Article

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Solar concentrating and redirecting systems for application in an agricultural construction

Sistemas de concentración y redireccionamiento solar para su aplicación en una construcción agropecuaria

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Abstract

This work deals with the design and evaluation of a concentrator-luminoduct system for daylighting. A concentrator with a truncated cone profile was designed to capture, transfer and diffuse sunlight, which was concentrated and transported by reflection along the walls of the system and finally projected to the interior of an agricultural building. The illuminance achieved by the system with and without concentration was compared and a significant difference in illumination levels was found. The concentrator obtained concentration factors between 1.7 and 3.6. The critical aspects that determined the concentration of natural light were the angle of acceptance (45.68º), the orientation (45º and 90º) and the reflectance of the material used (95%), in addition, it was possible to reduce the dimensions of these systems, conserving the illuminance. It was proven that this system increased the illumination of the interior space where the light did not reach naturally, improving the illuminance levels (300-500 lx), according to CIE (Commission Internationale l'Eclarige). It was demonstrated that the system represents a viable and adaptable solution for naturally illuminating buildings.

Agricultural, Reflectance, Concentrated, Illumination, Solar collection

Resumen

El presente trabajo trata sobre el diseño y evaluación de un sistema concentrador- luminoducto para iluminación natural. Se diseñó un concentrador con perfil troncocónico para captar, transferir y difundir luz solar, esta fue concentrada y transportada mediante reflexión a lo largo de las paredes del sistema y finalmente proyectada al interior de una construcción agropecuaria. Se comparó la iluminancia lograda por el sistema con y sin concentración encontrándose una diferencia significativa en los niveles de iluminación. El concentrador obtuvo factores de concentración entre 1.7 y 3.6. Los aspectos críticos que determinaron la concentración de luz natural fueron el ángulo de aceptancia (45.68º), la orientación (45º y 90º) y la reflectancia del material utilizado (95%), además, se logró reducir las dimensiones que ocupan estos sistemas, conservando la iluminancia. Se probó que este sistema aumentó la iluminación del espacio interior en donde la luz no llegaba de forma natural, mejorando los niveles de iluminancia (300-500 lx), según CIE (Commission Internationale l'Eclarige). Se demostró que el sistema representa una solución viable y adaptable para iluminar construcciones naturalmente.

Agrícola, Reflectancia, Concentrada, Iluminación, Captación solar

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Introduction

Most human and biological activities on earth are governed and powered by the sun, as the sun has been a source of illumination throughout human history. The development and use of efficient artificial lights has led humans to separate themselves from the healthiest and best source of illumination: natural light. Studies have shown the benefits in health, safety and labor productivity when buildings are naturally illuminated (Boyce, 2022; Roche, 2000). In addition to the quality of natural light, another reason to use it is its compatibility with lighting control systems to achieve a reduction in the use and cost of conventional energy, thus achieving a sustainable system.

Undoubtedly, sunlight is beneficial inside facilities that house living beings (air quality, non-toxic materials and occupants' health) (Gissen, 2002), resulting paradoxical the use of artificial light during daylight hours, being that there is a great abundance of natural light for illumination (Muhs, 2000). Consequently, although artificial light provides sufficient levels of illumination, it cannot provide physiological and psychological comfort (Brainard & Glickman, 2003) (Jenkins & Munner, 2003:2004), benefits of natural light. However, transporting natural light into the facility is sometimes not possible with simple windows and/or domes. Solar concentrators coupled with light pipes are passive systems, and represent a simple solution to the problem of natural light deficiency.

Normally, any light transport system refers better performance when it has a system of concentration and tracking of the sun, with which small diameters can be used, but with respective increases in the costs of the system, in addition, highly reflective materials and collimation systems are required.

On the other hand, another important factor that directly determines the performance of daylight transport systems is the direct sun component. The performance of these systems is reduced when only the diffuse component of the light is present (cloudy sky). Solar concentrators have been used for heat production purposes and to improve the efficiency of solar cells, but have not been used for daylighting purposes in agricultural buildings.

The natural light transport systems that have been developed, applied and studied worldwide have been used to illuminate interior spaces of large architectural buildings (lumiducts, lenses, prismatic guides and optical fibers) (Callow, 2003). Researchers have focused on evaluating and improving the efficiency of the components of these systems (collection, transport and emission-distribution), using experimental modeling techniques, which makes the research costly and of little applicable scope (Mohammed & Carter, 2006; Hansen, et al, 2006; Jenkins & Munner, 2003:2004; Callow & Shao, 2003; Carter D., 2002).

From the above, we can deduce and verify the emergence of new details susceptible of study and applicability to other areas, such as agriculture and livestock, in order to reduce costs in the consumption of non-renewable energy and those of the natural lighting system itself.

Therefore, the study of this thesis evaluates passive and active daylight transport systems and investigates the solution by means of a new configuration of a tracking system with solar concentration and redirection, which captures, concentrates and disperses natural light, with application in agricultural installations, and which represents an efficient and feasible solution.

Methodology

1. Mathematical modeling

The model that is selected to calculate the performance of the lumiducts is shown schematically in Figure 1, in general the mathematical model includes the determination and selection of the sky conditions:

- Calculation of daylight availability (lx),
- Dimensions of the entrance aperture of the system,
- Collection area (solar concentration, depending on the solar elevation angle),
- Incoming light power (available light depending on collection area),
- Light reflected and not reflected by the system),
- Extracted and distributed light (illuminance levels obtained).

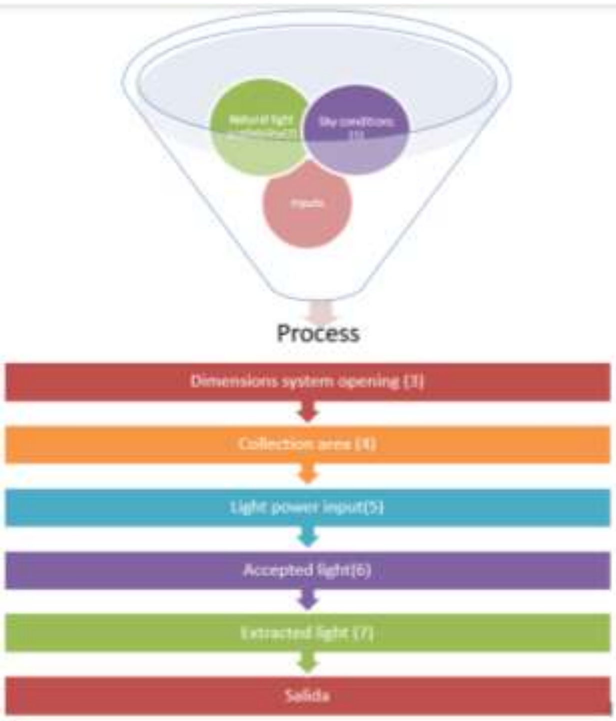

Figure 1 Schematic diagram of daylighting model performance calculation
Source: Own

2. Availability of daylight

To design and analyze the performance of light transport systems, it is necessary to know the amount of light according to geographical location, which can be determined by measurements of horizontal illuminance at hourly average intervals, direct and diffuse, or from the illuminance distribution of the sky vault. Included are means of obtaining daylight data, which includes direct measurement of daylight or solar radiation, models based on measured data, and theoretical models. Additionally, models to estimate the luminance distribution for clear and cloudy sky conditions according to CIE, and the theoretical irradiance values described and determined by Bounger's Law.

3. Sky models

Daylight can be evaluated for different conditions, this section describes the sky model used in this work. Figure 2 shows the scheme for calculating daylight availability (γ_s solar altitude, γ_p altitude angle path in the sky), for clear or clear sky. CIE standard.

While Figure 3 shows the scheme for calculating daylight availability (γ_s solar altitude, γ_p altitude angle path in the sky), for clear or clear sky. CIE standard.

Figure 2 Schematic for calculating daylight availability (γ_s solar altitude, γ_p altitude angle path in the sky), for clear or clear sky. CIE standard
Source: Own

Figure 3 Schematic for calculating daylight availability (γ_s solar altitude, γ_p altitude angle path in the sky), for cloudy sky. CIE standard
Source: Own

To calculate the luminance distribution of the sky, it is necessary to locate the solar position on the celestial vault and the appropriate geometry that describes it (sky types). By finding the luminance of the sky, it is converted to illuminance.

4. Study model propose

For the present study, a Dome+Fresnel (passive concentration) + Lumiduct + Emitter type model was considered, hereafter referred to as DFLE.

The daylighting system will be mounted in a prototype house, on which light sensors will be mounted at the entrance and exit of the system, this will allow measuring the amount of light that is transported within the system.

For this, the following 8 configurations will be made, where:

$\emptyset = inlet\ diameter$,
$L = length\ of\ the\ lumiduct$, and
$angle = angle\ of\ entry\ of\ the\ rays$

Table 1 shows the study configurations.

Configuration	Parameters
1	$\emptyset = 254\ mm\ (10\ ")$ $L = 1m$ $angle = 90°$
2	$\emptyset = 356\ mm\ (14\ ")$ $L = 1m$ $angle = 90°$
3	$\emptyset = 254\ mm\ (10\ ")$ $L = 2m$ $angle = 90°$
4	$\emptyset = 356\ mm\ (14\ ")$ $L = 2m$ $angle = 90°$
5	$\emptyset = 254\ mm\ (10\ ")$ $L = 1m$ $angle = 45°$
6	$\emptyset = 356\ mm\ (14\ ")$ $L = 1m$ $angle = 45°$
7	$\emptyset = 254mm\ (10\ ")$ $L = 2m$ $angle = 45°$
8	$\emptyset = 356mm\ (14\ ")$ $L = 2m$ $angle = 45°$

Table 1 Experimental configurations
Source: Own

Results

The results obtained from the 8 models generated for this study are presented graphically below, showing the behavior of illuminance, measured on a normal, cloudy or clear day in two different months, December and January.

Why consider these months, because they are considered critical in the year, they are the months with the least amount of illuminance, in addition to having less time of natural lighting, the behavior in these critical months can identify if the system is viable and efficient.

1. Configuration 1. Ø=254 mm (10 "), L=1m, angle=90°.

The graph in Figure 4 shows the number of lux allowed for this configuration:

It can be observed that maximum interior illumination levels of 1000 lux are reached, which exceeds the average visual comfort in work areas of 400 lux for light work and 500 lux for specialized work.

In addition, at an average level, it can be noted that the system handles values that allow work to be carried out, since the measurement is taken at a height of 65 cm.

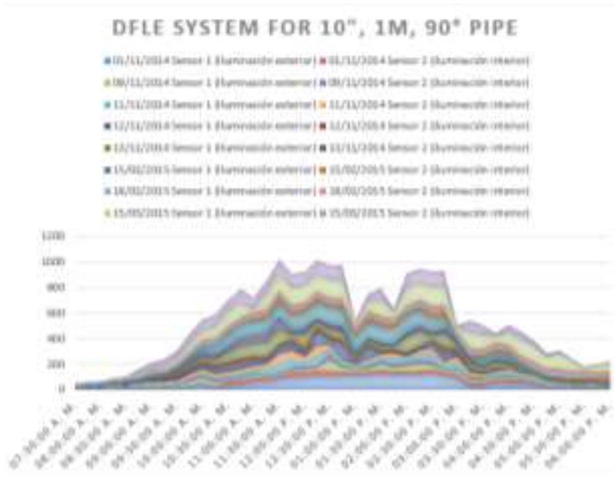

Figure 4 Graph of results for configuration 1
Source: Own

2. Configuration 2. Ø=356 mm (14 "), L=1m, angle=90°

The graph in Figure 5 shows the number of lux allowed for this configuration:

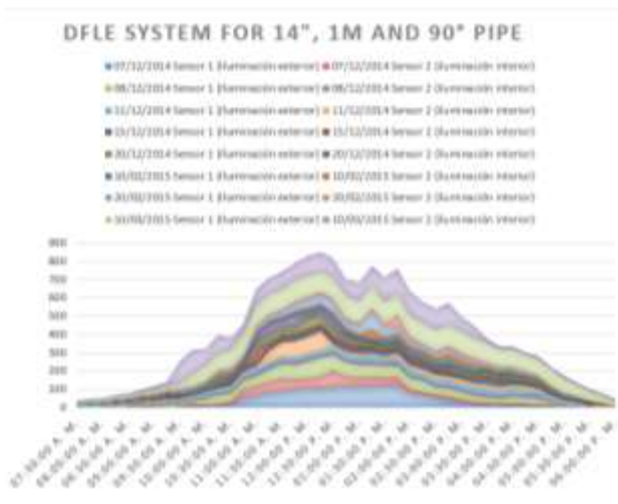

Figure 5 Graph of results for Configuration 2
Source: Own

As can be seen in this configuration, average values between 100 and 850 lux were obtained, which makes the system efficient, since it allows both light and special works, also measured at 65 cm from the ground.

3. Configuration 3. Ø=254 mm (10 "), L=2m, angle=90°.

In the graph shown in Figure 6, the behavior of the given system for configuration number 3 can be observed.

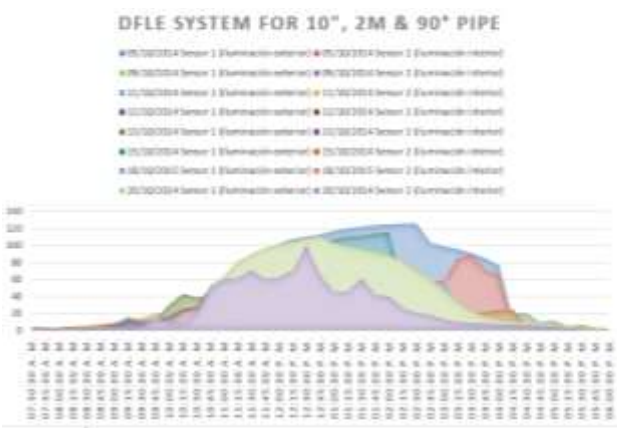

Figure 6 Graph of results for configuration 3
Source: Own

It can be observed that for this system, in spite of the fact that the length of the lumiduct is increased to 2m, illuminance values of between 100 and 1100 lux are obtained, which allows both light and special works to be generated, and will allow the length of the lumiduct to be increased, without affecting the amount of illuminance that enters the work site.

4. Configuration 4. Ø=356 mm (14 "), L=2m, angle=90°

The graph in Figure 7 shows the behavior of the system.

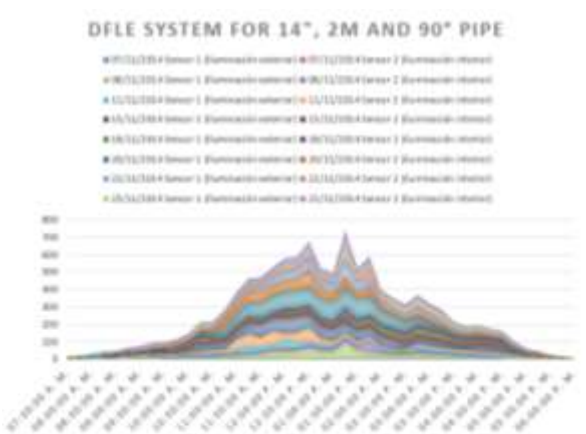

Figure 7 Results graph for configuration 4
Source: Own

The performance of this system shows that internal illuminances are received in an average of 100 to 750 lux, recommended for indoor work. Therefore, the length of the lumiduct can be increased and the illumination levels do not decrease with respect to a shorter length.

5. Configuration 5. Ø=254 mm (10 "), L=1m, angle=45°

The graph in Figure 8 shows the illuminance results of the System using configuration 5.

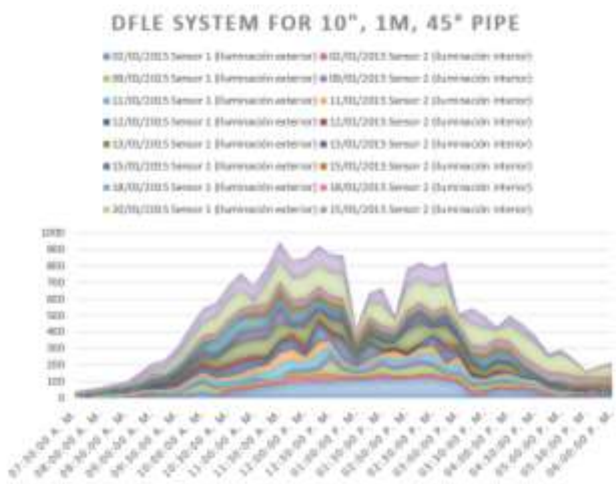

Figure 8 Graph of results for configuration 5
Source: Own

As can be seen in the graph in Figure 102, the illumination levels for this daylighting model configuration are in the range of 75 to 900 lux, which allows indoor work to be performed between the hours of 10:00 to 17:00. Note that even when using a 45° elbow, the system is able to transport the light rays indoors.

6. Configuration 6. Ø=356 mm (14 "), L=1m, angle=45°.

The graph in Figure 9 shows the results obtained from the modeled system under configuration 6.

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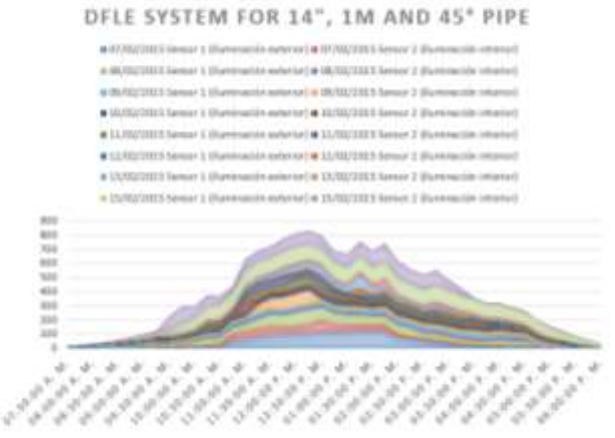

Figure 9 Graph of results of configuration 6
Source: Own

It can be observed that the behavior of the system shows that the amount of interior illuminance is in the range of 65 to 800 lux, which allows to develop works inside the building, it can be observed that the angle given to the system does not affect the transport of light rays into the interior.

7. Configuration 7. Ø=254 mm (10 "), L=2m, angle=45°

The graph in Figure 10 shows the results obtained in terms of illuminance in the configuration 7 system.

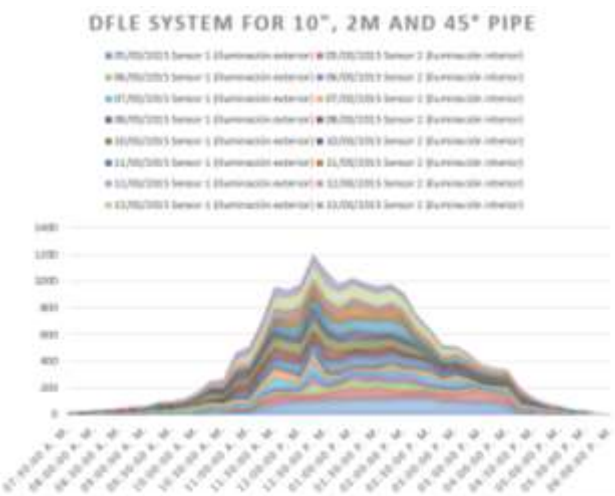

Figure 10 Graph of results for configuration 7
Source: Own

It can be observed that this system shows good levels of interior illumination, since values from 100 to 1200 lux were obtained, which allows performing specialized work inside the building, once again the angle does not affect the transport of light into the interior.

8. Configuration 8. Ø=356 mm (14 "), L=2m, angle=45°

Figure 11 shows the graph of the results obtained for this configuration.

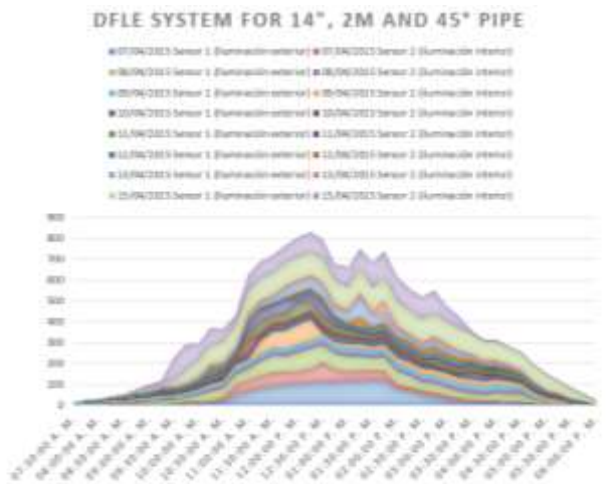

Figure 11 Graph of results for configuration 8
Source: Own

It is observed that under this configuration, the system obtains an average illuminance value of between 65 and 800 lux, which allows for good interior illumination, allowing the development of various tasks and jobs.

Acknowledgments

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Conclusions

The concentrator obtained concentration factors between 1.7 and 3.6. The critical aspects that determined the concentration of natural light were the angle of acceptance (45.68º), the direction (45º and 90º) and the reflectance of the material used (95%). In addition, it was possible to reduce the space taken up by these systems, conserving the illuminance. It was proved that this system increased the illumination of the interior space where the light did not reach in a natural way, improving the illuminance levels (300-500 lx), according to CIE (Commission Internationale l'Eclarige).

It was demonstrated that the system represents a viable and adaptable solution to illuminate constructions naturally.

It was also noted that the selected parameters do not really influence to a great extent the quality of natural light that is introduced in an agricultural construction, but it is the fact of the days of the year, the sky conditions, and the position of the structure to be illuminated.

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