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Solar light collection from buildings façades

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Abstract. We present an analysis of the light collection from the building's façade for interior lighting using diffuse reflective surfaces. The use of diffuse surfaces may increase the acceptance angle of such systems, in order to collect more sunlight coming from different directions according to the objects surrounding the building façade for longer periods of the day without the use of sun tracking systems. We discuss a numerical analysis and experimental results comparing light collection with the proposed system with respect to an equivalent system using specular reflecting surfaces. Results show that the collection is around 50 lx with a system of dimensions 10 cm x 15 cm and is of about of 55% higher than the collection achieved by a system of specular surfaces.

1. Introduction

The contribution of natural light available on the façades of buildings (in densely populated areas), comes mostly from reflections from the ground or nearby objects, which is non-directional light rather than light coming from the sun [1]. Light pipe lighting systems in different versions are most commonly used but they generally require modifications to the building structure [2] or to be planned previous a building's design [3]. Light pipes work more efficiently in the case of sunny days but its performance decreases considerably on cloudy days [4]. Another approach to capturing sunlight are the anidolic systems that are proposed for capturing light with good efficiency through specular reflectors installed on the façade of the building principally in sunny days [5].

Since most of the available sun light in the building's façade is not directional or diffuse, in the case of cloudy days, in this work we analyze the use of collection systems with diffuse reflective surfaces to improve the light collection that can be extended to more hours during the day in different type of weather conditions.

1. Proposed system

Most sunlight collection systems for interior lighting found in literature make use of surfaces that reflect incident light in a specular manner, as shown in Figure 1A, limiting light collection to only some specific angles of the incident light.

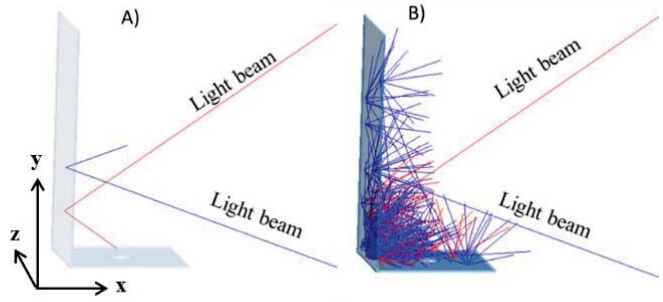

Figure 1. A) Reflection of light beams in specular surfaces. B) Reflection of light beams in diffusing surfaces.

Moreover, a uniformly diffusing surface reflects the total incident light in multiple directions with the same intensity [6] as shown in Figure 1B, it is for this reason that is of our interest to analyze the use of a system formed with diffuse reflectors. We propose a system using two diffuse reflectors joined by one of its edges as shown in Figure 2.

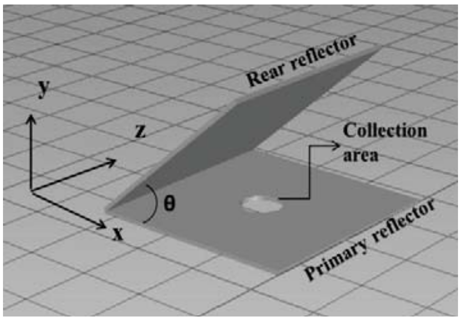

Figure 2. Schematic of the collecting system.

This system consists by a primary reflector (PR) where the day light from the sun directly enters and then is reflected by a rear reflector (RR) in which also reflects the light from the ground and surroundings objects. The reflected light will be collected in the collection area. We consider as the collected light all the radiant flux measured trough the collection area. The luminous flux emitted by the diffuse reflecting surface in the direction of the observer depends on the solid angle in the x-y-z plane as shown in Figure 3 therefore;$\mathbf{d\omega = Sen\phi d\psi d\phi}$ and depends on the light ray direction with respect to the $\boldsymbol{\phi}$ angleand the $\boldsymbol{\psi}$ angle formed between the normal to the surface and the direction of the observer with respect to the x-z plane. The proposed system surfaces reflect light according to the cosine law given by Lambert [7]. In this type of surfaces the reflected light flux (irradiance L) is given by:

$$\mathrm{L} = \frac{\mathrm{dp}}{\mathrm{dA}} = \mathrm{L_d d\omega Cos\phi}, \qquad (1)$$

where $\mathbf{L_d}$ is the radiant flux per unit area and solid angle.

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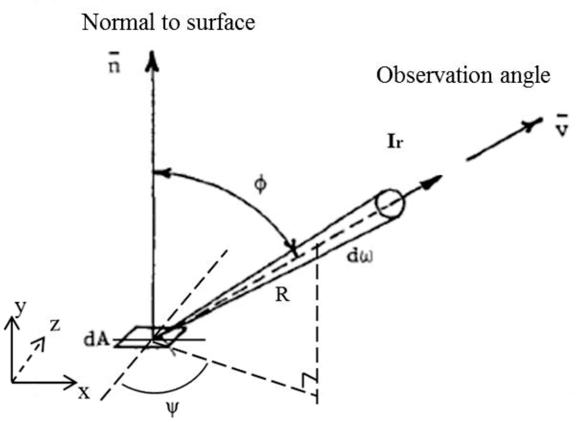

Figure 3.Projecting light reflected from a diffuse surface in the direction of the observer

It is possible to calculate the total optical power emitted by an ideal diffusing surface (Lambertian surface) when it is illuminated by an external source as follows:

$$\mathbf{M = \frac{dP}{dA} = \int L_d cos\phi d\omega = \int_0^{2\pi}\int_0^{\frac{\pi}{2}} L_d cos\,\phi sen\phi d\phi d\psi} \quad [\mathbf{Wm^{-2}}] \qquad (2)$$

Since the irradiance is not a function of φ or ψ, the solution of this double integral leads to the total power radiated by an illuminated Lambertian surface is constant as:

$$\mathbf{M = L_d \int_0^{2\pi}\int_0^{\frac{\pi}{2}} cos\,\phi sen\phi d\phi d\psi = L_d} \qquad (3)$$

The equation (3) is essential to calculate the interaction of radiant flux between diffuse surfaces, this term represents the total radiant flux reflected by a diffuse surface. The total radiant flux interaction between diffuse surfaces was estimated numerically using a ray tracing software as shown in next section.

2. Numeric simulations

To estimate the response of the proposed system we performed a series of simulations using a computer ray tracing program Zemax. For these simulations a homogeneous light source with a non-directional light distribution is used as the case of a partially cloudy day [8]. This source was placed at a distance of 1m from the collection system at a position where the emission of light flux completely covers the system.

In these simulations we tested different possible configurations to determine which should better collect light. To estimate the amount of luminous flux collected by the system a sensor was placed at the center of the PR in the collector area and we varied the angle θ formed by tilting the RR with respect to PR. We present in Table 1 results of these simulations.

Table 1 Luminous flux collected for different values of θ.

θ [°]	Luminous flux [lx]
10	3.58
20	6.41
30	9.84
40	10.4
50	8.96
60	8.42
70	6.25
80	4.73
90	4.05

From Table 1, it can be observed that the maximum light collection is found at 40° with 10.4 lx collection, below and over this angle there is a flux decrease by more than 40% of luminous flux collected by the system.

Regarding to the number of incident rays at the reflector surfaces, in Fig 4 we plotted the incidences of light rays (number of hits) at the RR and PR reflectors considering an angle θ=30º. For the RR and PR surfaces the number of incident rays is higher near the apex formed by the two reflectors where they are closer.

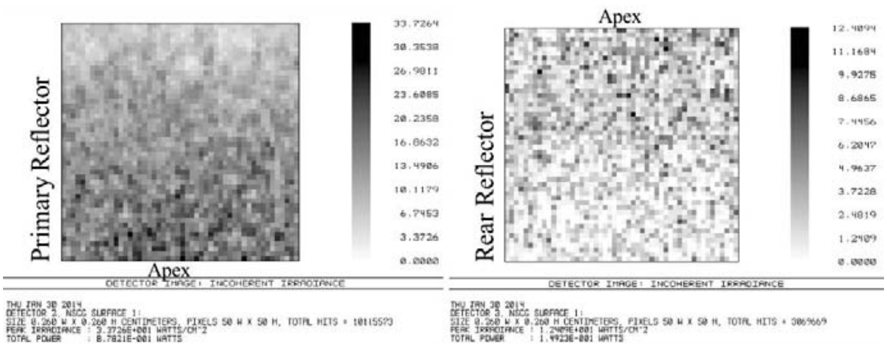

Figure 4. Incident rays at the PR (graph on the left) and RR reflector (graph on the right).

According to this we placed a sensor as the collecting element within the apex zone and calculated the luminous flux at the sensor for two systems of the same size but one formed by diffusing reflectors and the other formed by specular surfaces. The collector sensor was placed at the same distance from the light source for both of the systems. To emulate light coming from different angles at different hours of the day, we used 5 light sources configurations by placing at 5 different positions. For the five configurations we considered the same distance of 1m to the RR reflector as shown in Figure 5A. Results are shown in Figure 5B where we also plotted the flux detected by the sensor for the light source coming directly to the sensor without any reflector.

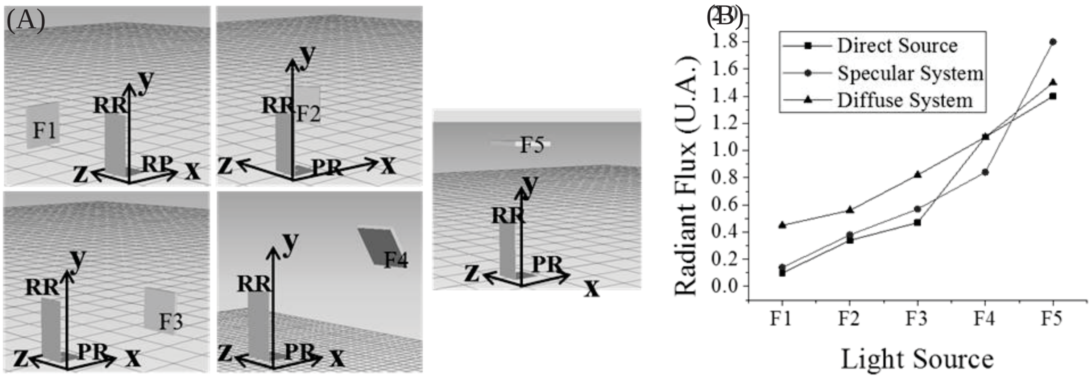

Figure 5. (A) Position of the light source with respect to PR. (B) Simulation results comparing the luminous flux collected using a diffuse system, a specular system and the light source without reflectors.

From results in Figure 5B one can see that the proposed system with diffusing reflectors collects nearly to 20% more radiant flux than the system with specular surfaces and over 25% of radiant flux coming directly from the light source. It is noteworthy that the specular system collects a larger amount of radiant flux that the diffuse system when the light source is located at 90 ° of inclination with respect to the PR, this is because at this position light reaches the sensor directly without undergoing many reflections. Results of these simulations were used to construct a collector that was tested under natural light illumination.

3. Experimental results

The diffuse system was constructed using carton reflectors of 15*cm* x 20*cm* coated with white paint, while the comparison system was made of common mirrors of the same dimensions as the diffuse system.

As shown in the numerical simulations most of the light was collected along the apex of the RR and the PR, for this reason we placed a plastic Fresnel lens covering the front of the system so it could increase light collection at the collection area. Light collected was measured by an optical fiber bundle, of 6 plastic fibers of 1mm core diameter, placed at one end collection area and the bundle output was connected to a light meter, as shown in Figure 6.

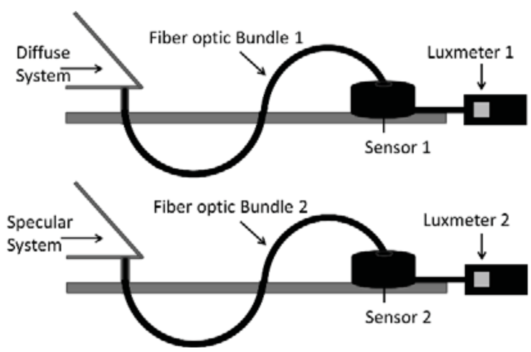

Figure 6. Assembly diagram of the elements used in the tests under natural light.

The measurements were carried out in periods of 8 hours on the north side façade of our laboratory. In figure 7 is presented the total luminous flux collected by the diffuse system compared with the collection of the specular system in a cloudy day.

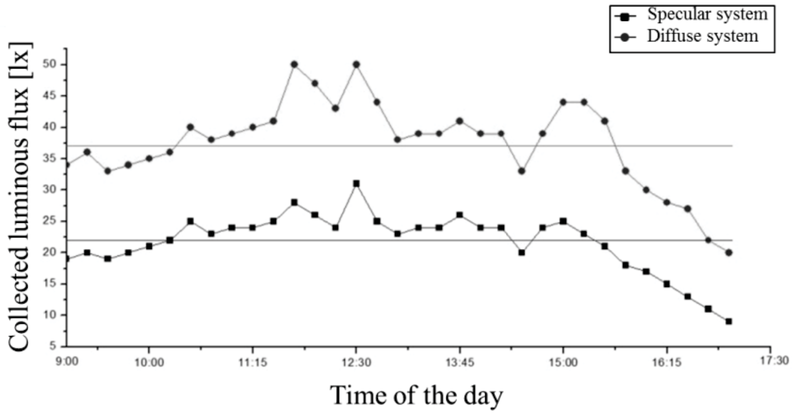

Figure 7. Luminous flux collected on a cloudy day for a system using diffuse reflectors (points) and the collected flow for a system using specular reflectors (squares).

It can be noted in Figure 7 that the proposed system collect about a 35% to 55% more light collected compared to the system formed by specular surfaces. The fluctuations in the measurements are due to changes of cloudiness along the day. It is also shown that the collection average for the diffuse system (around 40 lx) is higher than the specular system (around 25 lx) in an 8hrs period without the use of a sun-tracking system.

4. Conclusions

We propose a passive light collection system using diffuse reflectors, which can be installed in existing buildings façade. This system prove to be reliable in overcast day conditions where the diffuse system collected in average about 50% more light than the specular system in an 8 hours measurement.

It was shown in the numerical simulations which was the systems configuration that could collect a larger amount of radiant flux. This configuration was used to test the response of the proposed system experimentally. It was observed in the numerical simulations that the system formed by diffuse surfaces are able to capture about 20% more radiant flux compared to a system consisting of specular surfaces. It is also shown that the most collected radiant flux is concentrated in the apex of the PR and the RR, this is why we propose the use of a Fresnel lens to concentrate the light in the collection area. It is observed that the system, despite the small size of both the collecting system as the means of transport of light, managed to collect a significant amount of radiant flux.

This is why we can say that by adding more systems like this, we could meet the CIE interior lighting standards [9]. The possibility of a passive low-cost system is shown, this type of systems could be used to take advantage of the light available in the façades of the buildings without the need to modify the structure of them and thus have a significant reduction in the consumption of electricity [10] by increasing the actual hours of operation of this type of systems response over a day.

References

[1]Cheung H, Chung T. 2005 Calculation of the Vertical Daylight Factor on Window Façades in a Dense Urban Environment. Architectural Science Review.Vol.48 Iss 1.
[2] SolaTube international Inc. Daylighting systems Internet: **http://www.solatube.com/. Enero 2013.**
[3] Rosemann A, Kaase H. 2005. Lightpipe applications for daylighting systems.Solar Energy.Vol. 78 Iss 6.
[4] Beu D, Carter D.Lighting Design Methods for Obstructed Interiors. CIE 161:2004. CommissionInternationale de I'Eclairage, Vienna.

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[5] Ruck N, AschehougØ,Aydinli S. 2009*Daylight in Buildings*. International Energy Agency. Washington, D.C.
[6] S. K. Wittkopf, E. Yuniarti, L. Soon. Prediction of energy savings with anidolic integrated ceiling across different daylight climates. Energy and Buildings. Vol. 38, Issue 9. 2006. P.P. 1120-1129.
[7] J. Walsh. Photometry. 1958. New York. Dover Publications. pp. 136-52.
[8] Mills A. *Heat Transfer* 1999. New Jersey. Prentice Hall. pp. 538-591.
[9]Uetani Y, Aydinli S. Spatial Distribution of Daylight - CIE Standard General Sky.CIE S 011/E:2003. Commission Internationale de I'Eclairage, Vienna.
[10]CIE S 008/E: 2001/ISO 8995-1:2002(E). Lighting of Work Places - Part 1: Indoor. CommissionInternationale de I'Eclairage, Vienna.

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