Renewable Energy 116 (2018) 335–343

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

The solar noise barrier project: 3. The effects of seasonal spectral variation, cloud cover and heat distribution on the performance of full-scale luminescent solar concentrator panels

Michael G. Debije [a, *], Chris Tzikas [b], Minne M. de Jong [b], Michalis Kanellis [c], Lenneke H. Slooff [d]

[a] Dept. Chemical Engineering & Chemistry, Eindhoven University of Technology, 5600 MB, Eindhoven, The Netherlands
[b] Solar Energy Application Centre, 5656 AE, Eindhoven, The Netherlands
[c] Smart Energy Buildings & Cities, Eindhoven University of Technology, 5600 MB, Eindhoven, The Netherlands
[d] Energy Research Centre of the Netherlands (ECN), 1755 ZG, Petten, The Netherlands

A R T I C L E I N F O

Article history:
Received 6 April 2017
Received in revised form
15 August 2017
Accepted 22 September 2017
Available online 28 September 2017

Keywords:
Luminescent solar concentrator
Photovoltaics
Temperature
Indirect light
Spectra

A B S T R A C T

We report on the relative performances of two large-scale luminescent solar concentrator (LSC) noise barriers placed in an outdoor environment monitored for over a year. Comparisons are made for the performances of a number of attached photovoltaic cells with changing spectral illumination, cloud cover conditions and other seasonal variations, and the temperatures of the cells. Differences in performance are attributed to the positioning of the panels, whether facing North/South or East/West. In general, the panels facing East/West run cooler than those facing North/South. The LSCs in both orientations appear to perform more efficiently under lower light conditions: one factor contributing to this increased performance is better spectral matching of the solar spectrum under cloudy conditions to the absorption spectrum of the embedded fluorescent dye. This work is a step forward in the characterization of a large-scale LSC device, and suggests predictions of performance of devices could be made for any location given sufficient knowledge of the illumination conditions, and provides an important step towards the commercialization of these alternative solar energy generators for the urban setting.

1. Introduction

The luminescent solar concentrator (LSC) is a device with the potential of bringing attractive solar energy generating devices into an urban center [1]. First described in the late 1970's [2,3], the LSC has mainly been confined to the laboratory, with only a few examples of full-scale devices being deployed for research purposes [4–8]. The LSC is based on the concept of using a luminophore embedded in a large-area polymer plate. The luminophore absorbs a fraction of the incident sunlight: because of the nature of the luminophore absorption, both direct and indirect sunlight can be equally absorbed [9]. The absorbed light is then emitted by the luminophore. Since the plastic plate has a higher refractive index than the surrounding air, it will act as a lightguide, trapping a significant fraction of the emitted light within the polymer. The guided light can then only escape through the edges, where photovoltaic (PV) cells can be placed to convert the emission light into electricity [10–12].

For the LSC to attain commercial success, it is necessary they be tested in real-world environments, at realistic sizes. With this in mind, we constructed two large scale LSC-based panels in a noise barrier configuration and installed them outdoors alongside a major roadway in the Netherlands and monitored their performance for a little over one year. We have previously reported on several aspects of the LSC noise barrier (the SONOB project) performance. In our first work, we focused on the effect of variation in solar position with respect to the surface plane of the barrier for both North/South and East/West facing barrier panels, and noted the self-shading seen by the frame of the device as we tracked performance during the span of a single day [13]. The second work considered the effect of application of graffiti and street art on the surface of the barrier, and the impact it had on performance of the individual cell strips attached to the edges of the device [14].

In this work, we consider the seasonal changes, the effects of

* Corresponding author.
E-mail address: m.g.debije@tue.nl (M.G. Debije).

https://doi.org/10.1016/j.renene.2017.09.079
0960-1481/

external temperature, and the effect of cloud cover on the general performance of the LSC barriers. We show the relative performance of the device tracks well with the variations of the seasonal solar spectrum, suggesting output of the LSC can be predicted if local solar conditions are known. The PV cells attached to the edges of the LSC plates demonstrate temperature increases with respect to the ambient conditions, but this may be dramatically affected by the orientation of the panels: East/West barriers show quite a different response than North/South facing barriers. Finally, the response of the LSC is relatively insensitive to the cloud condition, similar to what was seen in scale model devices.

2. Experimental

Two cast PMMA plates $1 \times 5 \times 0.012$ m^3 were used in the large-scale experimental setup. One contained the fluorescent dye Lumogen Red305 [15] and one contained the fluorescent dye Lumogen Orange240 (both dyes purchased from BASF). The top and bottom Red305 panel edges were attached with two strips of series connected monocrystalline silicon PV cells or GaAs cells. Fig. 1a below shows the positioning of the cell strips on the Red305 LSC plates. The strip pairs of series connected monocrystalline silicon PV cells each contained seven 12×78 mm^2 cells, and were mounted at four different locations on the LSC plate, labelled TS (Top, Side), TM (Top, Middle), BM (Bottom, Middle) and BS (Bottom, Side) by a silicone-based, optically transparent flexible glue. The GaAs cell strips were mounted in a similar fashion at the locations indicated in Fig. 1a. On the Orange240 LSC plate, only 2 strings of two cell strips were placed in the middle right position, each strip containing seven 12×78 mm^2 cells. White tape masked the overhang to the edge of the LSC lightguide plate. The performance of each of the cell strip pairs was independently monitored. The vertical edges of each LSC panel were affixed with a white scatterer.

Two noise barrier assemblies were created, overseen by Van Campen Industries. Each consisted of four panels: a Red305 panel was on top, the Orange240 below this, and the two bottom panels hosting mounted silicon bi- and mono-facial PVs, as may be seen in Fig. 1b. Heijmans installed the two assembled noise barriers with one barrier facing North/South and the other East/West in the city of Den Bosch, the Netherlands. The tilts were such that the barriers reclined 15° towards the North and East, respectively. The barriers' wiring was attached by SEAC to the various detectors used in the experiments and the controlling computer. Two EKO MS-802 pyrometers were mounted atop both the barriers, in plane with the front and rear side of the barrier to collect information on irradiance. The output of the PV cells was monitored by an EKO MP-160 IV tracer in combination with a number of switching units.

3. Results and discussion

3.1. Effect of the seasonal spectral fluctuations

It is already known that the spectral distribution of sunlight changes over the course of a day and over the period of a year [16]. Previously, we demonstrated LSC performance varied in response to changes in spectral quality [9]. In general, increased cloud cover shifts the effective spectra towards the blue owing to the rejection of infrared light [17]. In general, this is a positive feature for LSCs, especially those based on organic luminophores, which tend to be most effective at absorbing shorter wavelengths of light. The overall efficiency of the LSC increases with cloudy conditions (of course, absolute output drops due to reduced intensity incident on the lightguide). Still, this increased performance efficiency under low light and blue-shifted spectra is in direct contrast to the performance of silicon-based PV, which in general perform less well in low light and reduced efficiency in blue-shifted spectra [18,19].

Fig. 2 shows a monthly-averaged spectrum of the incident solar light measured at the barrier site at 13:00 for a whole measurement year. The Red305 dye absorbs only part of the solar spectrum (see Fig. 3): a shift in the solar spectrum can cause changes in the collected current by the cells [9].

To compare performance in the LSC noise barriers, we use the 'performance ratio', *PR*, for the attached cells. The definition of PR is [13].

$$PR = \frac{\textit{Field Efficiency}}{\textit{Theoretical Efficiency}} = \frac{P_{measured}(W)}{P_{rated}(W)} \times \frac{E_{stc}\left(W/m^2\right)}{E_{measured}\left(W/m^2\right)} \quad (1)$$

where $E_{stc} = 1000$ W/m^2, P_{rated} is the nominal power outputs of the cell, $P_{measured}$ is determined from the maximum power point on the PV cell I-V curve, and the total measured irradiance from both sides of the LSC panel at the test site is $E_{measured}$. The PVs used had fill factors around 80%. As described earlier [13], PR may not be an ideal parameter to describe LSC performance, but gives a comparison between cell performances given similar weather and lighting conditions. Since the data presented in this paper is based on single large LSC panels, less emphasis should be placed on comparing absolute numbers of PV cell strips but more on the relative performance of individual cell strips throughout a measurement period: there are variations between the strips arising from differences in the optical connection between the polymer plate and the cell strips.

The PR is determined by comparing the performance outdoors

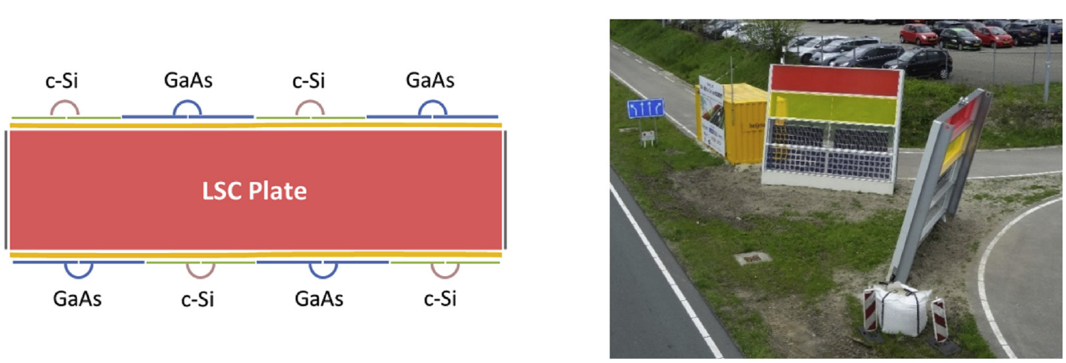

Fig. 1. a) Positioning of the cell strips along the Red305 LSC plates as seen from the side facing the road. Around the Orange240 plates, only two c-Si and two GaAs strips were placed, in the middle-right position. b) Photograph of the LSC noise barrier site. The barrier to the left in the image faces North/South, and the right barrier in the image faces East/West.