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Paper

Photometric Performance of the Solar Bottle Bulb

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ABSTRACT

The solar bottle bulb has become a very important source of light in poor regions and/or in those that have difficult access to power. Its extended use results in the need to have a more rational knowledge of its performance. In this work, we carried out the photometry of the solar bottle bulb considering the sky models that simulate cloudy and sunny days with the sun at different angles. The results show a performance varying from 50 to 70%, according to the position of the bottle and the characteristics of solar radiation, together with a distribution of light that greatly improves the one given by a hole in the roof, thereby reducing up to 32 times its maximum intensity.

KEYWORDS: solar bottle bulb, daylight, efficiency, optics

1. Introduction

The use of the solar bottle bulb as a source of illumination arose as an alternative to provide natural light in places where access to the same is very limited and at times non-existent. The solar bottle bulb was invented in 2002 by the Brazilian mechanic Alfredo Moser and has turned out to be a very economical and ingenious element for capturing light and introducing it inside a room that has no other way of having access to natural light in places where the cost of electric power to minimally light a room on a daily basis can be prohibitive for its inhabitants. Thereby, this sustainable source of light has changed the lives of many people who use his invention to illuminate homes and small shops saving money that would otherwise be spent on electrical power.

At present, there are organizations promoting the use of this illumination system in numerous countries which, if we merely take into account the metropolitan area of Manila, have introduced this technology to 2.000 households. It is expected that by the year 2015 one million solar bottle bulbs will have been installed around the world[1]. This idea has also generated enthusiasm in the area of design and some applications of the solar bottle bulb can be seen in buildings where, even if natural light is seen from a window, this resource has been used for aesthetical reasons. The main reason that popularized this light source quickly is that it is made of a discard material by a very simple process. Otherwise, the duration of this type of light source is five years, after which period it is necessary to change the water in the bottle and replace the bleach to keep it clean, and clearly the main disadvantage of this light source is that its true potential is only exploited during daylight hours.

Whatever the reason for its use, it is necessary to have rational studies regarding its performance to better understand the different alternatives of use and can to do qualitative predictions of its implementation. In a solar bottle placed on the ceiling of a room there are two optical phenomena distributing the light that reaches it. On one hand, the refraction of the incident beams: while some beams are refracted through the bottle recovering the angle of incidence at the exit, others will be reflected down toward the basis of the bottle, acting the bottle as a waveguide. Moreover, all the light that hits the bottle will be spread in some degree by the media inhomogeneity. As a result the solar radiation will be redistributed in the interior in a more profitable way that when the light enters directly. In a first approximation, general aspects of the performance of the solar bottle bulbs were determined and gave out the first photometric data of this technology[2]. However, in that work, only the measuring of horizontal illuminance under the bottle and vertical illuminance at one side of the same was performed, which did not allow for an integral photometric characterization to explain its working and to do predictions. In that study, the authors claim that, thanks to a mixture of refraction and total internal reflection in a solar bottle bulb, we can also make better use of daylight than simply by opening a hole in the roof to allow direct sunlight in.

Studies regarding the performance of the solar bottle bulb can be carried out directly in the place where the artefact is installed. In that case, measuring corresponds to a specific solar condition which makes it difficult to

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compare different aspects of design. An alternative to fully understand the properties of the solar bottle and take advantage of its properties would be to determine the Bidirectional Transmittance Distribution Function (BTDF) that described the full set of the optical properties of the bottle. The BTDF, is defined by the Commission Internationale de l'Eclairage as the quotient of the luminance of the medium by the illuminance on the medium, and therefore it is angle dependent at both the incidence and the emergence levels and expresses the emerging light flux distribution for a given incident direction[3]. BTDF was used for different complex fenestration system to determine the resulting indoor lighting conditions under a given external luminance distribution[4]. Although this approach based on simulation increase flexibility and cost effectiveness compared to experimental approaches, all properties of each and every component (geometry and material) need to be known in advance, which often still requires measurements[3]. In our case, the amount of measurement for a four dimensional table would be large, even if polar symmetry were invoked to reduce the amount of measurement. Instead of doing a full measurement of a BTDF we chose to use an experimental system measuring the light output of the bottle using a goniophotometer.

In this work, we study the distribution of luminous intensities of the solar bottle bulb when it is exposed to both a diffuse illumination and to illumination with a strong direct component presented at different angles, and consider experimental conditions such as the proportion of the illuminated bottle and the reflectance of the internal surface of the roof where the bottle is placed. To do this type of experiments, we built an illuminant that simulated the conditions of interest and that can be installed for measuring in a goniophotometer. In this way, it is possible to establish comparisons between different experimental arrangements because they are evaluated in a simulated solar condition that remains constant during each experiment.

2. Methods

To perform the photometries of a solar bottle bulb we designed a suitably sized illuminant to be mounted on the gonio-photometer and, at the same time, capable of reproducing lighting conditions comparable with natural lighting. The iluminant system consisted of a cubic box measuring 45 cm on each side, with a circular hole with a 10.5 cm diameter in the centre of its base that emulates an opening in a roof through which natural light enters and where we introduced a bottle of polyethylene terephthalate (PET). The bottle used has the shape of a cylinder with a diameter somewhat narrower in the central area (a very common shape in soda bottles) containing water with a 2 litre capacity and a height of 36.5 cm.

The inside of the box was painted matt white and the exterior was painted matt black. To simulate the diffuse illumination condition four compact fluorescent lamps of 20 W and 6500 K were placed inside the box in a vertical position and at the corners of the base, each of them with a nominal flux of 1140 lm. In addition, to achieve a more uniform distribution of the light on the bottle, a diffuser screen of white paper was placed between the lamps and the hole of the box. With this arrangement, the surface of the hole emitted a luminous flux of 49 lm. The side and plan views of the illuminat system can be seen in Figure 1.

To simulate a mixed illumination with a strong direct component in the box, we incorporated a halogen reflector lamp of 50 W with a beam angle of 24° directed towards the hole without it being obstructed by the screen. The halogen lamp was placed in three positions to take into account three different solar angles: an almost zenithal position (5°), a position where we favour the total reflection in the interior of the bottle (20°) and in one of the superior corners of the box (35°) where the total reflection is minimized. The proposed lighting system presents the drawback that there is light passing through the bottle and being reflected back into it. This uncontrolled stray light appearing in the illuminant

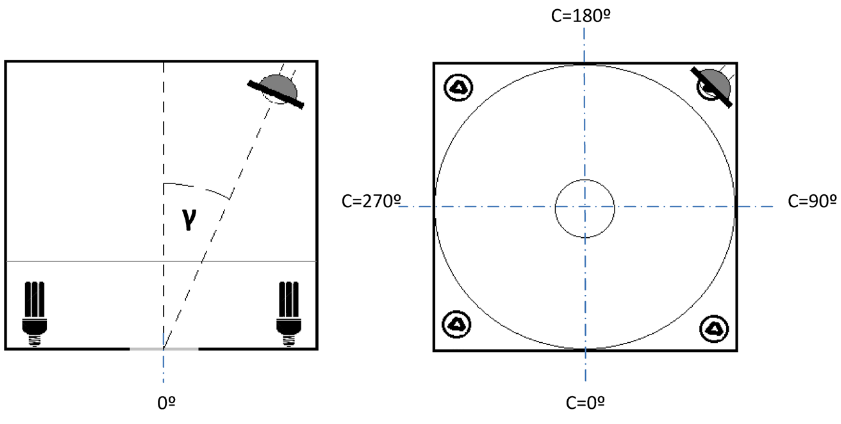

Figure 1 Side view (left) and plan view (right) of the experimental sky.

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with bottle may result in a little increase in the efficiency values computed using the Eq. (1) described later.

For the photometric measuring we used a gonio-photometer LMT model GO-DS 2000 that evaluated the distribution of the luminous intensity of the different configurations of the illuminant system and the experimental conditions for gamma[5] angles from 0° to 180°, with intervals of 5° in the range from 0° to 95°, and of 10° in the range of 95° to 180°, and for angles C[5] from 0° to 360°, with intervals of 2.5°.

3. Evaluation of the implemented illuminant system

As a reference parameter we measured the photometric distribution of a simulated cloudy sky where only the component of diffuse light is considered, obtaining a nearly uniform distribution (Figure 3, dark grey line) with four maximums in the zones that correspond to planes C=45°, 135°, 225° and 315° owing to the location of the four fluorescent compact lamps inside the box. We also took into account a clear sky simulating an opening in a roof through which light with direct and diffuse components comes in. In this case, the halogen reflector lamp located inside the box generated maximums of luminous intensity of 6071 cd for gamma=5° and C=157.5°, 6861 cd for gamma=20° and C=130°, and 6386 cd for gamma=35° and C=315°. Flux values were computed by means of the luminous intensities provided by the photo-goniometer. In Table 1 were presented the values of the flux of the diffuse component, of the direct component, the global flux and the relationship between diffuse and global fluxes for the different kind of implemented illuminant systems. In addition, measurements carried out in two cities of Argentina: San Miguel de Tucumán (26°49′00″S 65°13′00″W, altitude 431 m, subtropical weather with a dry season, 1600 annual average sunlight hours) and Mendoza (32°53′40″S and 68°52′32″W, altitude 834 m, semi-arid/dry weather, 2850 annual average sunlight hour) for different seasons and hours[6)7)] are also presented in Table 1. Given that the measuring of illuminance was carried out during a short period of time, where it is considered constant and using the same area of measuring, it can be assumed that the illuminance is directly proportional to the flux and, therefore, the illuminance ratio E_{dif}/E_{global} is equivalent to the flux ratio ϕ_{dif}/ϕ_{global}. Taking this into account, in Table 1 it can be observed that the different illuminant systems used to test the light bottle bulb have characteristics similar to those obtained in real skies determined in both latitudes of Argentina geography.

Table 1 ϕ_{dif} and ϕ_{global} computed for the three experimental skies and E_{dif} and E_{global} measured in real conditions of Tucumán and Mendoza, together with the respective ratios ϕ_{dif}/ϕ_{global} y E_{dif}/E_{global}.

Clear sky models	ϕ_{dif} [lm]	ϕ_{global} [lm]	ϕ_{dif}/ϕ_{global}
With a direct component at 5°	49	214	0.23
With a direct component at 20°	49	140	0.35
With a direct component at 35°	49	192	0.26
Real skies	E_{dif} [lx]	E_{global} [lx]	E_{dif}/E_{global}
Tucumán (June) 12:00 hs.	11300	60900	0.19
Mendoza (January) 10:00 hs.	11800	55400	0.21
Mendoza (April) 18:00 hs.	4500	10900	0.41

Based on the results of the distribution curves taken from the simulated skies, it is also possible to determine some parameters of comparison between the conditions studied such as the performance η of the bottle bulb, defined as the ratio between the flux value re-emitted by the bottle and the one emitted by the hole of the illuminant system, expressed in the form of percentage, as shown in Eq. (1).

$$\eta = \frac{\phi_{\text{illuminant with bottie}}}{\phi_{\text{illuminant hoie}}} \times 100 \qquad (1)$$

In each test, the lamps were fed with a constant stabilized voltage of 220 V and 50 Hz. Before beginning the measuring process the lamps were stabilized to guarantee the same conditions in each case, following the recommendations employed in the conventional photometric measuring[3)].

4. Results

4.1. Evaluation of the position of the solar bottle bulb

To evaluate the luminous performance of the solar bottle bulb, a photometry was taken of the hole of the simulated cloudy sky for two different positions. In position 1 most of the bottle bulb (23 cm measured from its base) is in the exterior of the box and in position 2 the smaller part of the bottle (some 5 cm measured from the base) is found on the outside. In this way, position 1 received less luminous radiation than position 2 although position 1 had a greater emitting surface (Figure 2).

In Figure 3 both photometries of the bottle are represented together with the simulated cloudy sky (only the hole). The distribution curve obtained for the solar bottle bulb in position 1 produces a more uniform distribution of light which, in the zone of the nadir and close to the same (Gamma=0°) generates lower values of intensity and produces maximums in gamma angles of between 20° and 30° respect of the curve of the simulated sky. As a result of this greater uniformity, the four maximums corresponding to the lamps disappear. From the point of view of performance, the behaviour of the bottle in position 1 was really optimum as it measured practically the same flux as that of the simulated cloudy

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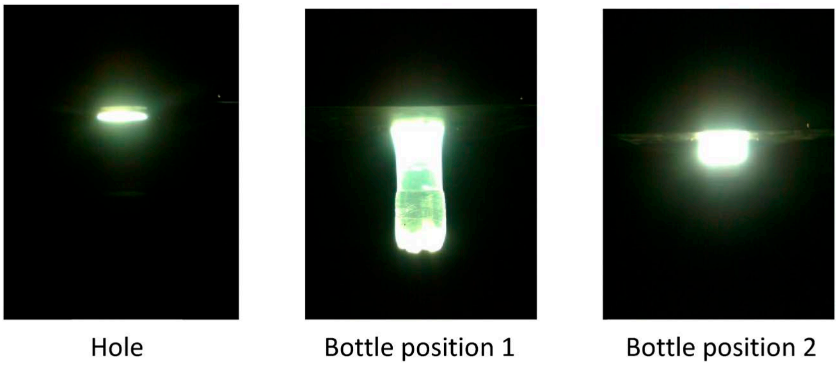

Figure 2 Pictures of the emitting experimental sky. At the left the emitting hole, at the center with the bottle in position 1 and at the right with the bottle in position 2.

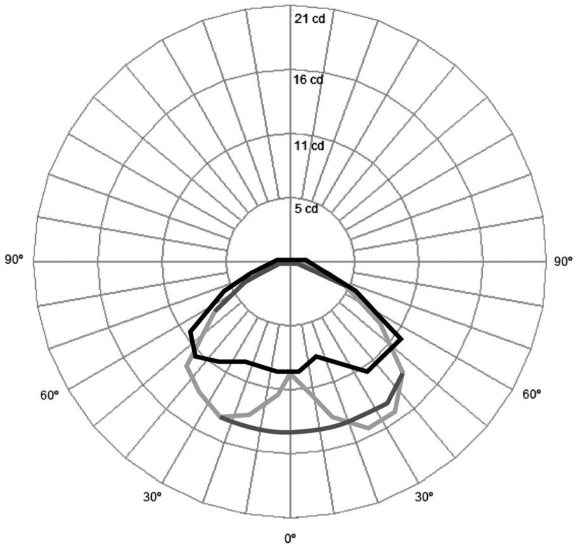

Figure 3 Distribution curves of luminous intensities of the simulated cloudy sky (dark grey line), the experimental sky with the bottle in position 1 (light grey line) and the experimental sky with the bottle in position 2 (black line).

sky: 49 lm. At the same time, the bottle placed in position 2 also produced a more uniform light distribution, with lower values of intensity in the zone of Gamma angles between 0° and 40°, taking the maximums to gamma angles of between 40° and 50° with respect to the curve of the simulated sky. In the same way as in position 1, the four maximums corresponding to the lamps disappeared. This position of the bottle produced a flux of only 44 lm, that is to say, a reduction of 10% with respect to position 1 and to the simulated cloudy sky.

4.2. Evaluation of the effect of reflectance of the roof

In previous tests, we used a box painted matt black on the outside to measure the emission of the irradiated bottle only. As this kind of lighting system is generally used on roofs of galvanized sheet, which usually have a greater reflectance allowing for a reorientation of light, the external surface of the face of the box, where the bottle bulb is placed, was lined with metalized paper to simulate this frequent condition and, in this way, evaluate the effects that it might produce. For this test, we used position 1 of the bottle bulb considering it to be the best of those tested previously. Although the distribution curve was not modified significantly, the emitted flux reached 60 lm, 22% higher than that determined by a dark roof.

Table 2 Efficiency (η) of the bottle for a cloudy experimental sky. Positions 1 and 2 of the bottle were considered and a metal roof with the bottle in position 1.

Condition	Luminous Flux [lm]	η
Hole (only diffuse)	49	—
Bottle (position 1)	49	100%
Bottle (position 2)	44	90%
Bottle (position 1). Metal roof	60	122%

4.3. Evaluation of the solar bottle bulb exposed to a simulated clear sky

We determined the distribution curves using the illuminant system that combine diffuse and direct components with the bottle bulb located in position 1, in order to simulate a clear sky. In the case of the illuminant system with a direct component at 5° (Figure 4a) in a very noticeable zone of maximums, the uniformity in the emission is improved in such a way that the maximum of intensity is reduced from the 6071 cd measured for the hole ($I_{max\ H}$) to 187 cd measured for the bottle ($I_{max\ B}$), which means a ratio of 0.031. The change in the distribution curves once the bottle is fitted is also reflected in the angular position of the maximum, when the gamma angle of 5° passes through the hole at 0° with the bottle bulb. With this type of illuminant the measured flux is reduced in 59% regarding the one

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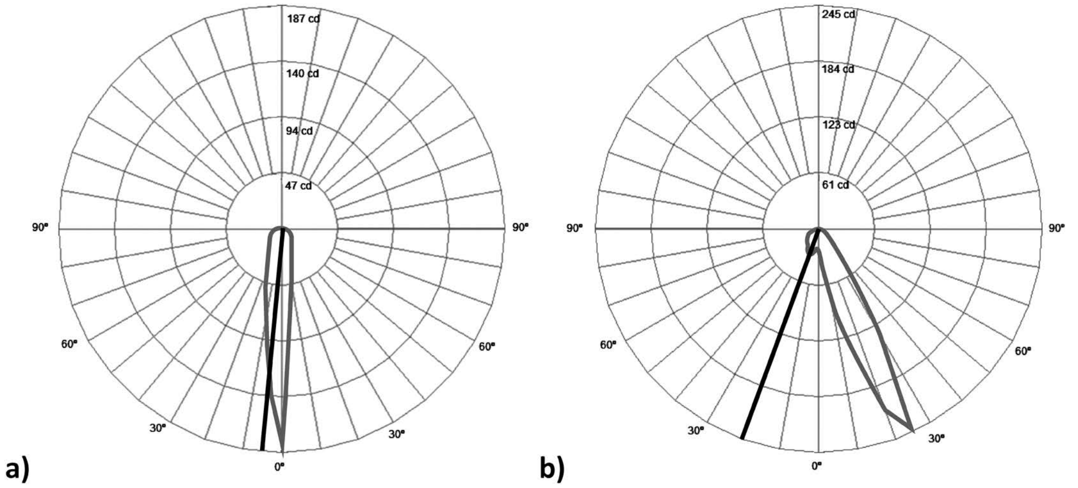

Figure 4 Distribution curves of luminous intensities obtained for the simulated clear sky (grey curves); a) with direct component at 5° (measured at $\gamma=5°$ and C=157.5°), b) with direct component at 20° (measured at $\gamma=20°$ and C=130°). The black line corresponds to the main component of the simulated clear sky (hole) which is out of scale.

provided by the simulated clear sky, going from 214 to 87 lm, which means a performance of 41%.

In the case of the illuminant system with a direct component at 20° (Figure 4b), we also find a very noticeable zone of maximums, although the uniformity in the emission greatly improves so that $I_{max\ H}$=6861 cd and $I_{max\ B}$=245 cd (a ratio of 0.036). The change in the distribution curves when placing the bottle in the hole was also reflected in the angular position of the maximum with the gamma angle of 20° in the hole, moving to 25° with the bottle bulb and the C angle of 130° in the hole to 315° with the bottle, a difference of 185°. We also found a secondary maximum (30 cd) quasi symmetrical (C=130°) and for a gamma angle of 20° giving a relationship of intensities between the principal maximum and the secondary one of 8.2. In this case, the measured flux was reduced by 33% with respect to the one provided by the hole in the simulated clear sky, going from 140 to 94 lm, giving a performance of 67%.

In the case of the illuminant system with a direct component at 35° (Figure 5), although there is still a noticeable zone of maximums, an improvement in the uniformity in the emission results in a reduction from $I_{max\ H}$=6386 cd to $I_{max\ B}$=216 cd (a ratio of 0.034). The change in the distribution curve when placing the bottle in the hole is also reflected in the angular position of the maximum, and results in the gamma angle going from 35° in the hole to 25° with the bottle and the C angle going from 315° in the hole to 320° with the bottle. We also found a secondary maximum quasi symmetrical (C=130°) and for the same gamma angle of the principal, resulting in a relationship of intensities between the principal and secondary maximums of 3.2. With this kind of illuminant the measured flux was reduced by 31% with respect to the one provided by the hole of

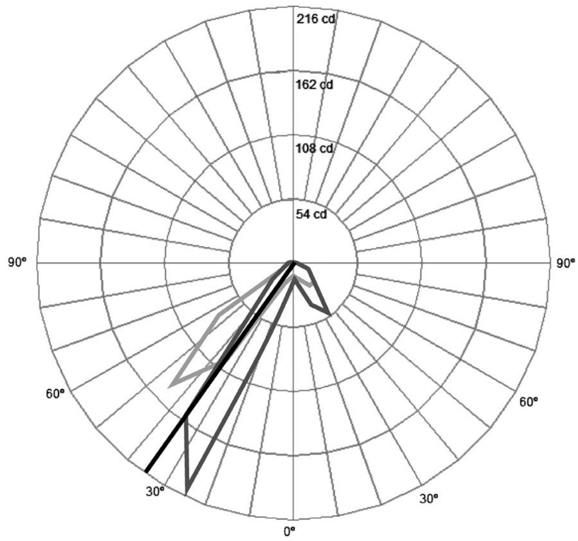

Figure 5 Distribution curves of luminous intensities obtained for the simulated clear sky with direct component at 35°. Light grey line: plane of maximum of the bottle in position 2. Dark grey line: plane of maximum of the bottle in position 1. The black line corresponds to the main component of the simulated clear sky (hole) which is out of scale.

the simulated clear sky, arriving at 133 lm, which implies a performance of 69%. For this angle of the halogen lamp, we also carried out a photometry with the bottle bulb in position 2, finding that starting with the shape of the distribution curve of luminous intensities there was an improvement in the uniformity of the emission in such a way that the maximum of intensity was reduced from $I_{max\ H}$=6386 cd to $I_{max\ B}$=144 cd (a ratio of 0.023) while the angular position of the maximum was also modified, with the gamma angle going from 35° in

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Table 3 Luminous fluxes, performances, maximum intensities, $I_{max\ H}/I_{max\ B}$ ratios and angles of the maximums obtained in the experimental clear sky.

Condition	Luminous Flux [lm]	η	I_{max}	$I_{max\ B}/I_{max\ H}$	γ (I_{max})	C (I_{max})
Hole (diffuse + direct 5°)	214	—	6071	0.031	5°	157.5°
Bottle (position 1)	87	41%	187		0°	All
Hole (diffuse + direct 20°)	140	—	6861	0.036	20°	130°
Bottle (position 1)	94	67%	245		25°	315°
Hole (diffuse + direct 35°)	192	—	6386	—	35°	315°
Bottle (position 1)	133	69%	216	0.034	25°	320°
Bottle (position 2)	100	52%	144	0.023	45°	300°

the hole to 45° with the bottle and angle C from 315° in the hole to 300° with the bottle. A quasi symmetrical secondary maximum was also found (C=115°) and for the same gamma angle of the principal, resulting in a relationship of intensities between the principal and secondary maximums of 5.5. At the same time, the measured flux decreased by approximately 48% with respect to the one measured for the simulated clear sky without the solar bottle bulb, which implies a performance of 52%. Table 3 summarized the luminous fluxes, the performances, maximum intensities and angles obtained, as well as the $I_{max\ B}/I_{max\ H}$ ratio obtained in the three clear sky evaluated.

5. Scale factor

As has been described so far, the experimental arrangement and the method employed allow us to characterise the performance of a solar bottle bulb in controlled lab conditions that emulate sky situations present in real life. In Table 1 we observe that the simulated skies can be designed to obtain relationships between photometric magnitudes of interest (in this case illuminance levels) that coincide with real ones. In this way, we can determine a scale factor (SF) that connects certain values measured in the lab with those that could be present in a real context, as shown in Eq. (2) taking global illuminance as a parameter.

$$SF = \frac{E_{\text{global real sky}}}{E_{\text{global simulated sky}}} \qquad (2)$$

Taking into account the above, if any value of luminous flux of Table 1 is multiplied by the scale factor, it is possible to estimate the flux to be obtained in a real environment. Given that the values of global illuminance vary according to the geographical location, the season of the year, the time of day and other factors, the scale factor that is calculated for the situation of interest would permit an estimation of the flux to be obtained in that environment in a determined condition. For example, based on our measuring, it is possible to estimate that the bottle in position 1 exposed to the simulated clear sky with a direct component at 35° produces an illuminance $E_{\text{global simulated sky}}$=17000 lx and considering that this laboratory condition can be compared to the real sky of the city of Tucuman at midday in winter (Table 1), with a $E_{\text{global real sky}}$=60900 lx and with a similar incidence angle of the sun, we arrive at an SF=3.6. In this way the estimated flux that would be obtained in real conditions would be 480 lm, a flux emitted by a 40 W incandescent lamp with an efficiency of 12 lm/w, and could be even greater if we consider that the bottle is installed on a clear or metal roof. This value is consistent with the comments of the users according to their perception of the lit space[2].

6. Discussion

Photometries of a light bottle were taken considering two kinds of sky: one which, providing diffuse light, simulates a cloudy sky and the other a clear sky, that provides an important direct component with three possible incidence angles combined with a relatively minor diffuse component, in consonance with previous measuring carried out by other authors and with measuring done by us, specifically, for this work. Other measured conditions made it possible to determine the best position to install the bottle bulb on the roof and to evaluate the benefit of the use of a roof of high reflectance. Both when the bottle is illuminated with a simulated cloudy sky and when it is done with a simulated clear sky, we found that the larger the emitting proportion of the bottle (position 1), the greater the quantity of light provided. While, in position 1, the majority of the captured light passes through the emitting body of the bottle, in position 2 a good part of the captured light is scattered in the same zone of the bottle i.e. the area that receives the light. However, in the case of the clear sky, the bigger emitting proportion of the bottle (position 1) reduces $I_{max\ H}/I_{max\ B}$ ratio decreasing the uniformity of distribution. The comparison with the results of Wang (2013) is not direct as, in that work, only the illuminanc-

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es in two points of the interior of the lit space was measured whereas, in this current work, we carried out an evaluation of the luminous intensity distribution. As previously said, the values of efficiency computed in the Tables 2 and 3 could be a little overestimated, and this fact could be verified by obtaining the same luminous flux (49 lm) both in the only-hole condition as in the bottle condition.

Independently of the type of sky, position of the bottle and the characteristics of the roof, the solar bottle distributes the light with a uniformity that is always bigger than the one provided by a simple hole in the roof, a characteristic that makes it suitable to limit the luminance ratio between areas with the known benefits when people conduct a visual task[6]. To understand the different optical phenomena that contribute to this characteristic of the bottle, it is interesting to compare the results obtained with the simulated clear skies with direct components of 20° and 35°. While the case of 20° favours the total internal reflection of the light that is observed in the inversion of the angle γ for I_{max} (going from 130° to 315°), for 35° the refraction appears as the predominant phenomena as the maximum is kept at approximately the same angle γ. At the same time, the presence of the secondary maximums, although notably lower indicate that both the refraction and the total reflection are present in some level in the evaluated conditions. Given that the performances in both cases are similar (67% for 20° and 69% for 35°) it cannot be concluded that the wave guide effect is necessarily more efficient than the refraction effect. However, for the quasi zenithal case of 5°, the efficiency of the system was reduced to 41% and can only be explained by the obstruction that is produced by the bottle cap.

An optical particularity that was found in the photometries when using a simulated clear sky with a direct component at 35° was the angular difference between the peaks of intensity in each position of the bottle (25° position 1 and 45° position 2) that can be explained by analysing how the predominant angles of refraction change in each position of the bottle. In position 1, the majority of the beams affect the top part of the bottle characterised by its convexity. In this surface, the beams that arrive are diverted in different angles according to the point of incidence but they always diminish the angle of the refracted beams with respect to the vertical axis of the bottle. Thus, when leaving the bottle, either by the vertical surface of the bottle or by the surface of the base, the refracted beams will have a smaller angle with respect to the vertical axis. As a result, the emerging beams have a maximum of intensity in a gamma angle lower than the incidence one. At the same time, in position 2, the majority of the beams of the simulated sky fall on the side of the bottle and are diverted in such a way that the beam angle from the vertical axis increases and is then refracted when it leaves the bottle bulb. In the case of beams leaving the counter-lateral part, the angle of incidence is recuperated (refraction in parallel surfaces) and, in the case that it is done through the base of the bottle, the angle will increase again owing to the concavity of this interface. As a result, the maximum of intensity tends to be in a gamma angle larger than that of the angle of incidence. The behaviour of the distribution curve measured for these two positions of the bottle could explain the results found previously[2] where the relationship between the vertical and horizontal illuminances determined for the bottles with two-thirds interior exposure level shows an increment respect to the other levels.

Other optic effects of less importance were found regarding the illumination, such as the deviation of the C angle in the principal maximums of both positions of the bottle with respect to the maximum obtained in the hole. The reason for this effect can be found in the characteristic geometrical shape of the base of the bottle that presents five alternate hills and valleys that can modify that angle. Because in position 2 the contribution of refracted beams in the base is relatively greater than the contribution in position 1, the maximums were found on different C planes. Another optic effect is the lack of coplanarity of the principal and secondary maximums. In this case, the asymmetry of the base of the bottle permits some of the principal beams that pass through the bottle, to confront on their way out a different refractive condition to some of the secondary beams.

The difficulty of designing illumination starting with a source of light that has a dynamic pattern of radiation is well known. However, the contributions of this work allow us to have a better understanding of the solar bottle bulb behaviour both in relation to the light performance and the handling of the angle of the principal beams. In each case, the illumination obtained with a solar bottle bulb will depend on the size, shape and position of the bottle, as well as on the characteristics of the incident light determined by the latitude, the solar availability, the season and the time of the day.

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References

(1) Liter of light around the world. Retrieved 14 August 2014, from http://aliteroflight.org/about-us/
(2) Wang, C., How V. L. and Abdul-Rahman, H.: The performance of solar bottle bulbs at different interior exposure levels, Lighting Research and Technology, published online 3 October (2013). http://lrt.sagepub.com/content/early/2013/10/02/1477153513505584.DOI:10.1177/1477153513505584.
(3) Andersen, M. and de Boer, J.: Goniophotometry and assessment of bidirectional photometric properties of complex fenestration systems, Energy and Buildings, 38, pp. 836–848 (2006).
(4) Maamari, F., Andersen, M., de Boer, J., Carroll, W., Dumortier, D. and Greenup, P.: Experimental validation of simulation methods for bi-directional transmission properties at the daylighting performance level, Energy and Buildings, 38, pp. 878–889 (2006).
(5) Commission Internationale de l'Eclairage, The Photometry and Goniophotometry of Luminaries, CIE Publication 121, Vienna, CIE (1996).
(6) Pattini, A., Mermet. A. and de Rosa, C.: An exterior illuminance predictive model for clear skies in midwestern Argentina, Energy and Buildings, 24, pp. 85–93 (1996).
(7) Pattini, A.: Eficiencia Lumínica de dispositivos de control y difusión de la luz solar aplicables a ventanas de aulas, en la provincia de Mendoza, PhD Thesis, Tucumán: Universidad Nacional de Tucumán (2007).