International Conference on Renewable Energies and Power Quality (ICREPQ'16)
Madrid (Spain), 4th to 6th May, 2016
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.14 May 2016

Propose of a low cost integrating sphere

Freitas, G. P.[1], Santana, M. V. F de[4-5], Neto J. M.[1-3], Spacek, A. D.[1-3], Biléssimo, L. D.[1], Ando Junior, O. H.[2], Pereira, T. C.[1]

[1] Departament of Mechanic and Automation
SATC,Beneficent Association of Santa Catarina Coal Industry
Street PascoalMeller, 73. Criciúma-SC (Brazil)
Phone/Fax number: +55 48 3431-75.50, e-mail: anderson.spacek@satc.edu.br, joao.neto@satc.edu.br, luciano.bilessimo@satc.edu.br,gustavo.freitas@satc.edu.br, tiago.correa@satc.edu.br

[2] Departament of Renewable Energies
UNILA, Federal University of Latin American Integration
Av. SílvioAméricoSasdelli, 1842. Foz do Iguaçu-PR (Brazil)
Phone/Fax number: +55 45 3576-73.07, e-mail: oswaldo.junior@unila.edu.br

[3] School of Engineering
UFRGS, Federal University of Rio Grande do Sul
Av. Osvaldo Aranha, 103. Porto Alegre-RS (Brazil)
Phone/Fax number: +55 51 3308-31.29

[4] Hidroelectric Power Plant
BAESA, Energética Barra Grande S/A
Street Madre Benvenuta, 1168. Florianópolis-SC (Brazil)
Phone/Fax number: +55 48 3331-0000, e-mail: marcus.santana@cscenergia.com.br

[5] Hidroelectric Power Plant
ENERCAN, Campos NovosEnergia S.A.
Street Madre Benvenuta, 1168. Florianópolis-SC (Brazil)
Phone/Fax number: +55 48 3331-0000, e-mail: marcus.santana@cscenergia.com.br

Abstract

This paper proposes the development of a low cost integrating sphere used for measuring flux characteristics and luminous spectrum lamps. The proposal provides the use of alternative materials as well the replacement of measuring high level equipment for more practical and common hardware accessories, providing a reduction in the cost of development. The objective is to minimize the cost of light sources assays, currently with a high cost, for research purposes, educational issues and the opportunity to use this alternative system for validation of new products, light bulbs and/or tubular daylighting devices for lighting indoors.

Keywords

Integrating Sphere, Alternative Materials, Low Cost.

1. Introduction

Adequate lighting is necessary for the performance of tasks effectively [1]. The first step to achieve this objective is to ensure that the lamp or system that will be used as the light source corresponds to the standards proposed by the manufacturer and that meets the needs of the end user.

The measurement of luminous characteristics of a lamp is made with the use of so-called integrating sphere. This device is capable of measuring the flux and light spectrum [2].

The structure of the integrating sphere shown in figure 1, is composed of a spherical shape with at least two openings, one is destined to the light source to be measured, and the other to a measuring device, typically photodetector or spectrometer [2][3].

The interior of the integrating sphere is coated with a white matte paint with capacity to ensure uniform diffusion of the light output inside it. This uniformity is ensured by the high reflectance (about 97%) of the material used, as exemplified in [2]. [3][4].

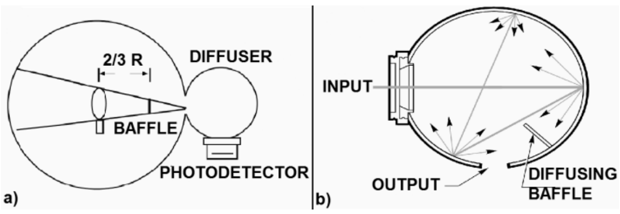

Fig. 1: General representation of an integrating sphere: a) With the light source at the center [5]. b) With side entrance [6].

These presented features are responsible for making that in an extremely fast speed, nanoseconds to tens of nanoseconds, the light is already completely diffused inside the sphere and favorable to a measurement devoid of errors [3].

For not presenting problems about the alignment of the luminous flux and because the quality of the integrating sphere, this measurement becomes standard in laboratories [3], however, this technology still has a high price [7].

It is intended to build and validate, by testing with marketed lighting products and with known technical specifications, an integrating sphere with alternative materials which maintain the product quality and allow the sphere to be useful for the purpose of measurement. The purpose is to search an economically viable way to non-commercial use.

It is also interesting to use this equipment together to unknown light sources and to validation of natural daylighting capture systems through domes and reflective tubes, because the sun does not maintain the same ratio of luminous flux everywhere and all times.

2. Confection methodology

To reproduce the structure of the sphere was used expanded polystyrene, which initially ensures a hollow spherical shape. The Styrofoam ball used in the preparation of this work has dimensions of 900mm in diameter [8].

The internal coating is required to be white, due to reflectance range may vary between 0 and 100%, and theoretically, black is the basis of range, 0%, and the ideal white is able to reflect a value of 100% the incident light [4].

According to Newton, in his "Experimentum Crusis", the white color, although it appears the simplest color, is the mixing of all colors, i.e., a composite form which when transferred by a prism has as a result the separation of all colors of the spectrum due to their different refrangibility [9]. The figure 2 demonstrates the utility of white color:

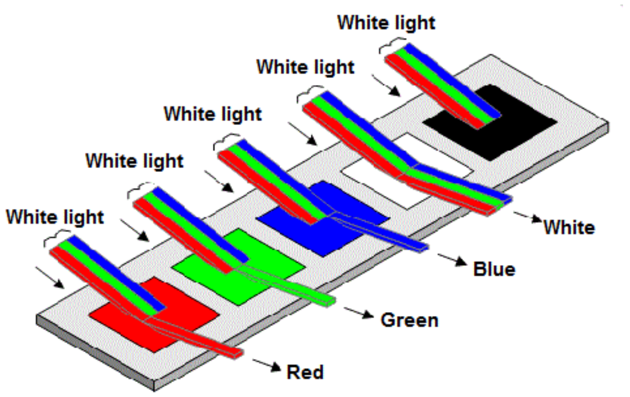

Fig. 2: Reflectance capacity per surface coating color [10].

There are other important aspects that need to be analyzed for the production and reproduction of an integrating sphere, according to [5]:

- The lower the fraction of the area that the apertures of inputs and outputs occupy, is dramatically greater the number of reflections of the incident light, so greater the diameter of the sphere better the measurement, smaller the influence of the measuring equipment and higher the power light source that can test. The area fraction of the openings cannot be longer than 5% of the total surface area of the sphere.
- It is necessary that the light radiation does not fall directly on the measuring sensor to avoid false readings, therefore, it is essential to insert a barrier, called baffle (Figure 1) between the source and the device used that has enough size to generate shadow over the location of measuring as the sphere is open.

With the definition of the material and dimensions that will be used for the elaboration of spherical body of the proposed measurement system and some features mentioned in the previous paragraphs that proved essential to ensure the operation of the integrating sphere, is possible to initialize the process of production.

2.1.Confection of the Prototype

To start the confection process of integrating sphere is necessary to ensure that the Styrofoam sphere internal coating is completely white and free of impurities and imperfections. The expanded polystyrene is already initially white, but not totally smooth and contains "pores" which allow the leakage of light, according to these characteristics seen necessary to apply some white paint.

According to a study done at the University of São Paulo (USP), the ink found and tested that presents higher reflection index is the Acrylic Matte White Paint, with a reflectivity of around 86.6% on a smooth surface. This paint does not have the ability to compromise the physical integrity of Styrofoam sphere, because it is water based.

Because of the size of the Styrofoam ball used in the development of the experiment, was chosen to work with lamps as luminous means, consequently it followed the model shown in Figure 1-a, where the lamp, positioned in the center of the sphere, is located exactly in the same horizontal line of the baffle and the opening where it will perform the measurements using the digital light meter.

The installation of the lamp and the baffle has been properly executed, and the lamp can easily be changed for other tests. To keep the white internal structure of the sphere the baffle was also developed with polystyrene and painted with the same paint. In the side opening is coupled the digital lux meter to perform the luminosity readings.

It is necessary to ensure alignment between the lamp and the measurement port, as well as to be sure that the baffle was positioned correctly and therefore there is no light shining directly into the opening. Therefore, it was necessary to connect the still open set, as shown in Figure 3, the integrating sphere prototype and its components appear functional.

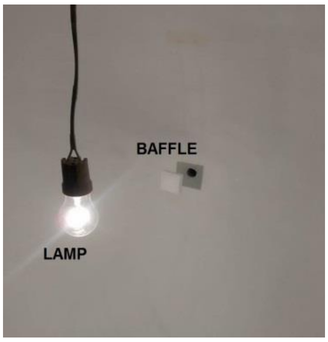

Fig. 3: Shading of the Baffle on the measurement port.

The last step in the production stage is to close the integrating sphere, in order to ensure that no luminosity leakage, consequently there is no influence of the external environment on the results. For this, the ball was sealed with several layers of brown paper and white glue. The end result of this stage of development is illustrated in Figure 4.

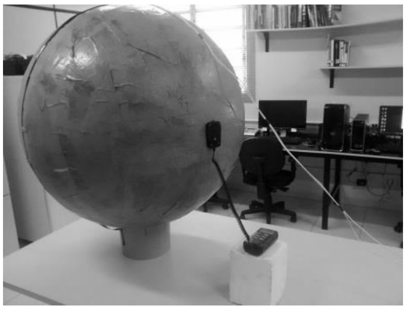

Fig. 4: Integrating sphere prototype in your final stage.

All through the planning process and development of the integrating sphere , it has searched to use common and accessible materials that do not contribute to raise the price of the system when compared to a commercial integrating sphere. The original idea to use only alternative materials was maintained throughout the production process, contributing to the viability of the proposed sphere.

2.2.Alternative system of measurement

The evaluation of the light source is performed using a photodetector and a set of optical fibers, which together have the function of capturing and analyzing the luminous flux [2][11].

An alternative to using with the sphere proposal is to replace commercial equipment for measuring the light spectrum such as the spectrometer or photometer, by a lux meter, which besides practical, is able by means of a silicon photodiode, making measurements of luminance (lux) from a local accurately [12]. In the work described was utilized a Digital Luxmeter from brand ICEL manaus, LD-590 model, which is a handheld luminous intensity meter, 3 1/2 digits and with accuracy of ± 3%and also has a datalogger system with transmission via cable up to 16000 points [13].

Theoretically, as may be accompanied in figure 5, 1 steradian projects an area of 1 square meter when placed at a distance of 1 meter. And, the light source will have a value of 1 lumen when the illuminance produced in the areais 1 lux [4][14].

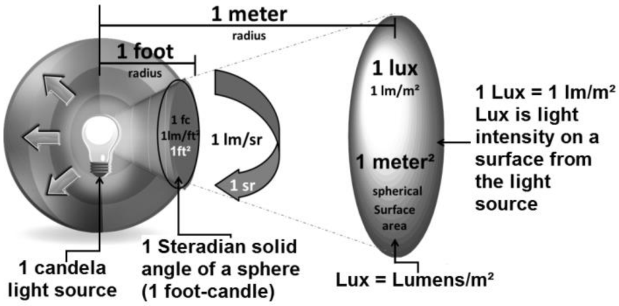

Fig. 5: Relation between lumens and lux [15].

A sphere (figure 6) which presents a radius of 1 meter will have an area of approximately 12.56 m², i.e., will consist of 12.56 steradians, and by definition, each have 1 lux of illuminance, and the source will have a total luminous flux of 4π lumens [14]. So equation 1:

$$\boldsymbol{Lumens(lm) = Lux(lx) \times 4\pi} \quad (1)$$

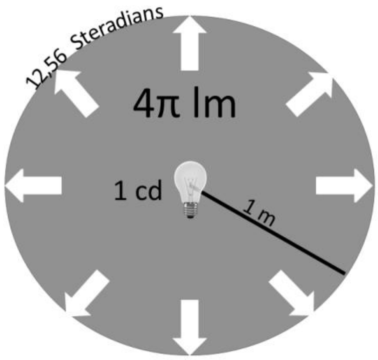

Fig. 6: Representation of a one meter radius sphere.

During the integrating sphere handling procedure must exist some care, one of them concerns the correct fixation of the lux meter does not occur to misleading results, because millimeters of approaching or spacing with the side opening generates as a consequence a misreading of hundreds of lux.

With the intention of reducing the cost of equipment in development, a Styrofoam sphere 90 cm in diameter was used, but this change prevents the application of the proposed theory. In exchange, the luminous flux in lumens provided by different light sources has linearity in relation to the illuminance value in lux measured by the lux meter, enabling the establishment of a mathematical relation between the units.

For the establishment of the relation is performed a comparison between the information obtained and the marketed value provided by the lamp makerr, securing and confirming the accuracy fo this work.

3. Results

Before starting the testing process and determination of the luminous flux from unknown sources, it must have the knowledge of how the prototype of the integrating sphere behaves towards commercial lamps. For this, a series of initial tests are part of the integrating sphere calibration process is performed, and are able to determine the accuracy of the produced device, as well the method to be used for correction of the next reading.

In this work, the calibration occurs manually performed and usual resources where lamps of different powers were used, all energized at 220 volts and tested individually for fifteen minutes, this period has proved necessary for the stabilization of illuminance.

In Table 1 shows the relevant features of each lamp employed in initial tests, as well as the illuminance value measured after the stabilization period. The displayed correction factor is an essential item for uptime guarantee of the prototype, which is generated from the ratio of the value of lumens provided by the maker by the number of lux measured in lux meter. This result is the parameter responsible for setting the measurement of conversion into lux for lumens.

Table 1: Specification of utilized lamps and results [16][17][18][19].

Type	Potency (watt)	Real flux (lumen)	Lux found (lux)	Correction factor (-)
Incandescent	60	715	2080	0,34
Compact fluorescent	10	590	1680	0,35
Compact fluorescent	15	844	2310	0,36
Compact fluorescent	25	1573	4360	0,36

It is apparent that the table correction values remained close, and that the measurement done by the lux meter actually showed up higher or lower according to the technical specifications of the maker.

For lighting sources with unknown technical specifications it can not establish an exclusive correction factor for the lamp, consequently it was necessary to determine a fixed value for the multiplication that fits general needs.

Based on the tests performed and the correction factors and conversion measures established for the worked lamps, an average was adopted for these factors, equivalent to 0.35, in order to be applied for the evaluation of daylighting systems through domes for lighting indoors. In Table 2, is possible to see a comparison between the real luminous flux values of the worked lights and the results from the presuppositions in the measurement and calibration.

Table 2: Comparison between values and accuracy estimation [16][17][18][19].

Type	Potency (watt)	Real flux (lumen)	Flux found (lumen)	Error (%)
Incandescent	60	715	739	+3,35
Compact fluorescent	10	590	597	+1,18
Compact fluorescent	15	844	821	-2,72
Compact fluorescent	25	1573	1549	-1,52

It is possible to observe that the conversion between units through the defined fixed correction factor ensures a very satisfactory approximation to the amount of lumens, assigned by the maker, in which the lamp is capable of emitting. The most perceptible error refers to the incandescent lamp, about 3.35%, however it does not result in a problem, due to the fact that the incandescent light bulb produces 95% of heat and only 5% of light, as a result of this phenomenon it has its luminous flux capacity decreased.

It has been searched to make the alternative sphere has closer precision from the commercial integrating sphere with even lower measurement resources and restricted materials, as a commercial measuring device of this size is able to determine the luminous flux, the wave lengths, the color temperature, the color rendering index, and some other aspects of the light spectrum [2], while the confectioned sphere could only set the luminous flux (lumens).

4. Conclusion

With the development of this study is possible to say that the elaboration of an integrating sphere with alternative materials becomes economically viable and extremely cheaper than a commercial sphere, besides which technically, after performing the calibration process and unit conversion, the measuring equipment confectioned behaves faithfully to the expected results and with relatively little accuracy error.

In addition to using the integrating sphere for testing with common light sources, it is interesting and viable apply it to evaluate daylighting systems, such as the directing of sunlight to indoor environments through domes and highly reflective tubes.

The objective of this paper is to present a quick, cheap and practical way to construct an integrating sphere, which can be applied only to non-commercial purposes, since a lamp to be sold requires other information besides the amount of lumens emitted. The idea is to apply this technology, in an alternative way, mainly in the academic world, as a method of study directed to energies areas, because it exemplifies and demonstrates the method to determining the quality of a lamp.

Acknowledgement

This project is being developed for under BAESA e ENERCAN for program of "Research and Development" regulated by ANEEL (3936-3314/2015). The authors would like thank to the BAESA and ENERCAN for supporting and facilities.

References

[1] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, “NBR ISO/CIE 8995-1: Iluminação de ambientes de trabalho. Parte 1: Interior.” ABNT, Rio de Janeiro, p. 46, 2013.

[2] P. S. Almeida, “Seminário de equipamentos,” Juiz de Fora, 2011.

[3] H. H. Bertan and Y. Iano, “Análise de Desempenho da Esfera Integradora para Calibração de Medidores de

Potência Óptica," *Rev. Científica Periódica - Telecomunicações*, vol. 09, no. 02, pp. 7–12, 2007.
[4] ILLUMINATING ENGINEERING SOCIETY OF NORTH AMERICA (IESNA), *LIGHTING HANDBOOK: Reference&Application*. New York: IESNA, 2000.
[5] Labsphere, "Technical Guide: Integrating Sphere Theory and Applications," 2011. [Online]. Available: http://www.labsphere.com/wp-content/uploads/2015/02/a-guide-to-integrating-sphere-theory-and-applications.pdf. [Accessed: 28-Dec-2015].
[6] Newport, "General Purpose IntegratingSphere." [Online]. Available: http://search.newport.com/?q=*&x2=sku&q2=70672. [Accessed: 26-Oct-2015].
[7] EBay, "Integranting Sphere." [Online]. Available: http://www.ebay.com/sch/i.html?_from=R40&_trksid=p2050601.m570.l1313.TR0.TRC0.H0.Xintegrating+sphere.TRS0&_nkw=integrating+sphere&_sacat=0. [Accessed: 28-Dec-2015].
[8] SÓISOPOR, "Bola oca de isopor." [Online]. Available: //www.soisopor.com.br/?2.6,ocas.html. [Accessed: 28-Dec-2015].
[9] C. C. Silva and R. Martins, "A TEORIA DAS CORES DE NEWTON: UM EXEMPLO DO USO DA HISTÓRIA DA CIÊNCIA EM SALA DE AULA," *Ciência Educ.*, vol. 9, no. 1, pp. 53–65, 2003.
[10] Physics, "Shining white light on different colored paints." [Online]. Available: http://physics.stackexchange.com/questions/72368/why-are-most-metals-gray-silver. [Accessed: 06-Jan-2016].
[11] Gamma Scientific, "Integrating Spheres." [Online]. Available: http://www.gamma-sci.com/wp-content/uploads/2015/04/Integrating-Sphere-Data-Sheet-Gamma-Scientific.pdf. [Accessed: 26-Oct-2015].
[12] Minipa, "LUXÍMETRO DIGITAL MODELO : MLM-1011." [Online]. Available: http://minipa.com.br/Content/img/proposta/MLM-1011-1300-BR.pdf. [Accessed: 26-Oct-2015].
[13] ICEL manaus, "MANUAL DE INSTRUÇÕES DO LUXÍMETRO DIGITAL MODELO LD-590." [Online]. Available: http://www.icel-manaus.com.br/imagens/produtos/LD-590 manual 2007.pdf. [Accessed: 19-Jan-2016].
[14] A. Ryer, *The Light Measurement Handbook*. Peabody: International Light Technologies, 1997.
[15] Photovoltaic Lighting Group, "Lumens, Lux and Watts." [Online]. Available: http://www.solarlightaustralia.com.au/2013/02/01/lumens-lux-and-watts/lumens-lux-watts-08/. [Accessed: 26-Oct-2015].
[16] Taschibra, "Incandescente A60." [Online]. Available: http://www.taschibra.com.br/site/web/pt/produto/incandescente-a60. [Accessed: 19-Jan-2016].
[17] Osram, "Lâmpadas fluorescentes compactas." [Online]. Available: http://www.osram.com.br/media/resource/HIRES/349938/catlogo-geral-2014---lmpadas-fluorescentes-compactas.pdf. [Accessed: 19-Jan-2016].
[18] Avant, "Lâmpada Fluorescente Compacta." [Online]. Available: http://www.avantled.com.br/2013/. [Accessed: 19-Jan-2016].
[19] G-light, "Lâmpada Fluorescente Compacta." [Online]. Available: http://www.glight.com.br/. [Accessed: 19-Jan-2016].