Distribution of Light Intensities of a Solar Bottle Bulb

Luis Maria T. Bo-ot [1]
ltboot@up.edu.ph

Cherry Dara S. Redulla [2]
dsredulla@gmail.com

Abstract

Solar bottle bulbs (SBB) have been proposed as an inexpensive, eco-friendly alternative to electric lighting in dense residential settlements typically found in urban areas. Interestingly, little testing has been done to verify a solar bottle bulb's performance in terms of light quality. Sunlight with which the solar bulbs operate is dependent on local geographical and climatic conditions. This study aims to describe the amount of light output of a solar bottle bulb by plotting and investigating the distribution of light intensities transmitted indoors. This is done by measuring light levels at every one meter for every 15 degree angle from nadir, on two perpendicular planes to produce a polar graph. The polar graph indicates at which points light redistribution is at its highest intensity. Results from the data should provide insight into the effectiveness of the solar bottle bulb in terms of providing the minimum lighting requirements for a given space.

Keywords: Solar Bottle Bulb, distribution, alternative lighting technology, polar graph

I. Introduction

In the Philippines, a study of the population without access to electricity placed the number at about 16 million (Gonzales, 2013). This translates to 2.36 million households as of 2016 (IRENA, 2017). In urban slum areas, dwellings are built too close to one another such that natural lighting using windows is not possible all the time. On the other hand, dwellings in remote areas can be located far from the electricity supply grid. In both cases, the Solar Bottle Bulb (SBB) provides a creative solution to lighting these households. It is constructed from a plastic soda bottle almost full with a water and bleach solution. It is installed upright to fit into a hole in the roof. The SBB works by redistributing exterior light through internal reflection and refraction. SBB's act like skylights by reflecting and amplifying the rays of the sun into a room (Wang, et.al., 2014). In one study, it was observed that the SBB was brighter and shone more luminously compared to a regular bulb (Dixit & Dixit, 2013). Except for Issolio and Buriek (2015), these previous studies were focused on measuring light levels alone, and not the manner which the light is dispersed in a given space. In this paper, the researchers took measurements to compare exterior and interior lighting levels with an SBB installed, and they also commented on the lighting quality in terms of brightness, contrast and uniformity in providing an optimal environment for seeing.

There is still a lack of technical information describing the SBB's performance. Related studies used boxes of cardboard (Maillet, 2012), and of unspecified material (Issolio & Buriek, 2015) as their testing site. The test used an actual structure, but no dimensions were mentioned. A single SBB is said to be able to provide as much as 55 watts (70 lumens) of light (Dixit & Dixit, 2013), however there are no data that describe the shape or form with which the light is spread or distributed into the room. In addition, examining the SBB from the perspective of lighting industry standards will put its use into a more relevant context. In actual practice, the type of light selected is based on its light distribution as well as its luminance.

Knowing the shape of light distribution will suggest how best to utilize the SBB in terms of spacing on the roof, or shape of the bottle used, and how it affects visual comfort. This study thus aims to provide initial information on an SBB's light distribution or spread through the use of polar graphs. The test was performed in a garage with an

[1] Dr. Luis Maria Bo-ot has a Bachelor of Science in Architecture degree from University of the Philippines Diliman, a Master of Science in Physics degree from the Peoples' Friendship University of Russia in Moscow and a Doctor of Philosophy in Physics degree from the National Institute of Physics of UP Diliman. He is currently an Associate Professor in the College of Architecture of UP Diliman and is a practicing Architect.

[2] Cherry Dara Redulla obtained her Bachelor of Science in Architecture degree from University of the Philippines Diliman in 2006. She is active in the profession with projects involving institutional buildings, architectural conservation, and fit-out of condominium units. She has also included teaching and graduate assistantship in her background experience. She is currently doing her thesis for a Master of Architecture degree in UP Diliman.

uninsulated, corrugated roof. Because the test was done in an actual site, data measured were expected to be dependent on the sun and sky conditions at the time of the test due to its geographical location and orientation. Through exposure and experience, it provided the researchers with first-hand information in the interior lighting conditions in human scale as effected by the SBB.

II. Methodology

The researchers measured illuminance levels at every one-meter incremental distance from the light source (SBB) at every 15-degree increments from nadir; and to produce a polar graph of the light distribution of the SBB. A polar graph is a type of photometric data used in the lighting industry to present in graphical form the angular spread of light intensity produced by wide spread lights (Photometry & Optimal Testing, 2016). Distribution refers to a discernible pattern of light spreading outwards from a light source. Empirically this can be observed as a pattern on the floor or any horizontal surface which receives the distributed light.

The research only measured light levels at a certain hour in the afternoon. The time of measurement varied depending on when the sky is clear, because it was found that measuring during overcast conditions yielded extremely low illuminance levels indoors. The test site was chosen to be a 53-square meter garage in Meycauayan, Bulacan for practical reasons. It also had the added advantage of being clear of any vertical surrounding obstructions thus giving a wider angle of exposure to the sun path. A manual method of obtaining illuminance values was devised by plotting points along vertically oriented X and Y planes with their center points coinciding with the SBB installed at the roof. Each plane consists of angular increments of 15 degrees from nadir along which distances of one, two, and three meters from the SBB were plotted. Strings and masking tape were used to identify the measuring points in the planes. Illuminance values are measured using a lux meter.

A. Materials

For Solar Bottle Bulb

The SBB is constructed of very common household materials. For instance, any plastic bottle that is one liter or bigger may be used, as long as it still has its cap. Bleach is a commercially available liquid domestically used for cleaning and removing stains. The sealant, and if necessary, the roof sheet, may be purchased in any neighborhood hardware store. It is important to get the same profile roof sheet as the one existing so that they match, as this facilitates easier installation and caulking (see Figure 1).

In order to simulate a completely dark room ideal for measuring, miscellaneous items such as rags, newspapers, cardboards, mats and blankets were used to cover up gaps and other openings.

For Measurement

The materials used are simple and accessible as shown in Figure 2. The only equipment are the light meters. For the measurement, the following were used:

- Protractor – This was used to manually measure angular distance from the SBB.
- Carpenter's chalk – Chalk was used to mark off on the ground the X and Y axes, as well as the mounting points for the nylon string indicating both angular and linear distances from the SBB.
- Nylon string – To help locate the radial distances from the SBB, string was mounted from a common point immediately below the SBB, and mounted at their respective end points of the angular distances required. Radial distances were then measured from the SBB along the string, at one-meter, two-meter and three-meter distances at which they were taped.
- Duct tape – Any tape will do. But preference for duct tape is due to its wide range of applicability. In this case, it was used to tape off linear distance markers on the nylon strings and seal off any small gaps in the structure.
- Lux meters – Two sets of light meters were used for the study to ensure precision. One lux meter used was the Sekonic® Flashmaster L-358, a digital meter capable of measuring for ambient and flash light; it was set on shutter speed priority mode in accordance with prescribed setting for measuring ambient light. The second unit is a Dr. Meter® LX1010B, with a measuring range of 0-100,000 lux. No setting changes were necessary for this meter.
- Level bar – This was used to ensure that the illuminance recordings were from a horizontal plane, such that the lux meters were placed on top of the level bar.
- Paper and Pens – For documentation and encoding.

B. Field Set-up

Constructing the Solar Bottle Bulb

Remove all wrapping from the bottle's surface. Sand lightly at about a third way down the bottle to ensure adhesion of sealant. Slot the bottle upright through to a custom cut hole in a 300mm x 300mm roof sheet, leaving only a third of its body above the sheet. Apply sealant to the joints above and below the roof sheet. When dry, fill the bottle with filtered water mixed with two capfuls or about 10 milliliters of bleach. Screw cap back in place. In a cut hole in the garage roof, place the sheet with the bottle over the hole, and rivet firmly in place. Apply sealant at edges and at rivets.

Establishing Measurement Planes

On the floor using a square edge, a line directly below the SBB perpendicular to the garage entrance was drawn using a carpenter's chalk to indicate the X-plane (C180 – C0). A perpendicular line was also drawn to be the Y-plane (C90 – C270). All openings and cracks in the structure were sealed to prevent outdoor light from contaminating the data. The SBB was installed on the roof of a garage shown in Figures 3 and 4. A single SBB with dimensions shown in Figure 5 was installed to determine the spread or the distribution the light intensities.

The nylon string was labelled at the one-, two- and three-meter radial distances from the SBB. A hoop was installed on the underside of the bottle to which the labelled string was hitched. This string was then used locate 15-degree angle increments from nadir. Using a level bar and a protractor, the string was aligned at nadir (0°, with string perpendicular to the floor), 15°, 30°, 45°, 60°, 75°, and -15°, -30°, -45°, -60°, -75°. Figures 6 and 7 show the cross and longitudinal sections setup where radial lines represent the nylon strings along which are the points at which to measure light with a lux meter. With the markers indicated on both the string and the floor, the location of the required points for measurement was done by simply aligning the string to the plane, affixing it to the angular marker on the floor, and positioning the lux meter on the distance marker along the string. Figure 8 shows the measurements presented on the floor plan. The negative/positive values for radial distances are drawn on the left and right of the SBB which occupies the center of the plan.

When discussing illuminance with respect to intensity, the Inverse Square Law for light states that the illuminance varies directly with the intensity, and inversely with the square of the distance from the light source to the surface,

$$I = Ed^2 \qquad (1)$$

where E is the illuminance in lux, I is the intensity in candela and d is the distance from point source in square meters.

Figure 1 (clockwise from top left). 1.5L plastic bottle to be filled with filtered water; Epoxy /rubber sealant; Bleach; and Galvanized Iron sheet to match existing roofing.

Figure 2 (clockwise from top left). Protractor; Carpenter's chalk; Nylon string; Duct tape; Lux meters; and Level bar.

Figure 3. Typical installation viewed from interior (left photo) and exterior (right photo).

Figure 4. Photo of testing site (Garage).

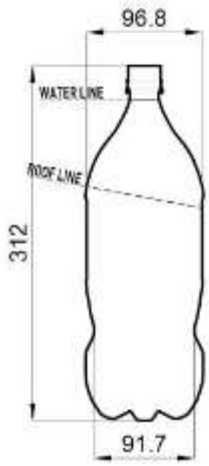

Figure 5. Typical dimensions of 1.5L plastic bottle (in mm).

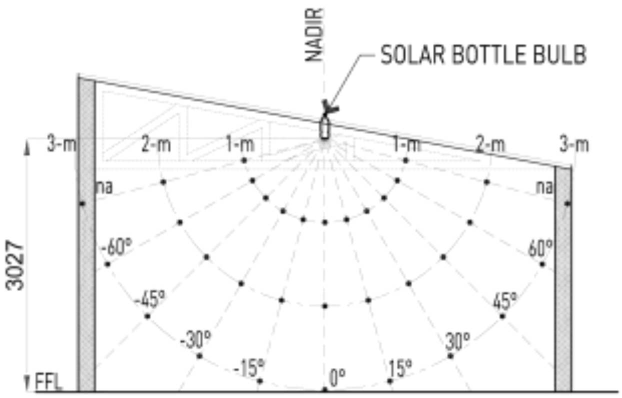

Figure 6. Field set-up along Y-plane (C270-C90).

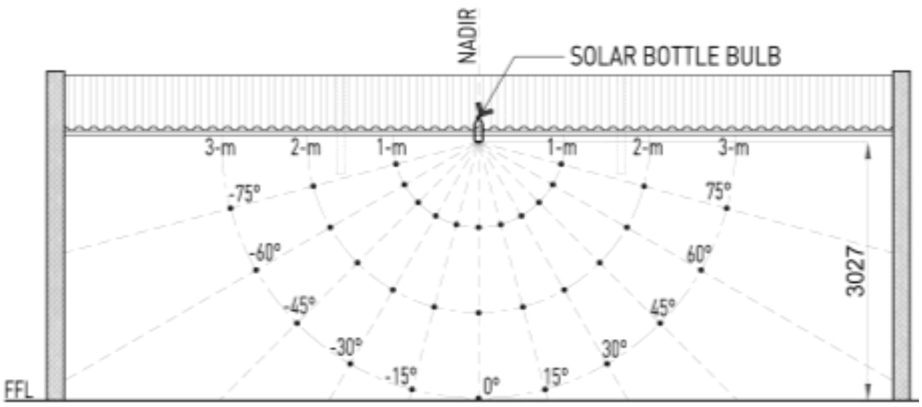

Figure 7. Field set-up along X-plane (C180-C0).

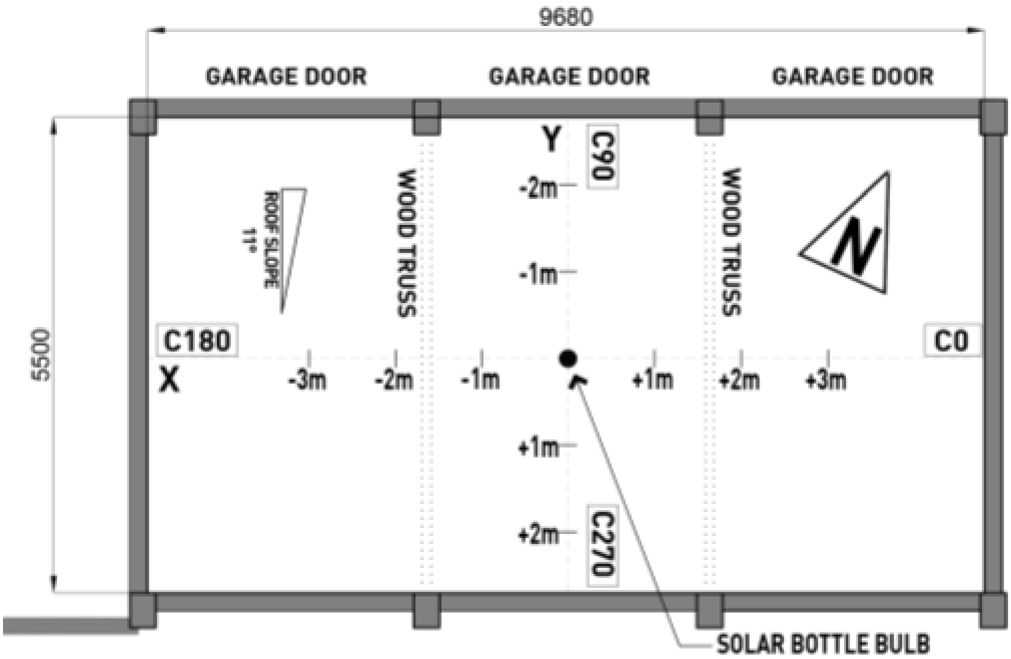

Figure 8. Garage layout and orientation with both X and Y-planes parallel to walls.

C. Data Collection

Measurements were taken for three separate afternoons on April 26, May 13, and May 16, 2015. The outdoor illuminance level was recorded, followed by the illuminance measurement right beneath the SBB. The percentage ratio of these two values is the daylight factor (DF). DF hints at the SBB's efficiency in allowing daylight into the room. This value is taken because the SBB is considered a daylighting technique, as it relies solely on exterior daylight to supply indoor lighting. Light levels were taken at one-, two- and three-meter distances from the light source, at every 15° angle increments from nadir for both planes. For consistency, the lux meter was always oriented facing directly upwards, not facing the SBB, when taking measurements to simulate actual conditions on a typical horizontal working plane. The illuminance values were then converted into candelas to isolate the luminous intensity value by disregarding the area of the surface onto which the light strikes. The luminous intensity was taken using Equation 1.

As an example, in the Y-Plane of Test Day 1, an illuminance of seven lux is recorded at two meters along nadir. Using Equation 1, the intensity is computed to be 28 candelas. These candela values were plotted in a corresponding graph where the concentric arches show increasing intensity the farther they are from the light source, and the radial lines indicating the angular increments. For every angle, the highest intensity was taken and plotted on the graph. The plotted points were linked to one another with a line that starts and ends at zero of both planes. Each plane is illustrated in one graph.

The resulting polar graph should indicate at which areas around the SBB the luminous intensity is at its highest, and therefore brightest to the human eye. It tells the viewer where to expect the most light to be spread. The shape should also indicate the type of distribution of light, whether it is concentrated mostly at one point, or more spread around and below the SBB. AutoCAD® was used to generate the polar graphs.

The location of the site with respect to the solar movement was necessary to provide context to the research. Because this is an actual test, actual sky conditions played a huge part in defining the results. Using an online sun path calculator (SunCalc, 2015), diagrams of the sun's location particular to the three test dates and times were generated as shown in Figures 9, 10 and 11. A floor plan of the garage was overlaid on the sun path images using a photo editing software (Adobe Systems Incorporated, 2007) to provide the site's solar context. The straight orange line indicates sun position at the specified time.

III. Results

The tables in the succeeding pages record the lux reading obtained on the test days. "NA" is supplied in points where the lux meter registered an error in reading, possibly due to light being blocked by roofing members, or reading may not have been possible as the reading location is beyond the given space on site. Prior to installation of SBB, the test site was measured and yielded zero (0). Despite the minimal unwanted light penetrating through the gaps, a reading of zero (0) could be due to the horizontal orientation of the meter.

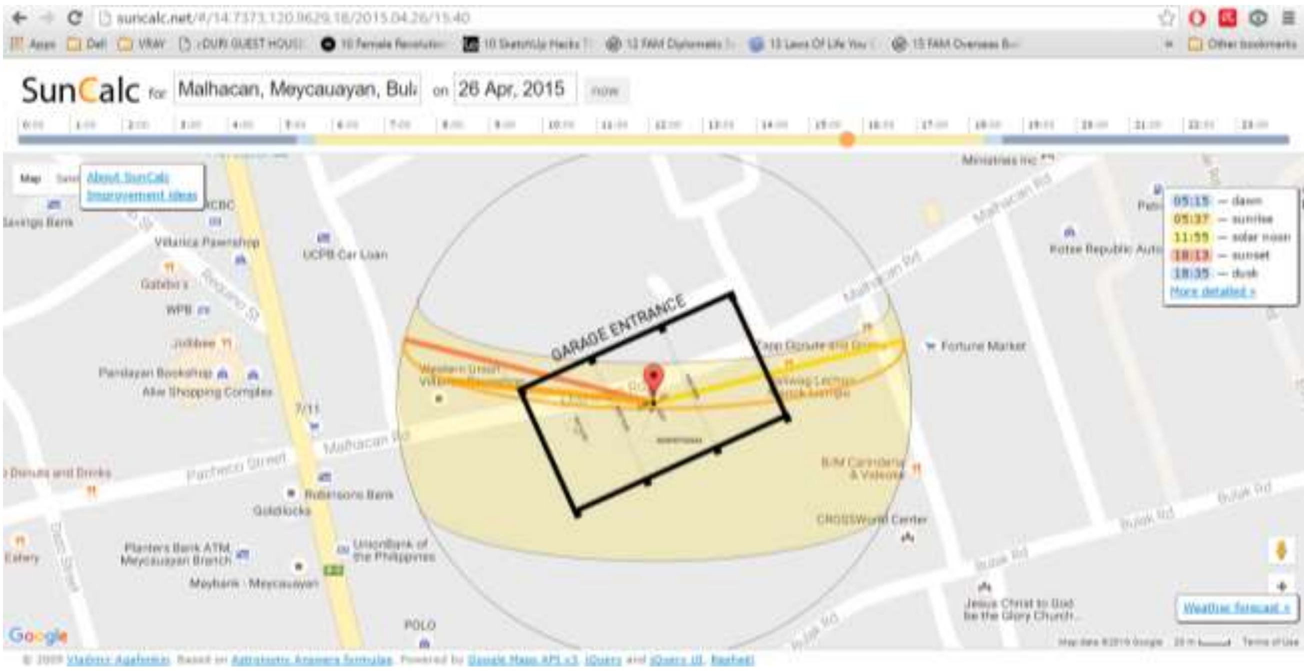

Figure 9. Sun path at test site at 3:45 p.m. on April 26, 2015.

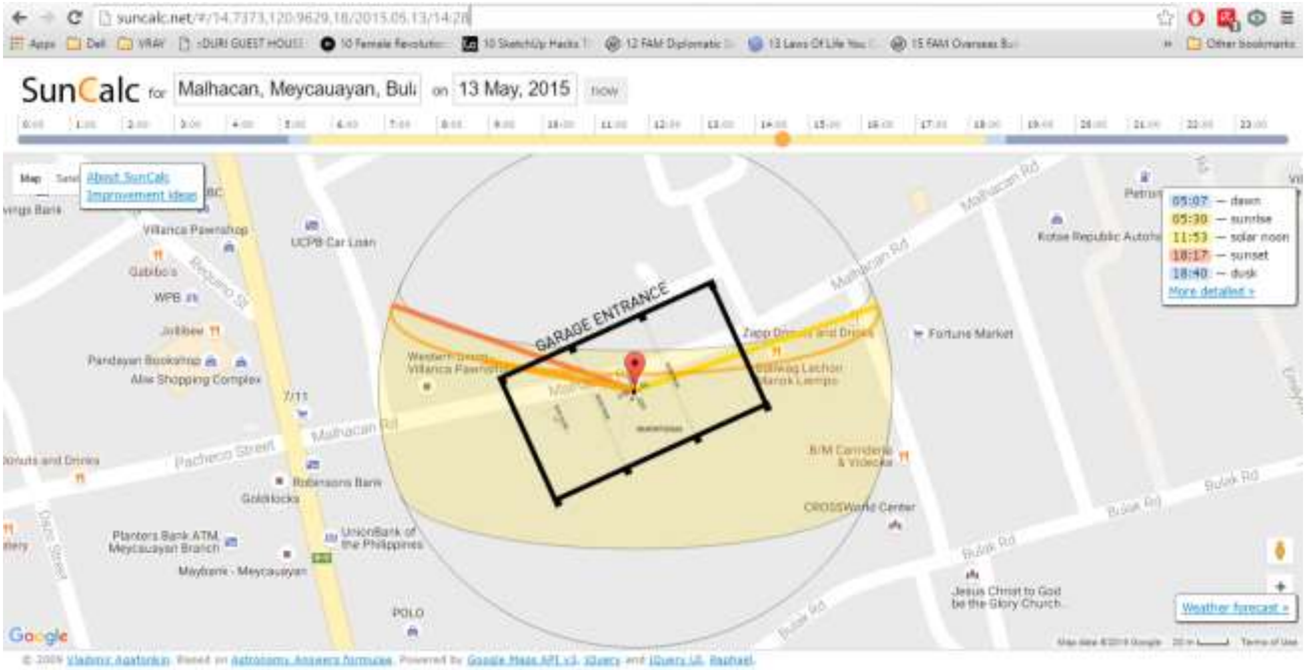

Figure 10. Sun path at test site at 2:30 p.m. on May 13, 2015.

Figure 11. Sun path at test site at 2:30 p.m. on May 16, 2015.

Table 1. Lux levels recorded on Day 1 (April 26, 2015, 3:45p.m.)

ANGLE	APRIL 26, 2015; 3:45p.m. External Light Level : 5,800 lux; Internal Light Level (near SBB) : 70 lux; Daylight Factor: 1.2%											
	X-PLANE						Y-PLANE					
	1-m		2-m		3-m		1-m		2-m		3-m	
	Lux	Candela	Lux	Candela	Lux	Candela	Lux	Candela	Lux	Candela	Lux	Candela
-75	1	1	na	na	na	na	0	0	0	0	0	0
-60	5	5	na	na	na	na	3	3	0	0	0	0
-45	10	10	1	4	na	na	13	13	1	4	0	0
-30	16	16	3	12	na	na	11	11	2	8	0	0
-15	33	33	7	28	na	na	12	12	2	8	1	9
0	31	31	8	32	2	18	35	35	7	28	2	18
15	29	29	6	24	2	18	25	25	6	24	2	18
30	25	25	3	12	1	9	18	18	4	16	1	9
45	11	11	1	4	na	na	15	15	3	12	0	0
60	na	na	na	na	na	na	5	5	na	na	na	na
75	na	na	na	na	na	na	na	na	na	na	na	na

Table 2. Lux levels recorded on Day 2 (May 13, 2015, 2:30p.m.)

ANGLE	MAY 13; 2015, 2:30p.m. External Light Level: 8,180 lux; Internal Light Level (near SBB): 62.4 lux; Daylight Factor: 0.7%											
	X-PLANE						Y-PLANE					
	1-m		2-m		3-m		1-m		2-m		3-m	
	Lux	Candela	Lux	Candela	Lux	Candela	Lux	Candela	Lux	Candela	Lux	Candela
-75	0	0	0	0	na	na	11	11	0	0	na	na
-60	15	15	1	4	0	0	11	11	1	4	0	0
-45	64	64	21	84	8	72	38	38	6	24	3	27
-30	33	33	9	36	3	27	35	35	8	32	2	18
-15	25	25	7	28	2	18	74	74	18	72	7	63
0	30	30	7	28	3	27	30	30	7	28	3	27
15	47	47	12	48	4	36	29	29	8	32	3	27
30	37	37	7	28	3	27	39	39	13	52	5	45
45	27	27	5	20	2	18	52	52	12	48	5	45
60	8	8	1	4	0	0	14	14	1	4	0	0
75	na	na	na	na	na	na	na	na	na	na	na	na

Table 3. Lux levels recorded on Day 3 (May 16, 2015, 2:30p.m.)

ANGLE	MAY 16, 2015; 2:30p.m. External Light Level: 3,600 lux; Internal Light Level (near SBB): 30 lux; Daylight Factor: 0.8%											
	X-PLANE						Y-PLANE					
	1-m		2-m		3-m		1-m		2-m		3-m	
	Lux	Candela	Lux	Candela	Lux	Candela	Lux	Candela	Lux	Candela	Lux	Candela
-75	0	0	0	0	na	na	0	0	1	4	0	0
-60	1	1	0	0	0	0	11	11	1	4	0	0
-45	15	15	3	12	0	0	14	14	2	8	0	0
-30	33	33	3	12	0	0	14	14	2	8	0	0
-15	43	43	7	28	2	18	15	15	3	12	0	0
0	18	18	4	16	1	9	18	18	4	16	1	9
15	11	11	2	8	0	0	45	45	11	44	4	36
30	13	13	2	8	0	0	24	24	7	28	2	18
45	10	10	2	8	0	0	28	28	5	20	1	9
60	2	2	0	0	0	0	6	6	1	4	0	0
75	na	na	na	na	na	na	2	2	0	0	0	0

IV. Analysis and Discussion

The data from the three test days showed a combination of outward and concentrated distribution where there are several high intensity spots corresponding to the SBB's profile at the base. In all but first case, the spread of light on the floor was clearly uneven, with two to three distinguishable areas of concentrated light. The light spread produced requires the observer to be at a location away from nadir to be able to see and perform tasks. The spotted patterns also indicate at the unevenness of light distribution not optimal for effective use and visual comfort.

Looking at the Day 1 polar graphs where the bottle cap was removed, the outline is considerably rounder and smoother than the succeeding test days. Light is most noticeably concentrated at the nadir and decreases abruptly towards the sides. But on the x-plane, the shape is rounder. It is possible that the bottle cap may have an effect in the light spread. The brightest area is approximately below the SBB with an intensity of 30 candelas (see Figure 12).

For Days 2 and 3, though the outlines differ as seen in Figure 12 and Figure 13, it is to be noted that the general trend is a split or a divide between two areas of high illuminance as can be seen in Figure 15. This would suggest either two causes: (1) the bottle cap, or (2) the steep concave curve of the bottle. The brightest areas register at 74 to 84 candelas, on one side of the nadir on both planes.

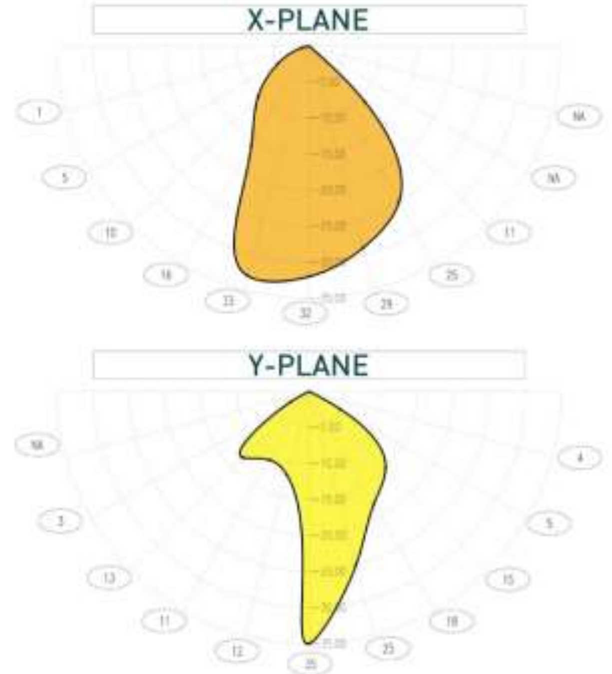

Figure 12. Polar graphs of C180-C0 plane (top) and C270-C90 plane (bottom) on Day 1.

In Figures 13 and 14, though the graphs for the last two test days do not look entirely the same, they have one key similarity – and that is presence of a dark area in the middle. The highest intensity registers at 45 candelas located at -15 degrees from nadir on the Y-plane. At the nadir, the light intensity available is very low.

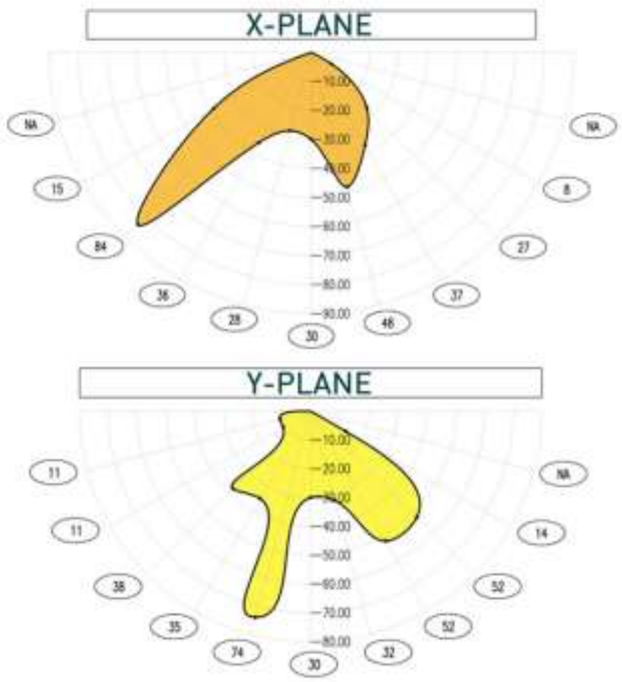

Figure 13. Polar graphs of C180-C0 plane (top) and C270-C90 plane (bottom) on Day 2.

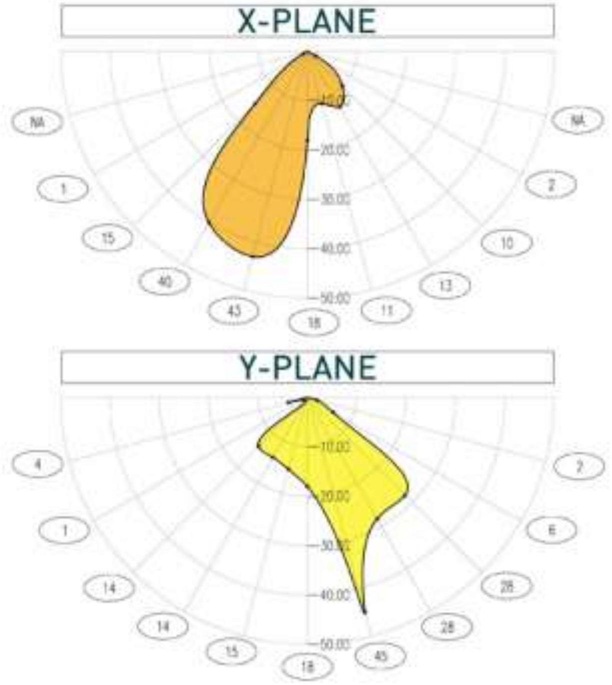

Figure 14. Polar graphs of C180-C0 plane (top) and C270-C90 plane (bottom) on Day 3.

In Figure 16, it is interesting to note that incidentally, reckoned in plan, the direction of sunlight is parallel to the line between the two lit areas in the room. It appears that the SBB performs mostly through directional light, and not diffused, omnidirectional daylight. Had the latter been true, the refracted light should have spread evenly and almost symmetrically on the floor. Figures 17, 18 and 19 show the location of the sun at the time of testing, as well as the combined polar graphs of the light intensities recorded at both X- and Y- planes. There is no apparent predictability in terms of the resulting graph with respect to the sun's location.

With a DF of 1.2 percent as the highest value, the study found that the SBB is not able to utilize the exterior light even for easy tasks, nor does it amplify the sun's rays as was suggested by Maillet (2012). The acceptable DF for easy tasks is at 1.5 percent to 2.5 percent (Grodznik and Kwok, 2015). However, it must be remembered that Maillet did not mention the distance from which the measurements were taken, i.e. they could have been taken very near to the SBB. In fact in our study SBB permits only a miniscule amount of light that one SBB typically would not suffice for a small household, and certainly not for a residential unit with approximate size to the test site. Some small increase in light transmission may be noticed if the roof were lower. DF is also more used in describing an array of lighting fixtures thus there is the option to install multiple units of the SBB as proposed by Maillet (2012), provided the most efficient layout and spacing has already been studied. In this study, the researchers measured specifically the distribution of light intensities for an individual SBB.

Figure 15. Light spread on the floor with two distinct areas of relatively high illuminance.

Figure 16. Light spread on the floor with floor distinct shadows in the middle, or in between the lit areas.

In addition, studies of multiple-bottle configurations and their ideal spacing must consider its impact on the roof structure, if any. The results also differ from those obtained by Issolio and Buriek (2015) due to several factors such as different test conditions. Whereas the Issolio study was done through simulation in a 45-centimeter box painted matte white on the inside, this study was performed in an actual structure.

The lower illuminance and candela values measured in this study can be explained by the larger test area and higher installation height. The erratic pattern on some graphs may have been the result of intermittent cloud cover during testing. The precision of the values in the Issolio study can be attributed to their use of a goniophotometer as a measuring instrument to record the performance of the SBB with respect to different locations of the sun or light source.

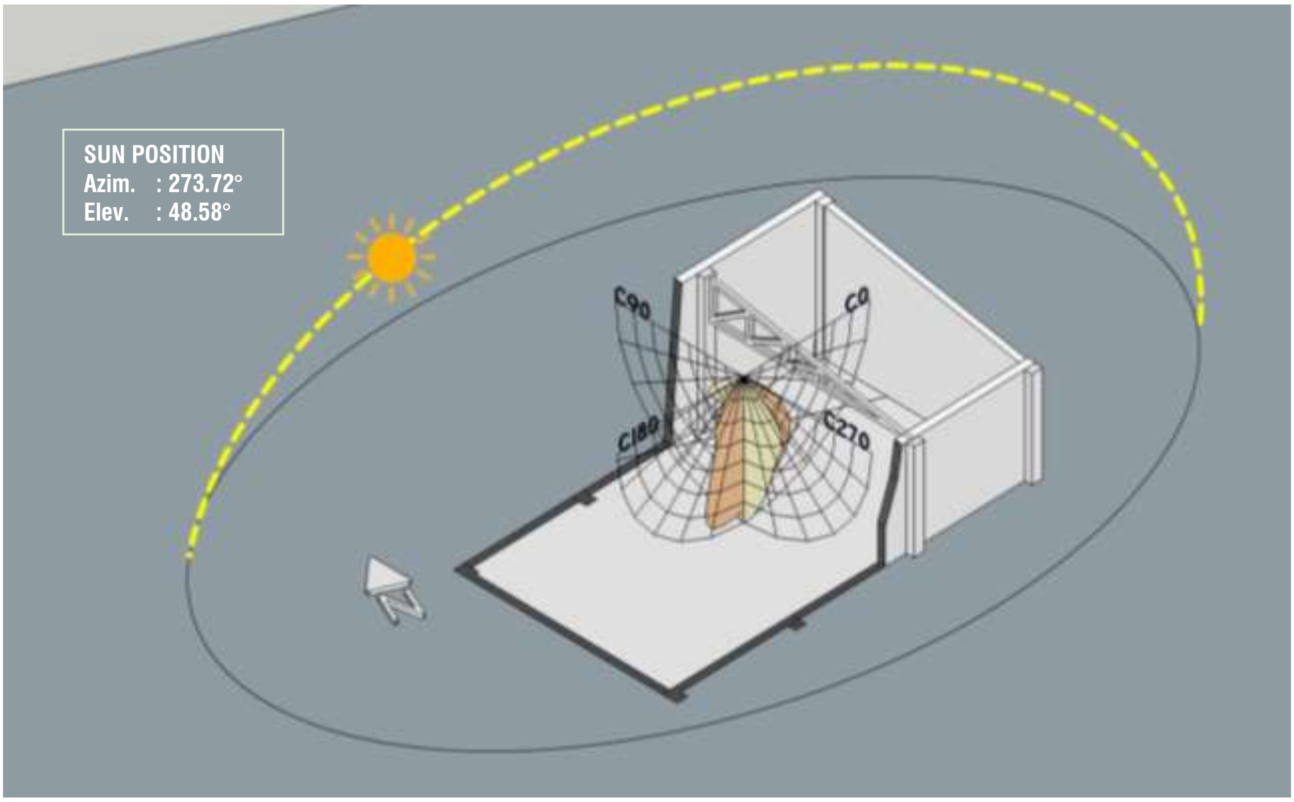

Figure 17. Combined X and Y graphs and sun path on Day 1 (April 26, 2015, 3:45 p.m.).

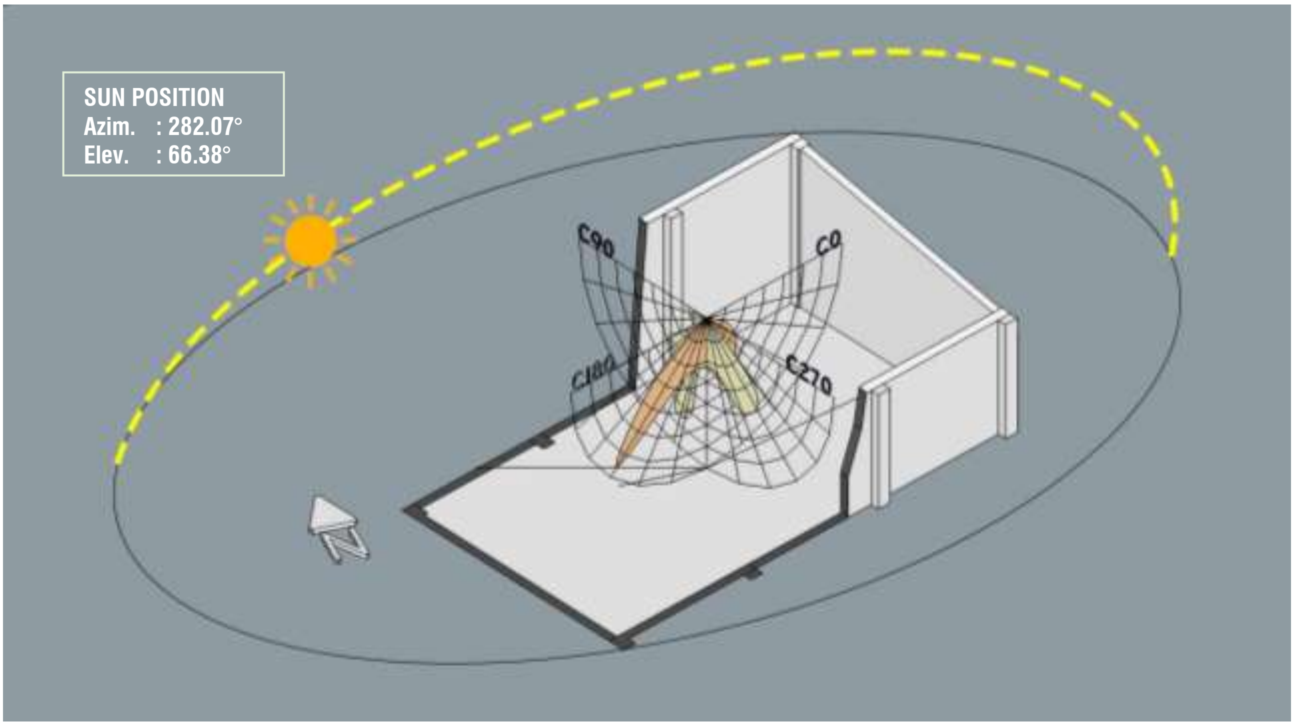

Figure 18. Combined X and Y graphs and sun path on Day 2 (May 13, 2015, 2:30 p.m.).

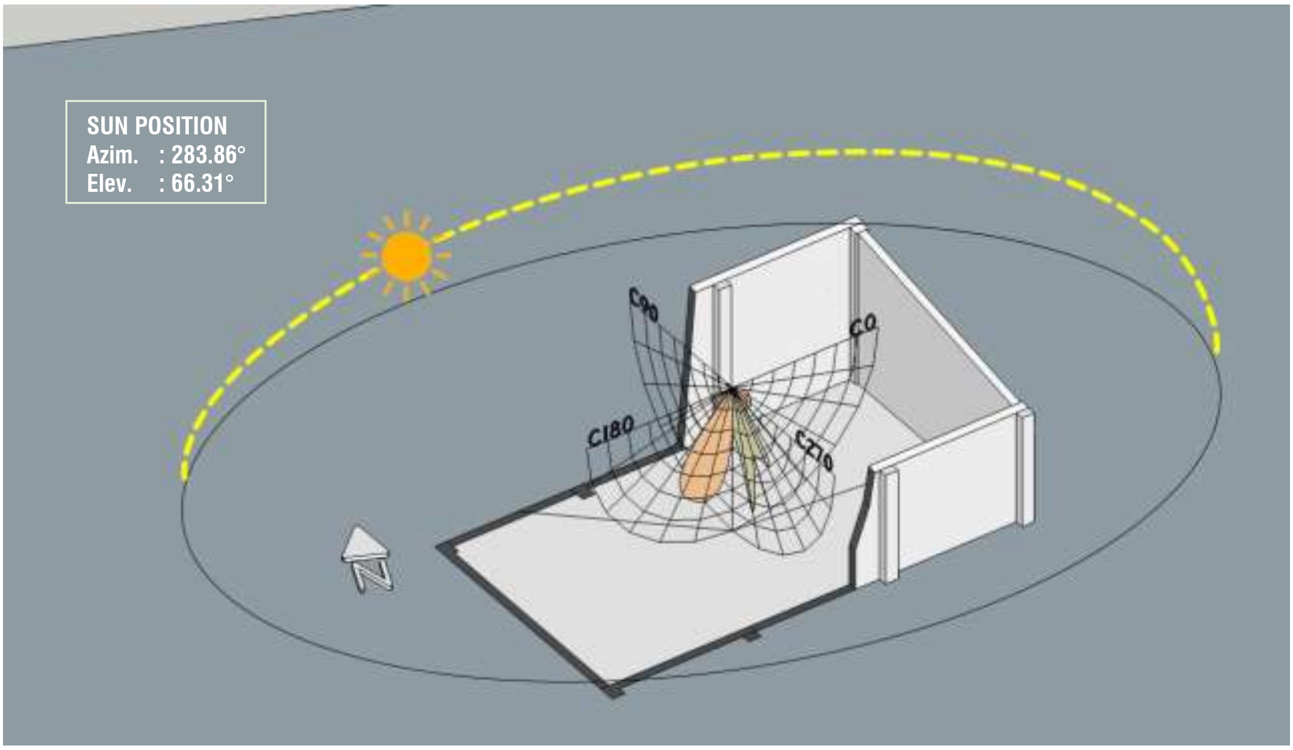

Figure 19. Combined X and Y graphs and sun path on Day 3 (May 16, 2015, 2:30 p.m.).

In this study, the highest illuminance recorded for all three days was 74 lux, a value lower than minimum requirements for comfortable visual environment. As a visual reference, an illuminance of 107 lux is typical of a very dark day; while twilight registers as 10.8 lux as charted by the NOAO (National Optical Astronomy Observatory, n.d.). Where distribution is concerned, the desired omnidirectional pattern for general lighting is not achieved. This does not appear to be a function of the materials used, but rather of the shape of the bottle. Based on the resulting light patterns visible on the floor, it shows that no light is transmitted below the central recess of the SBB's base. This can be attributed to internal reflection, where the inwards curve of the recess reflects light back towards the upper portion of the bottle instead of downwards. The low daylight factors may have resulted from measuring directly below the recess of the bottle, which was done for consistency at the time. The bottle cap affects light distribution the higher the sun's position in the sky, as suggested by stark contrast in intensity levels below nadir between test Day 1 which was done at 3:45 p.m. compared to test Days 2 and 3 which were done at 2:30 p.m.

By using an actual space as the test site, the researchers were able to differentiate this study from others which used boxes. The use of the garage provided human scale to the test and first-hand observation of an SBB's effect to the visual environment indoors. Furthermore, because the study relied on natural lighting as experienced in the Philippines, it provided usable and applicable data when these SBB's are to be applied in the country.

V. Conclusion

The highest intensity was 84 candelas at two-meter and angular distance of 45 degrees. Eighty-four candelas are approximately 40 lumens – a small value compared to 750 lumens (incandescent bulb); 3,000 lumens (Fluorescent Lamp); and 1,000 lumens (Halogen Lamp) which all consume 50 watts of power to produce light.

On Days 2 and 3 when the bottle cap was in place, the graphs show a trend of a defined dim area at the nadir. It appears that the recessed portion of the bottle's base prevents light from being refracted downwards. However, the five protruding domes of the base do not always present with illuminated areas, with the study showing at most two bright areas instead of five. The study has not attempted to understand why this is so, but it is possible that the SBB may favor directional incoming light.

The low illuminance values recorded can be ascribed to the horizontal orientation of the lux meter as an attempt to simulate the work plane. An alternative way of recording would be to orient the lux meter perpendicular to the light's angular distance. Furthermore, preciseness of values may be improved with the use of a goniophotometer, and a higher sensitivity lux meter.

While the SBB is an easily accessible alternative to electric lighting, the quality of light it provides is unpredictable as it is generally dependent on the sun. As the sun moves across the sky throughout the course of the day, so does the refracted light as it enters the room. Because the SBB works by refracting and internally reflecting the incoming sunlight to the interiors, it is apparent that the shape of the bottle itself affects the distribution or spread of light. At the very least, the research shows that the bottle shape spreads light unevenly, thus making it an unreliable bottle shape for this purpose. Tests using differently shaped bottles would provide further insight into this notion. Since SBB's are supposedly to be used by a considerable portion of the urban population, it should possess such characteristics as to be able to provide sufficient and comfortable lighting. By establishing the ideal SBB shape based on its light distribution shape and quantity of light refracted, the design and use of this alternative technology can be made more efficient and capable of competing with conventional lighting. Materials other than bottles may provide better light distribution capabilities. The primary challenge posed in the manual method lay in the execution. As it was necessary to take measurements continuously at both planes per test day in an attempt to keep up with actual sky conditions, it required the researcher to be contained within the sealed garage for the duration of the test. A way to improve this study is to use a goniophotometer which is able to more accurately measure light at the most precise locations or points specified.

A more immediate continuation of this study is to obtain measurements for a number of days covering the different times of the year. However, this study established a workable and comprehensive means of measurement of light intensities and illustrated them clearly. Once a method had been developed, it would be easier to make measurements for the other days of the year. Relatedly, at present, the Massachusetts Institute of Technology is modelling a night light version which uses a small solar panel to power four LED lights for use at night time.

References

Adobe Systems Incorporated. (2007). *Adobe Photoshop CS3 Extended*. [Computer Software].

Dixit, A.M. and Dixit, V.M. (2013). "Brightness of a solar bottle bulb at different times of the day compared to a regular light bulb". *International Journal of Engineering Science & Humanities* 3 (1). Retrieved from Academia: *https://academia.edu/12079412/BRIGHTNESS_OF_A_SOLAR_BOTTLE_BULB_AT_DIFFERENT_TIMES_OF_THE_DAY_COMPARED_TO_A_REGULAR_LIGHT_BULB*

Gonzales, I. (2013, November 25). "16-M Pinoys do not have access to electricity – study". *Philstar Global*. [online]. Retrieved from The Philippine Star: *https://www.philstar.com/business/2013/11/25/1260424/16-m-pinoys-do-not-have-access-electricity-study*.

Grodznik, W. and Kwok, A. (2015). *Mechanical and electrical Equipment for Buildings* 12th ed. Hoboken NJ: Wiley & Sons, Inc.

IRENA (2017). *Accelerating renewable mini-grid deployment: A study on the Philippines*. [online]. Retrieved from *http://www.irena.org*.

Issolio, L. and Buriek, F. (2015, December 25). "Photometric Performance of the Solar Bottle Bulb". *Journal of Light & Visual Environment* 39. Retrieved from *https://www.jstage.jst.go.jp/article/jlve/39/0/39_IEIJ150000567/_pdf*.

Maillet, R. (2012). *Liters of light: engineering a new soda bottle solar light*. Retrieved from The Scientia Review: *www.scientiareview.org/pdfs/226.pdf*.

National Optical Astronomy Observatory (n.d.). *NOAO Education & Public Engagement*. [online]. Retrieved from *https://www.noao.edu/education/QLTkit/ACTIVITY_Documents/Safety/LightLevels_outdoor+indoor.pdf*.

Photometry & Optimal Testing (2016). *Talking photometry: understanding photometric data formats*. Retrieved from: *https://www.photometrictesting.co.uk/File/understanding_photometric_data_files.php*.

SunCalc (2015). *SunCalc*. [Computer Software]. Retrieved from *https://suncalc.net*.

Wang, C., Yusoff, N., Rahman, H., Rahim, F., and How, V. (2014). "Critical view on daylighting through solar bottle bulb". *Building Research Journal* 61 (2). pp.115-128. Retrieved from ResearchGate: *https:www.researchgate.net/publication/273912152_Critical_View_on_Daylighting_Through_Solar_Bottle_Bulb*