Renewable Energy 72 (2014) 322–335

Contents lists available at ScienceDirect

Renewable Energy

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

Sunlight concentrator design using a revised genetic algorithm

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A R T I C L E I N F O

Article history:
Received 8 February 2014
Accepted 14 July 2014
Available online

Keywords:
Genetic algorithm
Layout design
Sunlight concentrator

A B S T R A C T

Solar light is a source of green energy that poses no harm to the environment. The layout of a sunlight concentrator has a significant effect on prism-based sunlight concentration systems. This study develops a genetic algorithm that improves the layout efficiency and symmetry of sunlight concentration, by considering light reflection and refraction given the assumption of vertical incident light angle and known transmission rate. Results obtained from the experiments, which involved different settings, show that compared with the current design, more than 400% improvement in brightness and 80% in symmetry can be achieved by the proposed approach. In addition, sensitivity analyses are conducted to simulate different practical scenarios, including different incident light angles.

1. Introduction

A prism-based sunlight concentrator is an optical device that receives sunlight and transmits it to guiding fibers for multilateral applications, such as in greenhouses, as shown in Fig. 1 [2,9,22]. A prism is a transparent optical object with flat and polished surfaces that refract and reflect sunlight. Prisms can be classified into two types. The first type receives sunlight, then concentrates and transmits it. The second type guides and redirects the direction of sunlight. The efficiency of sunlight concentration depends on the layout of prisms. In this study, a sunlight concentrator is regarded as the combination of independent prisms and comprises $I \times J$ square units.

Most studies on sunlight concentrators have focused on improving individual optical components to obtain an optimal design for light concentrators by developing new materials or adjusting the angles of light direction to reduce light transmission loss [1,4,14,17]. Few studies have used mathematical approaches to solve the light concentration problem [1,10,11,24]. However, such process is highly complicated and largely depends on the trial-and-error experience of the designer, which frequently results in local optimization in efficiency.

In this context, the current study develops a genetic algorithm (GA) to optimize the layout of a prism-based sunlight concentrator. First, an optimal layout design is created by considering prism type, sunlight transmission loss, and light direction. Then, the GA is developed to obtain the optimal layout. Finally, sensitivity analyses are designed to analyze the effects on results by different scenario for the light concentrator and the angle of incident light. The light concentration efficiency is affected by incident light angle, transmission loss, the materials, etc. This study is limited to the design of a prism-based sunlight concentrator layout particularly considering reflection and refraction given vertical incident light angle and known transmission rate.

2. Literature survey

Previous studies have made several achievements in the field of solar concentrators [6,7,12,19–21,23] and optical device design [3,4,13].

Most current studies solve the design problem of individual optical components and do not consider the optimization of light transmission efficiency of the entire layout. The design of a light concentrator remains dependent on empirical rules and trial-and-error methods. In addition, the optimal layout of a light concentrator remains unsolved because of the high complexity of determining the best layout design.

According to the Snell equation, loss occurs during sunlight transmission because of reflection. This equation states that $n_1 \sin\Theta_1 = n_2 \sin\Theta_2$, where n_1 and n_2 are the sunlight input and output, respectively, in a prism; and Θ_1 and Θ_2 are the angles of incidence and reflection, respectively. Transmission loss is the property of a substance that permits the passage of sunlight, during which some parts of incident sunlight are absorbed or damaged. The practical light transmission rate of a prism, which is measured as light transmission (%) = (Total Light Transmitted by the Prism/Incident Light) × 100, performs within the range of 50%–90%. The conditions of sunlight transmission and loss based on the Snell

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http://dx.doi.org/10.1016/j.renene.2014.07.020
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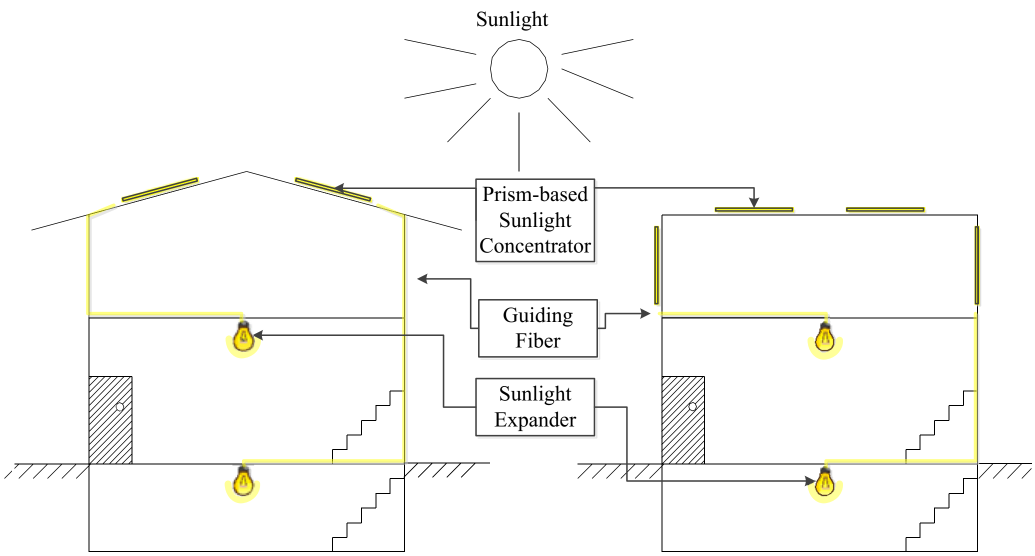

Fig. 1. Prism-based sunlight concentrator applied to greenhouse.

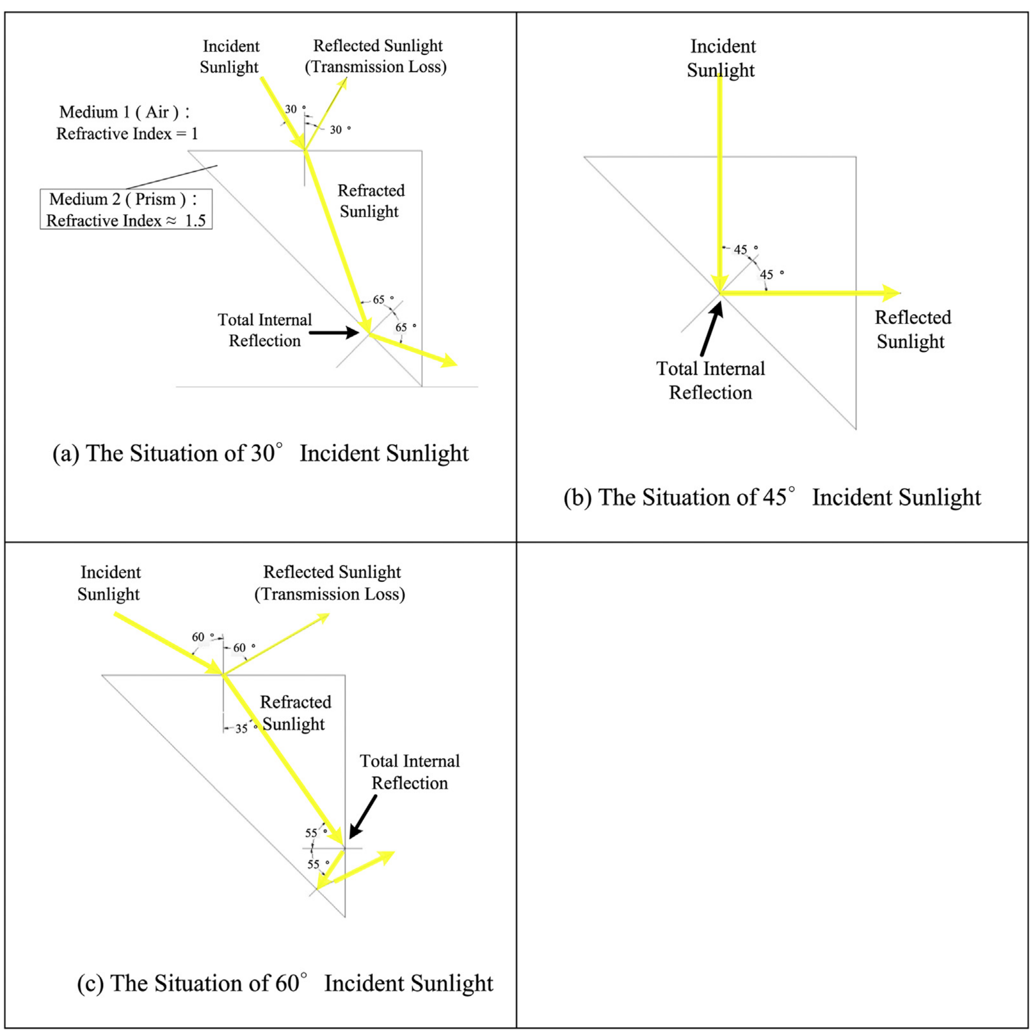

Fig. 2. Different incident sunlight movement in a prism as applying Snell equation.