

Performance Prediction of Fiber Optic Concentrators for Natural Lighting

Hyunjoo Han¹, Spencer Dutton², Saffa Riffat² and Jeong Tai Kim¹

¹Kyung Hee University, Yongin, Korea

² University of Nottingham, Nottingham, United Kingdom

ABSTRACT: The solar tracking daylighting system using a number of small reflectors (diameter: 25cm) investigated in the present work employs a very simple mechanism for the collection and transmission of sunlight to enhance its performance and applicability. It also offers substantial advantages over conventional solar designs in its fabrication, installation, operation, and utilization of the sun's energy. Especially, its utilization of optical fibre bundles to transport high-density sunlight makes the system rather handy to be integrated with existing building structures. This paper introduces the design and fabrication of the system as well as some of its operational characteristics by hiring a forward ray tracing software, Photopia. Results show that Photopia offers flexibility and accessibility compatible with the experimental investigation under various conditions.

Keywords: natural lighting, solar concentrators, fibre optic, daylighting performance

1. INTRODUCTION

These days, more than 20% of electrical energy is used for indoor lighting in developed countries including Korea, US, Japan, and UK. Considerable contributions could be made by daylight buildings in terms of reducing fossil fuel use and carbon dioxide emissions associated with global warming and climate change.

Introducing natural daylight to places where it is needed does not require complex mechanism or expensive hardware [1]. It is generally considered as one of the most viable means to harness sustainable energy technologies without undue difficulties. Tapping into the sun costs nothing to the environment but pays big dividends to building occupants by promoting healthy indoor environment connecting people to

the rhythms of nature while providing pleasing illumination. Unlike most artificial lighting, natural lighting delivers full-spectrum light, which is easier to read by and causes less eye strain. According to various reports, daylight improves the productivity of workers and favoured by most(90%) of hospitalized patients [2, 3].

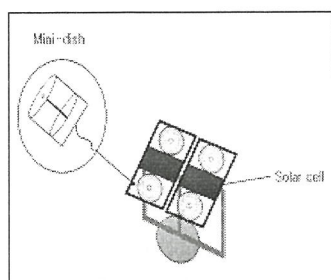
The fibre optic concentrator system investigated in the present work has been designed to capture sunlight and distribute it, using optical fibres, into the interior of a building to provide premium quality, controllable lighting capable of reducing energy consumption. Unlike skylights and windows, the system allows the user to have a control over where and how sunlight is to be used within a building and employs supplemental electric lighting if required to

automatically maintain a constant level of illumination [4].

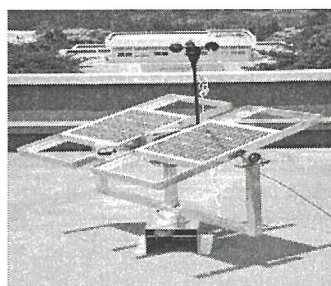
This paper briefly introduces various aspects of the fibre optic concentrator system using small parabolic reflectors and analyzes its functional performance by employing a ray tracing software package.

2. DESIGN AND FABRICATION

The daylighting system with fibre optic concentrators is designed to be mounted on a two-axis solar tracker. It constantly aligns each concentrator at right angle against incoming sun rays with the aid of a microprocessor-based controller, internal clock mechanism and sun sensors. The power to drive the system can be provided either by the utility lines or from the photovoltaic modules.



(a)



(b)

Figure 1: Solar tracking mount; (a) schematic diagram (b) fabricated.

Fig. 2 shows the design concept of the original fiber concentrator unit, which consists of three major components : a parabolic dish concentrator, flat mirror(2nd reflecting mirror), and a homogenizer.

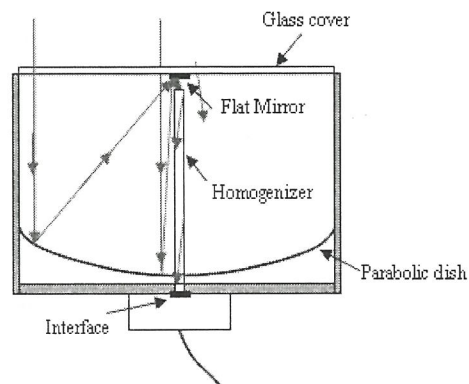


Figure 2: Original design of the concentrator.

As sun rays impinge on parabolic dish (25cm in diameter), they are focused onto a centrally-located small mirror(2nd reflector mirror) which is placed on the bottom side of the transparent glass cover to avoid dust deposition on the reflector and facilitate cleaning. The 2nd reflecting mirror directs the focused sunlight into the receiving aperture of a homogenizer (a highly reflective piece of tubing : multi-sided or circular tube with secular mirror surfaces) whose role is to provide a light passage before it enters the optical fibre bundles connected to a luminaire for terminal lighting.

To elicit the most effective way to collect and transmit sunlight to the designated position, two different schemes were tested for the 2nd reflecting mirror and homogenizer. First, a flat mirror and a tapered stainless steel pipe were used as it deemed rather straightforward. Second, a concave mirror with a short piece of highly reflective aluminium tubing was employed as shown in Fig. 3 (b).

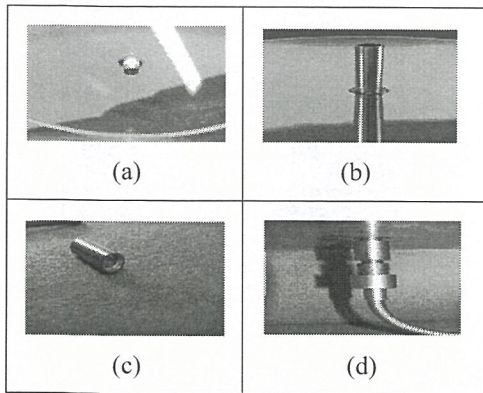


Figure 3: Major components tested : (a) convex 2nd mirror, (b) homogenizer, (c) convex lens, (d) optical fibre cord

A convex lens, Fig. 3 (c), was inserted near the lower end of the homogenizer for the latter to focus down streaming sunlight into the end of a fibre optic receiver. This facilitates the use of smaller optical fibre bundles regardless of the size of the homogenizer pipe.

It is not yet certain which scheme performs better in gathering and transmitting light as there are cons and pros in both methods. Using a small plane mirror(diameter:15mm) requires a taller homogenizer as its focal point should fall within the receiving aperture of a homogenizer. This restriction could be somewhat eased by using a larger plane mirror although it is not feasible anyway as incoming sun rays get blocked at the center. A concave mirror instead facilitates the use of a shorter and larger(in diameter) homogenizer. This, however, calls for a very precise positioning of the mirror and an utmost care should be exercised in this regard.

3. PERFORMANCE PREDICTION

A theoretical analysis has been carried out by using a ray tracing program, Photopia, to assess its feasibility in modelling the

present daylighting system. Photopia differs from other commercially available packages in that it can cope with the high number of reflections that occur within internally reflecting daylighting systems [5, 6]. This feature is, especially, useful in modelling our system as a myriad number of reflections take place inside the homogenizer, let alone the optical fibre bundles.

Table I summarizes the optical properties of the major components. A clear sky condition is assumed throughout the analysis.

Table I: Material optical properties

Material	Property value
Mirror reflectance	99% specular
Homogenizer outer reflectance	95% specular
Homogenizer inner reflectance	98% specular
Dish	95% specular
Acrylic case	92% transmitting

Fig. 4 shows a model close-up of the homogenizer tip in Photopia. As can be seen, the homogenizer tip and the 2nd reflecting mirror are very closely located as aforementioned.

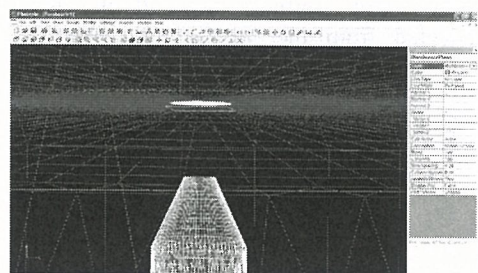


Figure 4: Model close-up of homogenizer tip in Photopia.

To test if all of the light concentrated by the parabolic dish is captured by the system, the total reflected illuminance directly above the dish concentrator is measured. Here, the illuminance plane is positioned just above

the reflecting mirror facing down. The shaded area in Fig. 5 shows that the dish reflector is concentrating light as expected and a proportion of the reflected light bypasses the mirror and escaping around the edges. The black disk in the centre of the image is the shadow cast by the mirror.

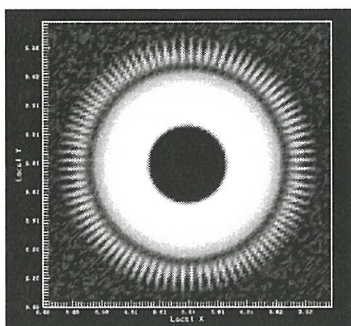


Figure 5: Total reflected illuminance measured directly above the dish concentrator.

Fig. 6 shows the illuminance distribution just below the rim of the homogenizer opening : the illuminance plane is positioned within the homogenizer. This is useful to test whether the light reflected by the mirror does get sent down the homogenizer. The bright area centred in the middle of the shaded plot confirms that all the light reflected from the mirror will enter the homogenizer

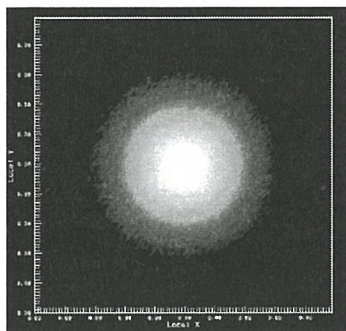


Figure 6: Illuminance distribution – homogenizer opening.

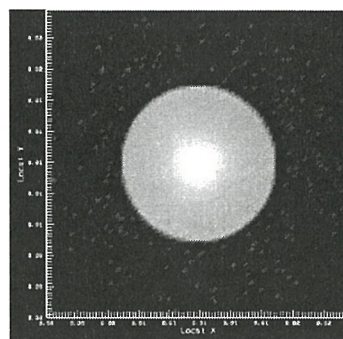


Figure 7: Illuminance distribution –bottom of tube

Fig. 7 gives the illuminance distribution at the bottom of the homogenizer. As shown, the brightest area is located at the center which indicates the homogenizer is transmitting light as expected. Fig. 8 is a contour plot of the illuminance distribution at the homogenizer bottom(exit), which shows an increase in its intensity toward the centre of the homogenizer. If the light is dispersed at the exit, it could make a luminaire of 1,145 lumen. This is comparable to our former experimental results and other commercially available daylighting systems with similar solar collector area. Of course, these data are subject to change according to the sky condition used for simulation.

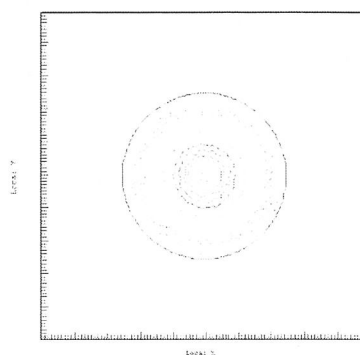


Figure 8: Contour plot of illuminance distribution – homogenizer exit. Clustering of circular contours at the centre exhibit high density solar flux.

4. CONCLUSIONS

This study has been carried out to predict the performance of a solar tracking fibre optic concentrator system for natural lighting. A forward ray tracing software package, Photopia, is used to simulate light intensity and its distribution at various locations within major components of the system. Simulation of this type offers the experimenter to “see” and “quantify” illuminance levels that would be very difficult to measure experimentally and the act of measurement itself would invalidate the results by creating shadows. Design factors such as the shape of the parabolic dish or the size and shape of the reflecting mirror can be altered, its performance assessed and compared to previous designs.

Further work is needed to model the transmission of light through the fibre optic system

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