides flexibility to change the lamp radiation angles so that all the tests can be conducted horizontally and vertically with good portability. Development of an electrical circuit was studied for three reasons; to reduce the power load on the switches, avoid any shortcut and design and appearance. Figures 8 to 11 show the arrangement results of 500 W halogens with varied heights 10, 20, 30, and 40 cm and distances 10, 15, 20, and 25 cm. The findings revealed that the lamp irradiance of 500 W was obtained between 400 W/m^2 to 1100 W/m^2 . The optimum irradiances were produced at 10 cm distance with a varied height between 200 W/m^2 to 1200 W/m^2 . The lamps have clear radiation curve with respect to distance from the center. However, when the distance of the lamp raised, the radiation distributions has a ununiformed curve.



Fig. 7. Experimental rig of solar simulator and lamps arrangement.

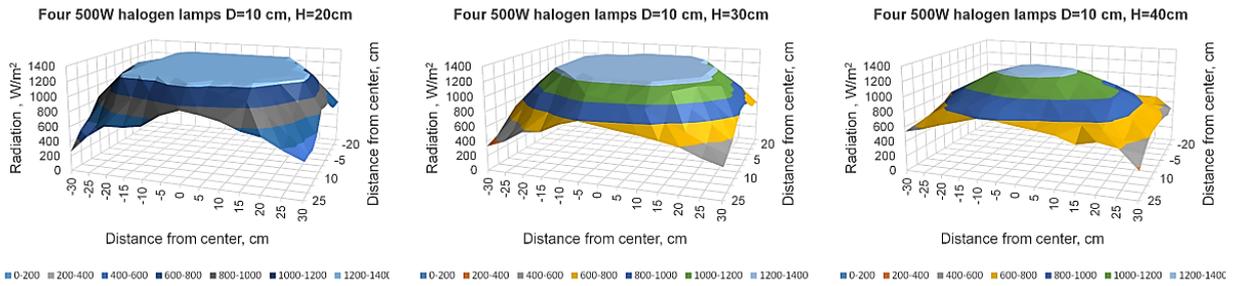


Fig. 8. The arrangement of 10 cm distance between edges of the lamp.

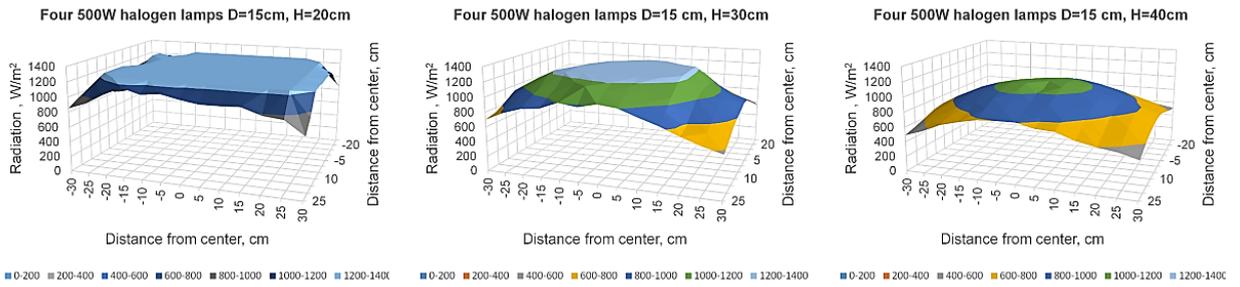


Fig. 9. The arrangement of 15 cm distance between edges of the lamp.

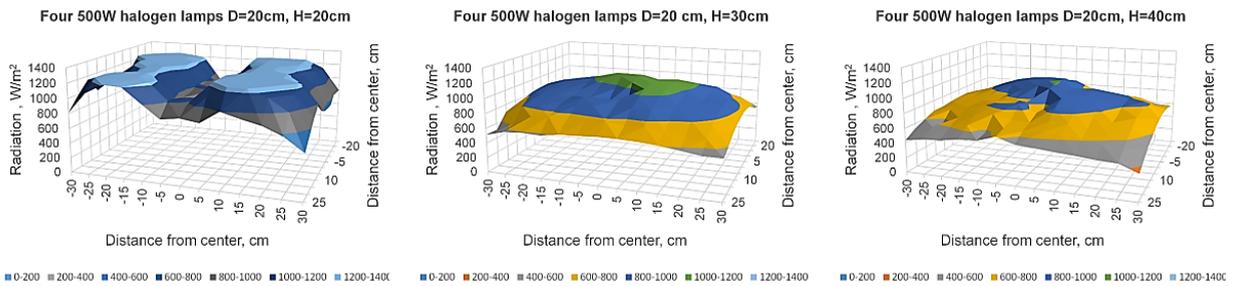


Fig. 10. The arrangement of 20 cm distance between edges of the lamp.

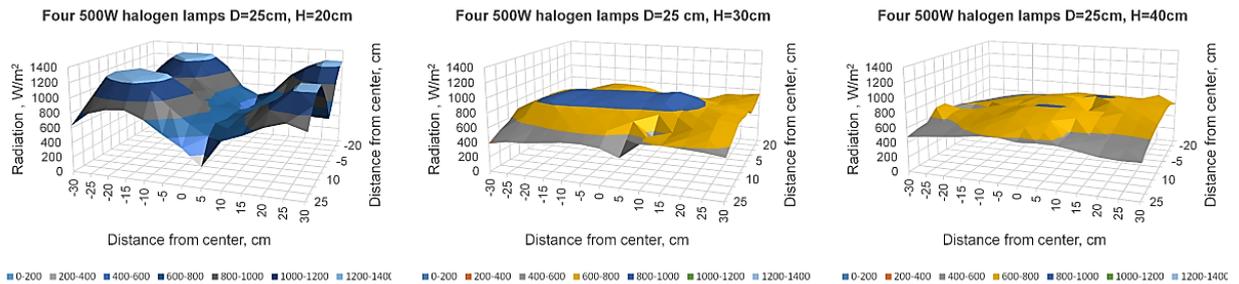


Fig. 11. The arrangement of 25 cm distance between edges of the lamp.

4. Conclusions

The following concluding remarks have been made based on the experimental study presented here:

- This study was about to develop a solar simulator which provides controllable indoor test conditions for testing solar cells, photovoltaic modules and solar thermal collectors under specified steady or conditions by producing illumination approximating natural sunlight.
- The study was developed especially for education purposes and research and characteristics of each lamp. The three lamps have been tested for three times to avoid any experimental errors.
- The lamps are placed in a frame which can be maxed. rotated to $\pm 40^\circ$ from horizontal plane. The frame is supported by a stand which is made to hold test subjects between 0.20 and 0.90 m from the light source which is calibrated to get total radiation between 200 and 1200 W/m^2 .
- There was a lower power consumption of halogen lamps of 500 W compared with 1000 W, which produced more radiation uniformity and heat.
- The 150W LED has a good intensity but very poor results in radiation and heat which produced between 10 W/m^2 to 400 W/m^2 .

References

- [1] M.Z. Jacobson, Review of solutions to global warming, air pollution, and energy security, *Energy & Environmental Science*, 2 (2009) 148-173.
- [2] G. Rockendorf, Design and Application of a Collector Test Facility Based on a Solar Simulator A2 - SAYIGH, A.A.M, in: *Energy Conservation in Buildings*, Pergamon, Oxford, 1991, pp. 294-300.
- [3] A. International, Standard Specification for Solar Simulation for Terrestrial Photovoltaic Testing, in, West Conshohocken, PA, 2010.
- [4] J. Petrasch, P. Coray, A. Meier, M. Brack, P. Häberling, D. Wüllemelin, A. Steinfeld, A novel 50 kW 11,000 suns high-flux solar simulator based on an array of xenon arc lamps, *Journal of Solar Energy Engineering, Transactions of the ASME*, 129 (2007) 405-411.
- [5] B.M. Ekman, G. Brooks, M. Akbar Rhamdhani, Development of high flux solar simulators for solar thermal research, *Solar Energy Materials and Solar Cells*, 141 (2015) 436-446.
- [6] X. Dong, G.J. Nathan, Z. Sun, D. Gu, P.J. Ashman, Concentric multilayer model of the arc in high-intensity discharge lamps for solar simulators with experimental validation, *Solar Energy*, 122 (2015) 293-306.
- [7] A.D. Pasquier, S. Miller, M. Chhowalla, On the use of Ga-In eutectic and halogen light source for testing P3HT-PCBM organic solar cells, *Solar Energy Materials and Solar Cells*, 90 (2006) 1828-1839.
- [8] H.P. Garg, A.R. Shukla, I. Madhuri, R.C. Agnihotri, S. Chakraverty, Development of a simple low-cost solar simulator for indoor collector testing, *Applied Energy*, 21 (1985) 43-54.
- [9] A. Namin, C. Jivacate, D. Chenvidhya, K. Kirtikara, J. Thongpron, Determination of solar cell electrical parameters and resistances using color and white LED-based solar simulators with high amplitude pulse input voltages, *Renewable Energy*, 54 (2013) 131-137.
- [10] T. Luka, S. Eiternick, M. Turek, Rapid Testing of External Quantum Efficiency using LED Solar Simulators, *Energy Procedia*, 77 (2015) 113-118.