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Improved Illumination Indices: Composite Design, Fabrication and Performance Evaluation of the Oziom Reflector

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Abstract

Lighting Assessment Templates for different forms of housing indicate that a lot of energy is expended in providing artificial lighting for tasks which ordinarily would have been sufficiently taken care of by daylighting. In response to this anomaly, steps were taken to harness daylight for extended periods of time through the fabrication of the Oziom Reflector that will, not only help in channeling light to challenged spaces, but also conserve the energy of daylight.

Different test cases of reflected light were taken at different locations for 183 days and measured with the aid of luxmeters conforming to internationally recognized specifications including the BS667:2005 and DW5032-7. Results indicated that the use of the apparatus greatly improved illumination values within DIN5035 standards thus sufficiently lowering energy consumption and usage. Such lowered energy cuts will improve energy utilization and conservation in housing developments.

Keywords: *Illumination, Oziom Reflector, Luxmeter, Daylighting, Lighting Assessment.*

1.0 Introduction

Light is electromagnetic radiation within a certain portion of the electromagnetic spectrum. The word usually refers to ***visible light***, which is visible to the human eye and is responsible for the sense of sight. Visible light is usually defined as having wavelengths in the range of 400–700 nanometres (nm), or 4.00×10^{-7} to 7.00×10^{-7} m. Infrared (with longer wavelengths) and the ultraviolet (with shorter wavelengths) are also parts of this electromagnetic radiation which actually constitute more than 50% of light.

The main source of light on Earth is the Sun. On Earth, sunlight is filtered through Earth's atmosphere, and is obvious as daylight when the Sun is above the horizon. When the direct solar radiation is not blocked by clouds, it is experienced as sunshine, a combination of bright light and radiant heat. When it is blocked by the clouds or reflects off other objects, it is experienced as diffused light. This means that daylight stems mainly from the visible part of sunlight whether as sunshine (direct radiation) or diffused light (indirect radiation).

The brightness of both of these sources of daylight is quite high, and reaches 5,000–20,000 lux for indirect and 100,000 lux for direct radiation. Such high lux indices can be quite injurious to health especially when they are not adequately controlled.

Propagation of light refers to the manner in which an electromagnetic wave such as light transfers its energy from one point to another. Three main processes generally occur when light passes between boundaries from one medium to another: Transmission, Refraction and Reflection. Reflection is when light bounces off an object. If the surface is smooth and shiny, like glass, water or polished metal, the light will reflect at the same angle as it hit the surface. *This is called specular reflection*. Reflection, being the focus of this study, is a veritable way of redirecting daylight through the use of reflective and phosphorescence materials (Schielke, 2014).

Before the electric light was invented, and for a good while after that too, designing buildings so that daylight could enter interior spaces was a necessity.

The problem is the incredible amount of energy in sunlight. On a clear day, the sun provides 0.00012607801366559297 to 0.00015759751708 watts per square meter (8,000 to 10,000 foot-candles of light). David Kozlowski explained that "light passing through glass provides 0.0000787987585409956 2W/m^2 (5,000 foot-candles) on a clear day and 0.000015759751708 W/m^2 (1,000 foot-candles) on a cloudy day" (Kozlowski, 2006).

Most people need a mere 0.00000055159130978693 W/m^2 (35 foot-candles) to read while the rest goes unharnessed (Converter.Eu, 2019).

Compounding the problem is sunlight which has as much heat as visible light (Kittler, Kocifaj, Miroslav, & Darula, Stanislav, 2012).

A good daylighting design can save up to 75 percent of the energy used for electric lighting in a building. The amount of daylight available, the occupancy pattern, and the control strategy can all affect energy savings (Cunningham, Paul Zaferiou, & Kera Lagios, 2014). In addition, because significant daylight is often available during utility peak demand hours, a good daylighting design can reduce demand charges. Electric lights, especially incandescent lighting points, also generate significant heat in a building and by turning off or dimming the lights when not needed, 10 to 20 percent of the energy used to cool a building can be saved. Using daylight correctly takes a multidisciplinary approach to design and an understanding of the strategies and technologies available to control and redirect sunlight (Lukš & Vlasta Perinová, 2009).

In the design process, there are various challenges which need to be taken care of to optimize the use of such spaces. These challenges could come in form of narrow tunnels as lobbies, poorly-lit gangways, 'fall-out' spaces that simply can't be avoided, dark atriums etc. Other challenges can be brought about by orientation, proximity of adjoining facilities that tend to create annoying shadow zones and location of the building fabric itself (Michael & Uzoezi Johnson., 2019).

Location has everything to do with access to daylight. An urban building may be shaded during part of the day, which will affect, not rule out, a daylighting strategy. In all, it is evident that there are still daylighting challenges which need to be solved in order to efficiently manage energy utilization and usage of our building envelopes.

This lends credence to the major thrust of this paper which is to bring to limelight an additional strategy adopted to improve daylighting techniques while harnessing the energy of daylight to be used at night time.

1.1 The Apparatus

The apparatus makes use of a rotational operational mechanism which enables a pair of steel flanges to reflect light into internal spaces through basic laws of light propagation. These flanges are enmeshed with phosphorescent materials like strontium aluminate laced with cobalt aluminate strips. Strontium aluminate (SRA, SrAl, $SrAl_2O_4$) is a solid odourless, non-flammable, pale yellow, monoclinic crystalline powder, heavier than water. It is chemically and biologically inert. When activated with a suitable dopant (e.g. europium, then it is labelled $SrAl_2O_4$:Eu), it acts as a photo-luminescent phosphor with long persistence of phosphorescence while the cobalt aluminate improves reflective properties of the apparatus. Strontium aluminate phosphors produce green and aqua glows, where green gives the highest brightness and aqua the longest glow time. The excitation wavelengths for strontium aluminate range from 200 to 450 nm. The wavelength for its green formulation is 520 nm, its blue-green version emits at 505 nm, and the blue one emits at 490 nm (Sharma, 2014).

The enmeshed steel flanges, which come in a pair, are fixed to a wooden shaft by nail fasteners thus making for a more rigid framework that is connected to crank spindle. These flanges are aligned to intersect at an obtuse angle of 102° to both trap and reflect light into the interior. The crank spindle allows the flanges to be rotated both clockwise and anticlockwise in response to the sun's azimuth. This also allows the apparatus to be adjusted to control glare and improve reflection of light to walls and ceilings. The whole apparatus rests on a steel housing which is fixed to sill positions of windows and other fenestration openings where daylight *illuminance* needs to be improved. The hangars allow the apparatus to be nailed to the wall and be fully secured to avoid damage.

Other components used include spindle cranks for adjusting steel flanges and steel flaps for securing the flanges to the wooden shaft.

2.0 Measurements

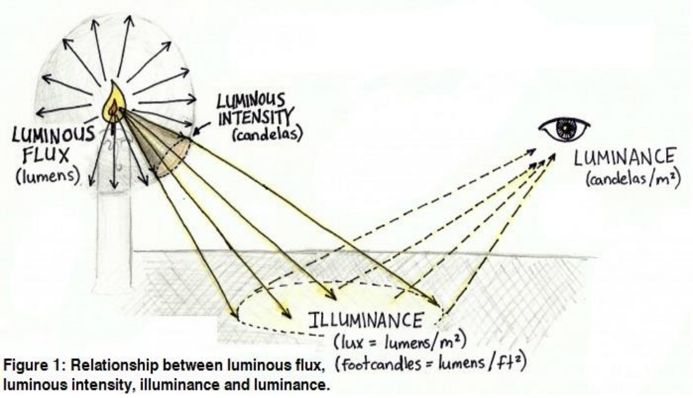


Figure 1: Relationship between luminous flux, luminous intensity, illuminance and luminance.

*Source: Measuring Light Levels.*https://sustainabilityworkshop.autodesk.com/BUILDINGS/MEASURING-LIGHT-LEVELS *downloaded on 2nd of May 2017 at exactly 3:22pm.*

The measurement and perception of light can be an in-depth topic, and effectively analyzing daylight requires being precise with the terms and metrics used. The "brightness" of light can mean different things: for example, the amount of light coming from a light source is luminous flux (lumens), the amount of light falling on a surface is illuminance (lux), and the amount of light reflected off a surface is luminance (cd/m^2). "These quantities are different because the farther a surface is from a light source the less light that falls on the surface, and the darker a surface is, the less incident light it reflects" (Tregenza & David Loe, 2014). This is because light follows the inverse-square law. For example, a point source like a candle that causes an illuminance of 1 lux on an object one meter away would cause an illumination of 1/4 lux on the same object two meters away, or 1/9 lux on the object when it is 3 meters away (Giangrandi, 2010).

The amount of light being given off by a particular source, in all directions, is called **luminous flux** (or "luminous power") and is a measure of the total perceived power of light. It is measured in lumens. For example, a 60W incandescent bulb is about 850 lumens (Standard, 2017).

The amount of light that travels in certain directions from the source is called the "**luminous intensity**" and is measured in ***candelas***. A candle emits about one candela in all directions (this candle would emit a total of 12.6 lumens). ***Luminance*** is the light reflected off surfaces and measured in candelas per square meter (cd/m2), or Nits (in imperial units). Luminance is what we perceive when looking at a scene, or when using a camera (Hiscocks, 2014).

The amount of light falling on a surface is ***"illuminance"***, and is measured in ***lux*** (metric unit = lumen/m^2) or foot-candles (English unit = lumen/ft^2). 1 foot-candle equals 10.8 lux. The design of the ***Oziom Reflector*** revolves around this measurement for optimizing daylighting because building regulations and standards use illuminance to specify the minimum light levels for specific tasks, environments and spaces (Chraibi, Lisan Crommentuijn, Evert van Loenen , & Alexander Rosemann, 2017).

Table 1: Illuminance levels results obtained for different tasks and spaces.

Standard Maintained Illuminance (lux)	Foot-candles	Characteristics of Activity	Representative Activity
50	5	**Interiors rarely used for visual tasks** *(no perception of detail)*	Cable tunnels, night-time sidewalk, parking lots
127 - 150	10-15	**Interiors with minimal demand for visual acuity** *(limited perception of detail)*	Corridors, changing rooms, loading bay
210	20	**Interiors with low demand for visual acuity** *(some perception of detail)*	Foyers and entrances, dining rooms, warehouses, restrooms
305	30	**Interior with some demand for visual acuity** *(frequently occupied spaces)*	Libraries, sports and assembly halls, teaching spaces, lecture theatres
511	50	**Interior with moderate demand for visual acuity** *(some low contrast, color judgment tasks)*	Computer work, reading & writing, general offices, retail shops, kitchens
750	75	**Interior with demand for good visual acuity** *(good color judgment, inviting interior)*	Drawing offices, chain stores, general electronics work
1000	100	**Interior with demand for superior visual acuity** *(accurate color judgment & low contrast)*	Detailed electronics assembly, drafting, cabinet making, supermarkets
1500 -2000+	150-200+	**Interior with demand for maximum visual acuity** *(low contrast, optical aids & local lighting will be of advantage)*	Hand tailoring, precision assembly, detailed drafting, assembly of minute mechanisms

Source: Recommended Light Levels (Illuminance) for Outdoor and Indoor Venues. https://www.noao.edu/education/QLTkit/ACTIVITY_Documents/Safety/LightLevels_outdoor+indoor.pdf

For all intents and purposes, the handheld ***LS-100 luminance meter*** which offers excellence and categorization in the upper levels of the DIN quality class B was used for all readings. This meter is powered by a 9-volt battery making this compact, lightweight luminance meter ideal for any location.

3.0 Materials and Methods

The materials selected for the fabrication of the ***Oziom Reflector*** are those that serve the desired objectives the apparatus is meant to achieve at a minimum possible cost. The following factors were considered in the selection of materials. They include:

1. Availability of the materials/local content
2. Cost
3. Sustainability of materials for the working condition
4. Physical properties of the materials
    - *Weight*
    - *Corrosion resistance*
    - *Thermal expansion*
5. Mechanical properties of the materials

- Strength
- Ductility
- Weldability

All these factors informed the selection of components that make up the ***Oziom Reflector***.

3.1 Steel flanges

The steel flanges were prepared in a local foundry. They are the main platform on which the phosphorescent materials are placed. These steel flanges are two in number. The top flange and the bottom flange. The top flange is 350mm wide while the bottom flange is 300mm wide. Both flanges are 7mm thick and are continuous in formation with an 85mm Ø cylindrical barrel separating them. The steel flanges are aligned in an obtuse formation. The top flange and the bottom flange are separated at an angle of 102°. This means that if the bottom flange is parallel to the horizontal, the top flange will be 12° from the perpendicular. This design is made to reflect as much sunlight and daylight as possible when the sun's azimuth is in the 2nd trimester.

3.2 The shaft

The shaft is a wooden cylinder of 1,200mm (design length) length. The wooden shaft has a Ø of 70mm. it can be made from any class of hardwood varieties especially of the '*obeche'* specie to improve local content. The wooden shaft was made in the wood workshop and planned to precision.

3.3 Support housing

The support housing is made of steel veneer welded to form leverage and carriage to the spindle bar. The support housing is 100mm high and designed to allow maximum rotation of both the top and

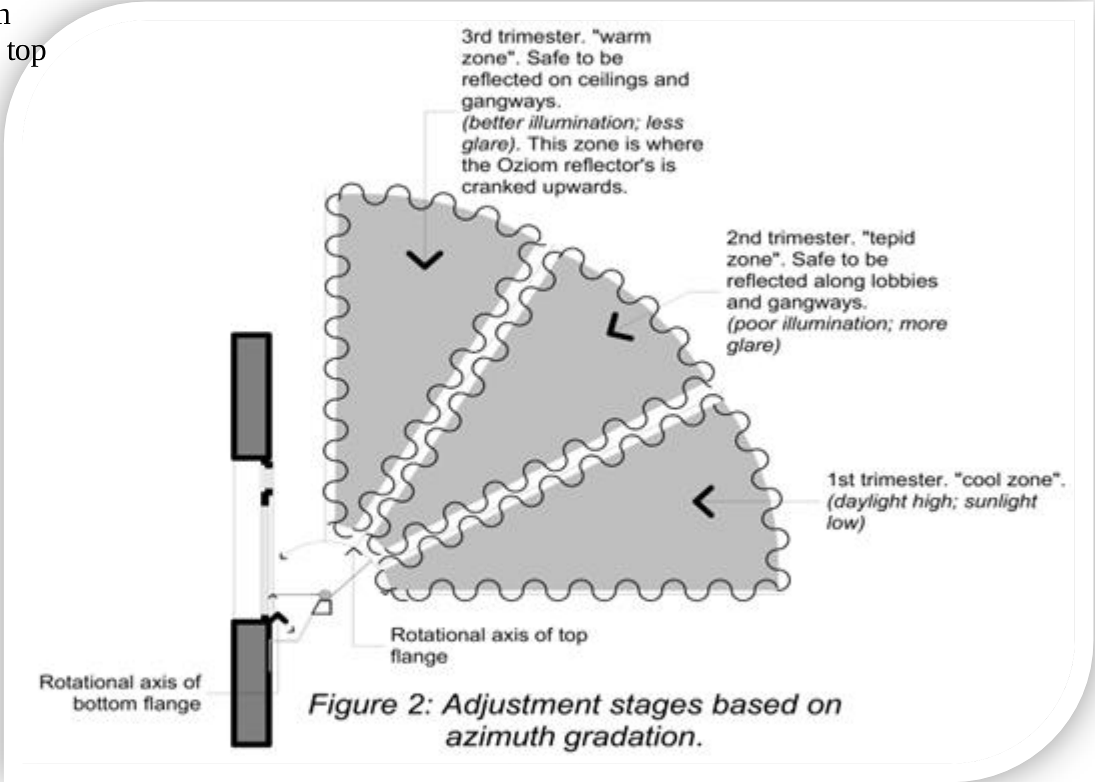


Figure 2: Adjustment stages based on azimuth gradation.

Source: Researcher's Field study and fabrication notes compiled on 22nd of June 2017 at exactly 3:38pm.

bottom flanges.

3.4 Crank box

The crank box houses the clockwork gear that aids in the rotation of the flanges. At any position of choice, the crank box is latched into position with a safety lock. The crank box is maintained by lubrication of the clockwork gear for optimal performance.

3.5 Spindles

The spindle and spindle bar aid in turning the wooden shaft. While the spindle is used to adjust the shaft manually, the spindle bar runs through the wooden shaft to the 2nd spindle at the other end. Invariably, there are two spindles that aid rotation of the wooden shaft.

3.6 Steel hangers

The steel hangers are 5mm thick steel bars formed to support the apparatus whilst in operation. Both steel hangers can be positioned and nailed to the wall for maximum efficiency.

3.7 Strontium and cobalt aluminate substrates

Ordinarily, strontium is not radioactive, nor is it toxic. Strontium aluminate is a photo luminescent phosphorous material; it absorbs photons (electromagnetic radiation) & ultraviolet rays to charge. It does not require direct or indirect sunlight to charge. The raw materials to be used for the chemical synthesis of light-absorbing and light storing strontium aluminate- and/or strontium-magnesium disilicate phosphors are non-toxic, highly purified standard chemicals as strontium carbonate, alumina, silica, europium oxide und dysprosium oxide, boron oxide. These raw materials form the phosphor crystals after a preceding mixing procedure, followed by a high temperature solid state synthesis reaction at about 1300 -1400 °C under reducing atmosphere over a period of 3-5 hours.

The new long lasting strontium aluminate phosphors are harmless as defined by the Laws of Chemical Substances. They do not contain any kind of radioactive additives or contaminations. Highly-reflective cobalt aluminate strips are used as a grid pattern on the strontium aluminate substrate. Aluminates are compounds with a negatively-charged alumina ion and a metallic oxide with various industrial applications such as water treatment and ceramics manufacturing. While the strontium aluminate substrate stores sunlight, the cobalt aluminate reflects subdued light into the interiors (Addington & Daniel L. Schodek, 2005).

3.8 Steel clips

The steel clips secure the wooden shaft to the steel flanges. Contact between the steel clips and the wooden shaft is secured with 2 inch nails while contact between the steel flanges and the steel clips is secured with arc welding.

4.0 Design Analysis

1. Determination of light path through two surfaces.

The law of reflection states that the incident ray, the reflected ray, and the normal to the surface all lie in the *same plane*. Both angles (*i* & *r*) are measured with respect to the normal to the surface. Now assuming there are 2 surfaces, we have to determine the most efficient angle of incidence (to maximise daylight from the second trimester) and reflection (to prevent glare and send the subdued daylight to the upper fringes of the internal space).

Θi *(on 1st flange)* $= \leq 45^{\circ}$. This is maximizing 2nd trimester of the sun's azimuth (Katz, 2002).

Ɵr (on 2nd flange) = ≥ 57°. This is describing the effective angular deflection of a brilliant source of light from visual field (Ryer, 1997).
<e = 90° – 45° = 45° (< at rt <); <d = 90° – 57° = 33° (<at rt <). Therefore, <f = 180° – (<e + <d) = 180° – (45° + 33°) = {sum of <s in a Δ) = 102°.

2.

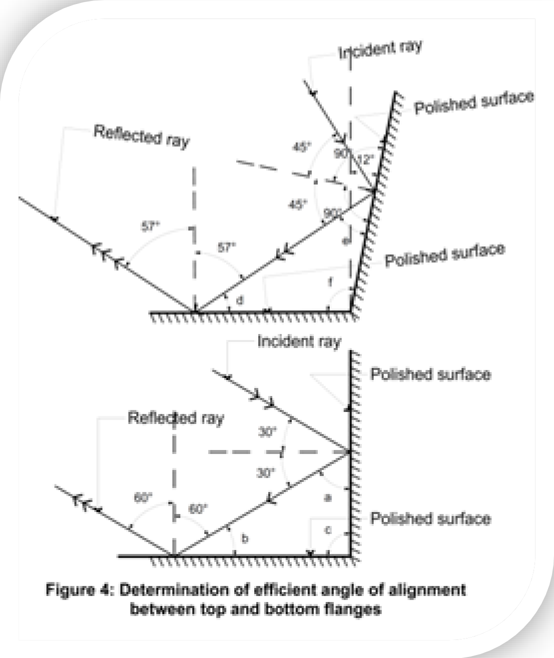


Figure 3: Determination of efficient angle of alignment between top and bottom flanges

Source: Researcher's design and fabrication notes compiled on 30th of June 2017 at exactly 4:28am.

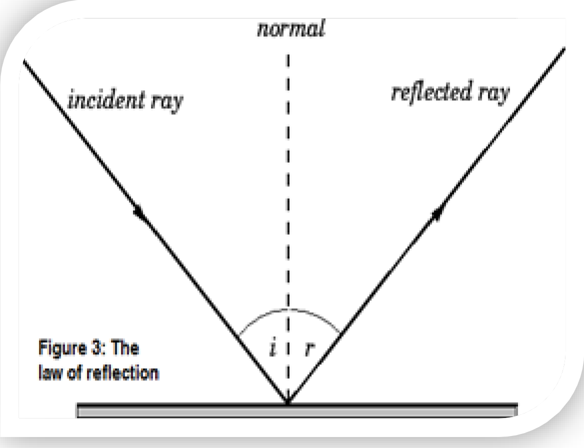


Figure 4: The Laws of Reflection

Source: http://farside.ph.utexas.edu/teaching/302l/lectures/node127.html downloaded on 3rd of May 2017 at exactly 5:22pm.

Determination of width and length of steel flanges.

From Table 1, we need 127-150 lux (10-15 foot-candles) of light to effectively illuminate corridors and lobbies. Now, "…..a Lambertian surface provides uniform reflection of ***0.428lux/mm***" (Ryer, 1997). Therefore, to generate 127-150 lux illumination with polished surfaces (in strict compliance to inverse square law);

$$^{150}/_{0.428} = 350.467\text{mm}; \quad ^{127}/_{0.428} = 296.72 \approxeq 300\text{mm}.$$

Therefore, for this fabrication, the ***Oziom Reflector*** flanges were made 350mm wide (top flange) and 300mm wide (bottom flange). The length conforms to the modular widths of fenestration openings. The angle separating both flanges is 102°. This angle is necessary to prevent glare effects to occupants of the building envelope.

5.0 Construction and Assembly

The central wooden shaft was carefully crafted in the wood workshop and planned to smoothness. This wooden shaft is fixed to the spindle bar to aid rotation. The spindle bar is connected to the clockwork housing which already has been pre-assembled with its crank spindle. Both the clockwork mechanism and the wooden shaft are mounted on the hollow steel housing.

The steel flanges are worked into shape with the half-barrel form to match the Ɵ of the wooden shaft. The strontium aluminate substrate is used to cover the entire flange. This laminate is pressed into form to cover the entire flange. Adhesive applications are used to secure them firmly to the polished steel flanges. 30mm wide cobalt aluminate strips are then used to line the underlying substrate. The strips are placed in alternating format to form a bold mesh on top of the strontium aluminate substrate. Both strontium aluminate substrate and cobalt strips are secured with Topgit pvc adhesives.

The shrouded flanges are then put into position on the wooden flange and secured with steel flaps that are nailed (contact between steel flap and wooden shaft) or arc-welded (contact between steel flap and corresponding flanges). Areas around the arc-weld must be free from substrate materials. The whole assembly is now mounted on the steel hangers as shown in the accompanying diagrams.

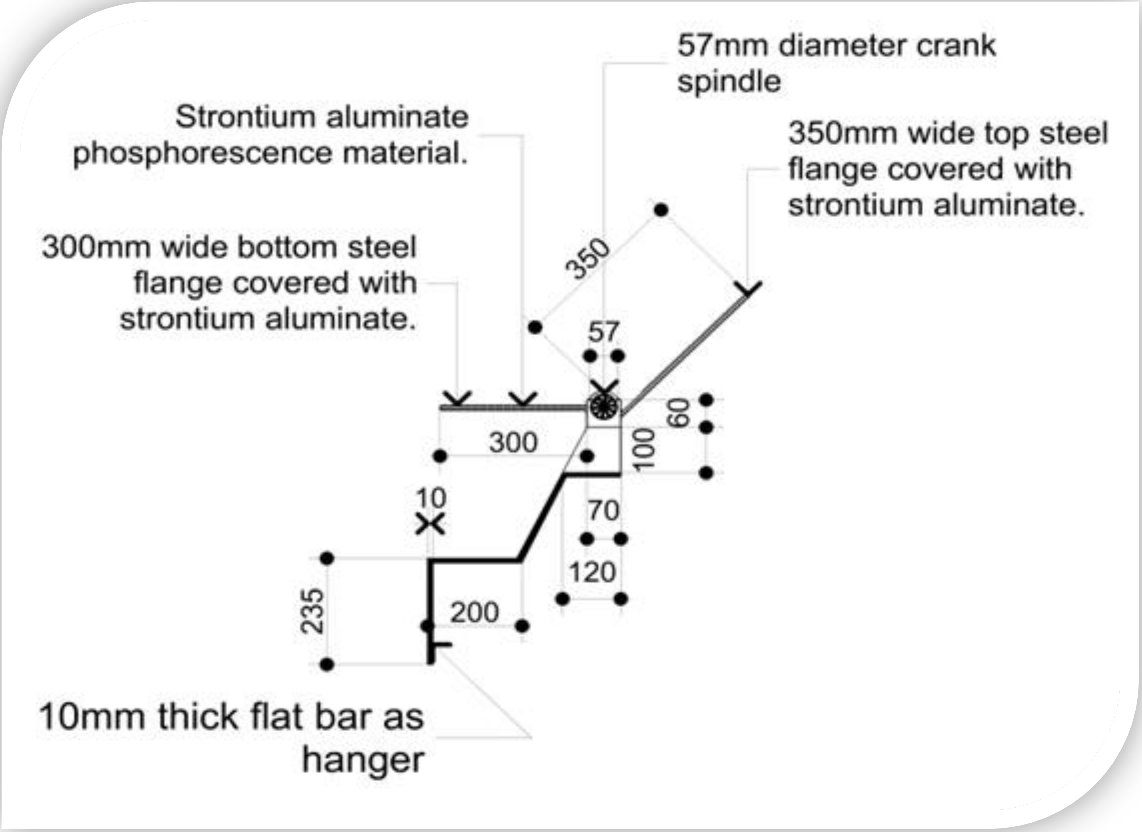


Figure 5: Side view of the Oziom Reflector.

Source: Researcher's design and fabrication notes compiled on 2nd of July 2017 at exactly 3:28am.

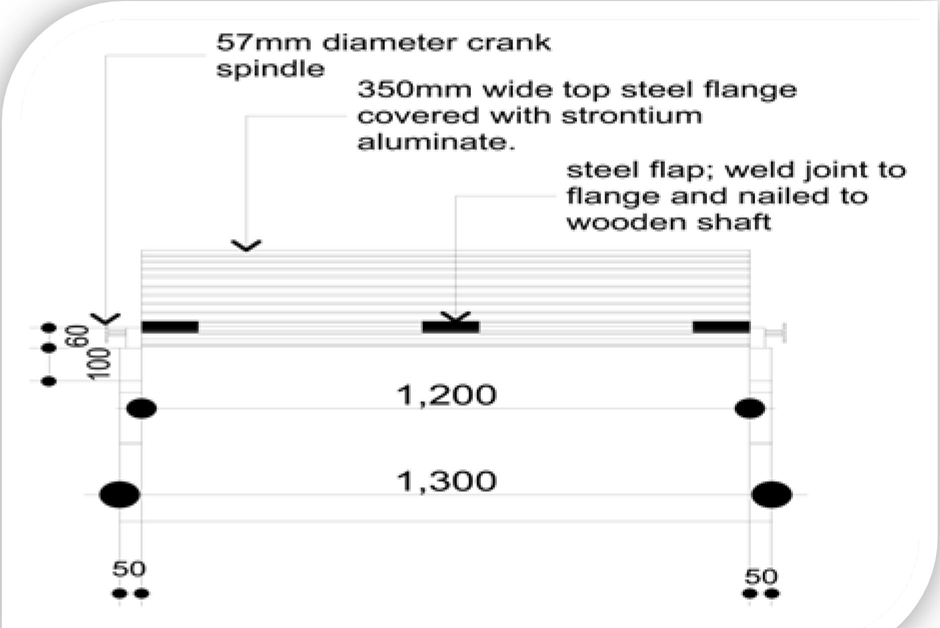


Figure 6: Front view of the Oziom Reflector.

Source: Researcher's design and fabrication notes compiled on 3rd of July 2017 at exactly 5:28pm.

Figure 7: Simulation model of the installed device.

Source: Researcher's design and fabrication notes compiled on 9th of July 2017 at exactly 4:28pm.

Figure 8: Simulation model of the Oziom Reflector in the second trimester.

Source: Researcher's design and fabrication notes compiled on 13th of July 2017 at exactly 5:01pm.

Figure 9: Simulation model of the Oziom Reflector in the second trimester.

Source: Researcher's design and fabrication notes compiled on 23rd of July 2017 at exactly 1:11am.

6.0 Experiment

6.1 Objective

The main goal of this experiment is to investigate the relationship between illumination and lumination indices before and after the installation of the ***Oziom Reflector*** at various designated and random places.

6.2 Introduction

Illuminance E, is the intensity of a luminous flux incident on a given point on a surface. It is measured in lux. 1 lux is caused by a light source with the intensity of 1 candela at a distance of 1 meter. E [$1m/m^2$ =lux]. 183 test cases were done. This experiment is documented in this research paper to determine whether there will be improved illumination indices where the device is installed.

6.3 Procedural Documentation of all Test Cases

1. The researcher identifies a space to be used as a test case.
2. The researcher conducts preliminary case studies and documentation for permission to run tests.
3. The researcher determines the orientation of the fenestration opening(s) to be used.
4. Lux readings are taken with lux meters conforming to BS667:2005 and Din 5032-7:1985 specifications. All lux readings are taken and recorded at the peak of the 2nd trimester of the sun's azimuth at exactly 10am for fenestrations facing the east and 2pm for fenestrations backing the west.
5. The researcher mounts the ***Oziom Reflector*** and adjusts flanges.
6. Lux readings are taken.
7. The researcher takes luminance readings of glow with the luminance meter.

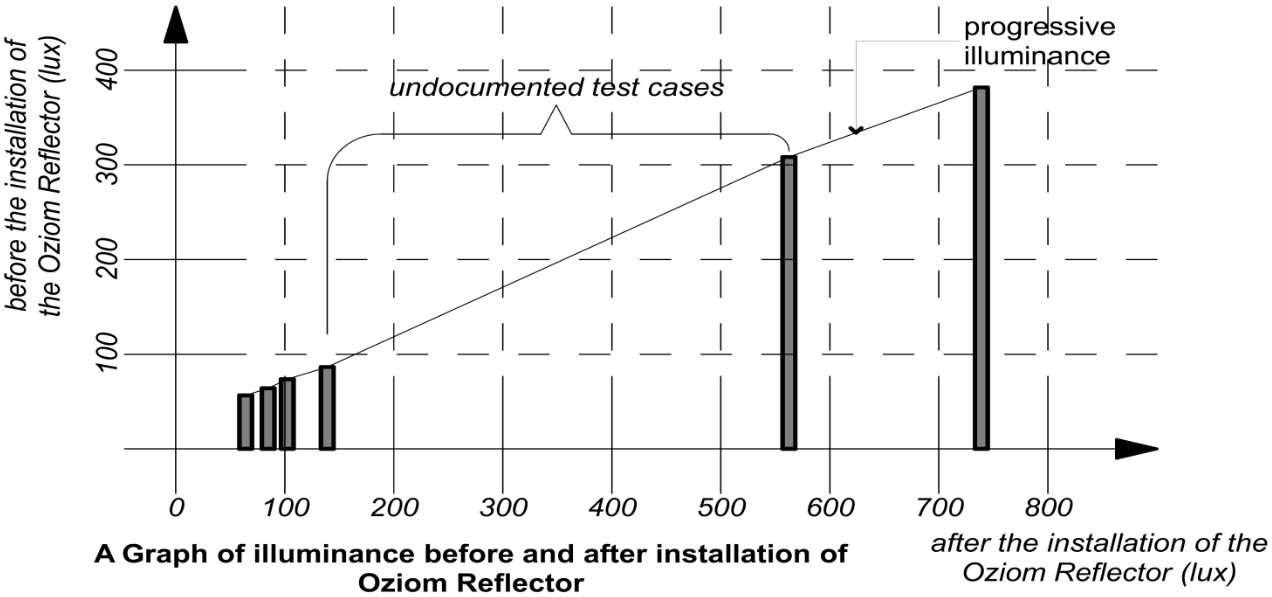
7.0 Results

Field study readings and measurements conducted at various locations and selected at random as shown in Table two contain lux and luminance readings of various spaces before and after the installation of the Oziom reflector. Out of 183 test cases, 6 random test results are documented in this paper shown indicating improved lux values after the installation of the device. All other test cases, not documented in this paper, exhibited the same positive deflection pattern.

2: Part of 183 test cases taken at random places to investigate illuminance and luminance before & after the installation of the Oziom Reflector

Facility	Location	Space	Lux readings		Luminance readings
			Before installation	*After installation*	
Mikko Plastic industry	No 7 Umuimo road, Abayi, Aba	Warehouse	48-68	73-78	8.5
St. David's Hospital	Ikenegbu, Owerri	Staircase	61-78	89-90	8.4
Nampak Nigeria Ltd	Asaba-Benin expressway	Emergency stairs	70-88	91-101	8.2
Man Plastic Industry	16 Eze Iweka road, Awada.	Exit/entrance passages	97-113	141-150	8.1
Divine mercy Plastic Industry	98 Ihionu layout Ontisha	Conference room	312-444	598-756	8.8
Renny's eatery	Wetheral road, Owerri	Cooking room	396-488	601-750	8.3

Source: Researcher's Field study compiled on 22nd of October, 2017 at exactly 12:38pm.



A Graph of illuminance before and after installation of Oziom Reflector

Source: Researcher's design and fabrication notes compiled on 2nd of January, 2018 at exactly 2:18pm.

8.0 Conclusion

All readings taken and documented in the research manuscript showed that there were improved lux values wherever the reflector was installed.

9.0 Recommendation

This apparatus is still passing through the crucibles of fabrication and advancement. A lot of improvement can be made in its general architecture. Manual operation/crank mechanism of the apparatus can be replaced with a more fluid and digital platform based on machine language where the flanges are configured to respond to the sun's azimuth. This requires improved and proper funding.

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