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Tackling the Sub-Saharan Energy crisis through a DIY Project

Supervisor: Prof. **Giacomo Festi**

Author: **Giuliano-Christian Aquaro**

ID: 942542

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Abstract

The goal of this study is the evaluation and understanding of the network of factors encircling the energy crisis in Sub-Saharan Africa, through research, semiotical analysis, product comparison, test and experimentation. Nonetheless, the analogies between a variety of designs and the assertion of the real needs of the user led to the testing and investigation of alternative light solutions.

The preliminary study touches various aspects of the issues surrounding the energy emergency by describing the causing factors and the actions taken to counter them. Through a fine tuned questionnaire and face-to-face interviews, exhaustive material was gathered to establish the necessities and ambitions of the user.

The studies conducted are to validate the path taken to face the issue by experimenting on the DIY project of the Solar Bottle Bulb. Tests have been conducted to create a dossier of information and figures to ameliorate the existing design. Furthermore , a solution is proposed to undertake the night light dilemma focusing the attention on Strontium Aluminate powder and its adaptability in different activity spheres.

Sommario

L'obiettivo di questo studio è la valutazione e la comprensione della rete di fattori che circondando la crisi energetica nell'Africa subsahariana attraverso la ricerca, l'analisi semiotica, il confronto di prodotti, test ed sperimentazione. Tuttavia, le analogie tra gli svariati design e l'affermazione delle reali esigenze dell'utente hanno portato all'evalutazione ed alla ricerca di soluzioni luminose alternative ma soprattuto innovative. Lo studio preliminare tocca vari aspetti delle problematiche che circondano l'emergenza energetica descrivendo i fattori causali e le azioni intraprese per contrastarli. Attraverso un questionario calibrato ed una serie di interviste faccia a faccia, sufficiente materiale esaustivo è stato raccolto per stabilire le necessità e ambizioni dell'utente. Gli studi condotti intendono di validare il percorso intrapreso nell'affrontare il problema attraverso la sperimentazione sul progetto fai da te della lampadina solare (Solar Bottle Bulb). Sono stati condotti esperimenti per creare un dossier di informazioni e dati per migliorare il design esistente. Inoltre, viene proposta una soluzione per affrontare il dilemma della luce notturna focalizzando l'attenzione sulla polvere di alluminato di stronzio e sua adattabilità in diversi ambiti sociali.

Introduction

Electricity crises are an issue faced by many prominent and Third World countries, rooted in different but relatable causes, where each one of them tackles and faces them differently. The California electricity market faced monstrous spikes in prices due to increase in demand but a failure to provide for it, Japan incurred in a crisis after the devastating earthquake in 2011 that disrupted the infrastructure and incurred heavy load losses. In Pakistan, Iraq, Brazil and so many other developing countries the supply cannot match the demand due to high infrastructural and managerial losses, together with a wide array of sub-socio economic problems. Sub-Saharan Africa has an agglomeration of various obstacles that disrupt and diverge possible solutions. More than 600 million people live without electricity in Sub-Saharan Africa and the majority of them lives in rural and often informal settlements. The electrification rates and the efforts put into it are slowly rising through the years, but at a much lower pace and predicted. Many stones in the path of improvement have origin at the managerial and infrastructural side of electrification. Lost battles have been fought by Eskom and countries' governments to eradicate this eye soaring issue, but due to the old aged infrastructure, geograpolitical disputes, local resentment and sociocultural complexities the overall progress has been slow. The effects of the hindered modernisation ripple and cascade into the hands of the poorest and least fortunate that by already living in slums and shanty towns their life expectancy is capped because of the lack of basic services, healthcare, education, transport but also by the harrowing shortage of electricity. Plenty of traditional lighting solutions have been opted by the residents of informal settlements, as candles, kerosene lamps and other fossil-fuel based alternatives, but to the expense of their health, and in the worst scenarios, their life. Because to survive and gain access to light they are ofttimes illegally connected to power lines risking electrocution or will use open fires in their small, cramped flammable shack. The reality of the dangers that people will go through to light their homes is startling. The importance of light is near oblivious to those who live a comfortable modernized life, but is vital for those who are the most underprivileged. Light affects not only the health and psycological well being of any human being but systematically blunters the growth and educational experience of those who cannot study after dark. Kerosene lamps, solar lights and even candles approach this issue promptly but even they come at a financial cost and, sometimes, physical effrot, as the distances between villages and cities can be excruciating. Furthermore, through a semiotician's eye, one is able to discern the bona feide impact that ligth has upon people, cultures and communities. Through the recognition of the value placed to and by light, from the obejct to the subject, and, thus, the correct placement of the target user in the project's spectrum it was made possible to clarify the shortcomings of similar projects. An ample gamut of products and systems confront the dilemma but fail to deliver a project made for the people by the people. Meaning that foreign projects birthed in alien countris will have a higher occurrence of gravely failing after a few years.Two pilot projects have been semiotically analyzed to comprehend how they were handled, why they floundered or succeeded and what can be learned and brought to this project. The impact of the semiotic approach is settled by a thorough study of the end user through online questionnaires and in person interviews. The resulting data is presented in the form of a family persona to refine the key issues to undertake. The crucial findings, in respect to electricity and light use, are researched and experimented in distinct ways.

The first one is to investigate a range of products that targets, in different ways, the light problem. The comparison of this variety of solutions allows for a broader horizon of enlightenment on the advantages and disadvantages of each artifact, thus creating an array of possibilities to scrutinize. Moreover, it will extrapolate the direction of the thesis by clearly showing, together with the previous research, the final area of development.

The products selected vary from traditional light solutions, such as kerosene lamps, to mirrored designs, as the light pipe, to alternative forerunners, like the SolarSack. Each one is selected for its features, manufacturing process, goals and technical level, to allow all a fair judgment. The projectual contrasts uncovered by the juxtaposition of the products revealed an irrefutable clue that to tackle a widespread electricity issue a DIY path is unavoidable. The Solar Bottle Bulb proved to be an eerily effective solution to take on the electricity crisis, by only using simple tools, adhesives and upcycled plastic bottles. But the unquestionable simplicity, replicability and that it only requires basic skills, make this project a glimpse of light and hope in a long lasting battle.

Secondly, the chosen pilot project is examined and checked thoroughly, as it is paramount that the science, and the apperception of how light is transported and refracted, is understood. Besides the studies targeting sunlight, a proposed approach to solving the night light dilemma is described. Luminescence, Fluorescence and Phosphorescence are reviewed to comprehend the mechanisms that stimulate these effects and how it would be possible to exploit them for this cause.

The final goal of the paper is to validate and give scientific ground basis, through tests and experiments, for the further development of the Solar Bottle Bulb. To create and to evaluate different hypotheses, ideas and peculiar findings has shown to fruit substantive advancements. The desire to establish and promote the incredible impact that the Solar Bottle Bulb has through the Liter of Light foundation starts here.

1. Electricity Crisis

The arguments presented in this chapter focus on understanding and underlining the foundamental problems causing the electricity and energy crisis in Sub-Saharan Africa.

A plethora of research studies and documentation has been archived over the issues of and causes of this crisis, however with the present-day improvement of both technologies and manufacturing methods new possibilities are created. Nonetheless, in depth study of the shortcomings and advantages of these new and traditional methods must be clarified to evaluate appropietly the best course of action to tackle this dilemma at the roots.

1.1 The Sub-Saharan Case

Sub-Saharan Africa (SSA) is the region that lies beneath the Saharan Desert, seen in Figure 1, it consists of over 950 million inhabitants but has one of the lowest electricity access and electrification rates in the world, as seen from chart 1. However, the issue is not only bound to rural and off-grid areas, as one fourth of the people without electricity

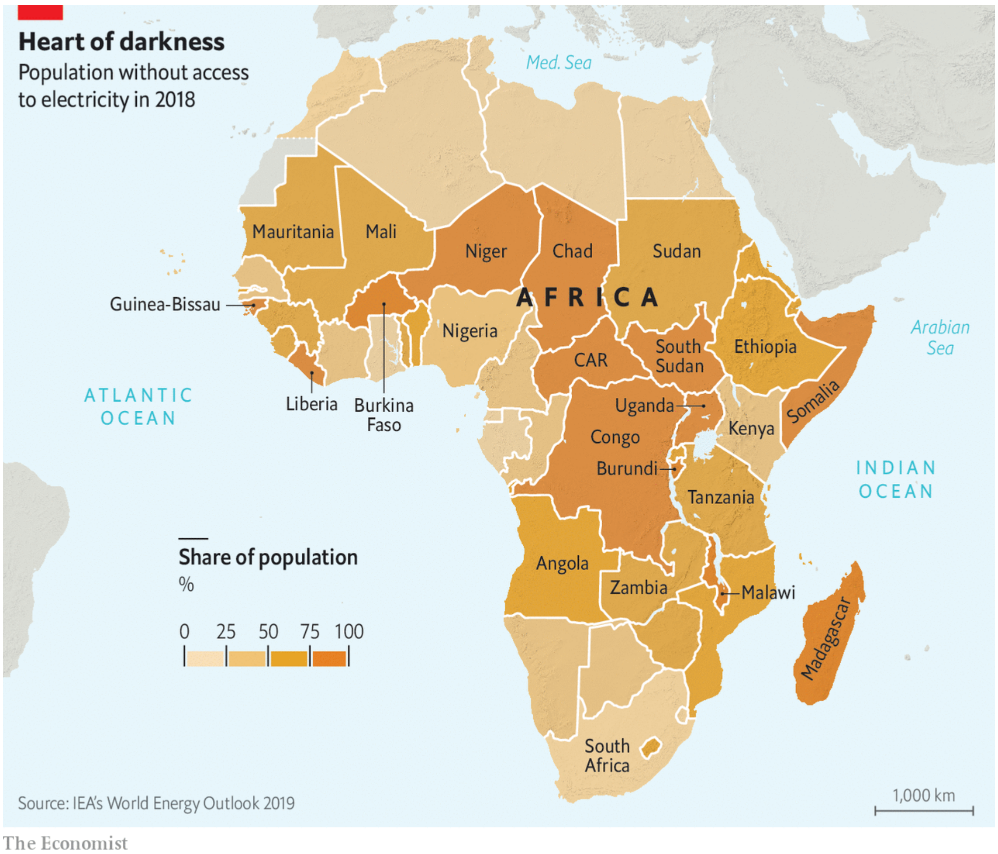


Figure 1: Regions and electricity access of Sub-Saharan Africa

IEA's World Energy Outlook 2019

live in urban areas. To put it in numbers, around 65% of the total Sub-Saharan population does not have access to electricity, around 660 million, and 20% of them live in urban zones. Furthermore, SSA is experiencing rapid urbanization across its regions but the electrification rates differ substantially amongst communes. [1][2]

This crisis crippling SSA derives from different, but key, issues intertwined in the power grid, existing outdated infrastructure, unreliability, disparities in electricity cost and a supply-demand mismatch. The aforementioned discrepancy between the needs of the ever growing SSA and the ability of Eskom, biggest electricity supplier in Africa, to withhold the demand, has been identified as an obstacle for investments, business and overall economic growth. [2]

The severe inadequacy of the decades old infrastructure and the high losses from electrical transmission and distribution aren't news to the nations of SSA, since 2008 national damaging outages have been taking place. Since then large investments have been made to build new power plants and improve the managerial structure of Eskom; however it has been argued that supplying more electricity won't solve the high power losses during 'transport'. [3]

Most of SSA relies of fossil fuel plants, having two of the biggest coal power plants, and recently with a heightened attention to the United Nations Sustainable Development Goals (SDGs) a great deal has been placed on reducing the impact of electricity

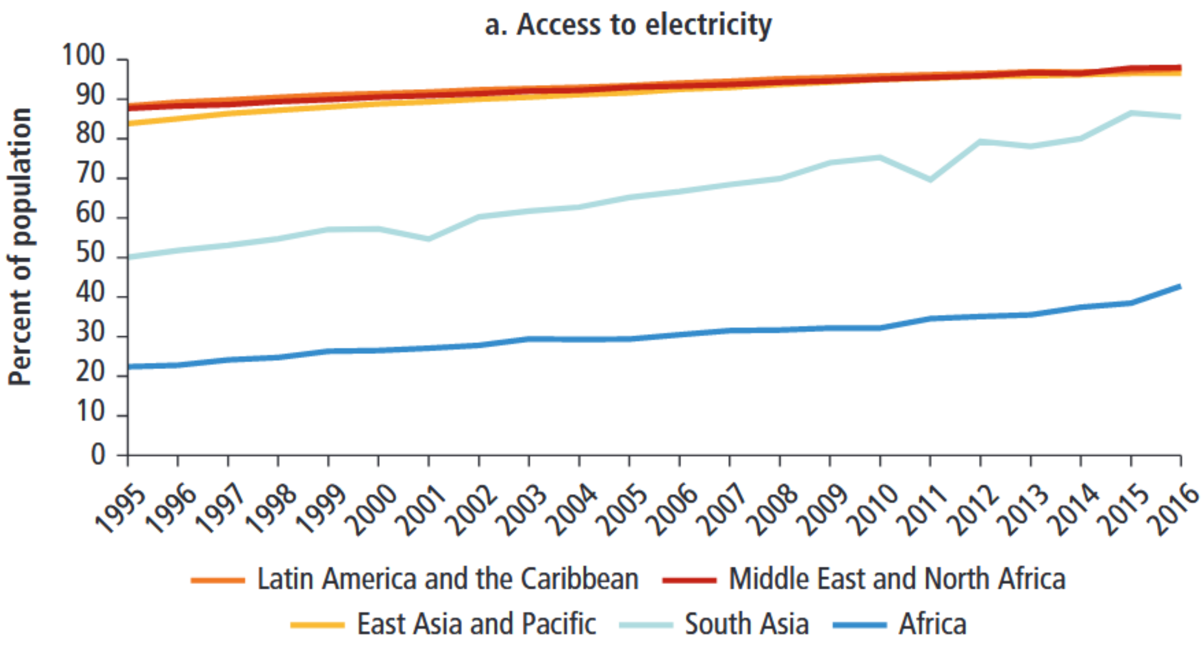


Chart 1: Electricity access around the world.

World Bank World Development Indicators; Demographic and Health Surveys; Multiple Indicator Cluster Surveys; national surveys consumption, therefore CO2 emissions, electrification reach. For this research the key SDG is the 7th stating: “Ensure access to affordable, reliable, sustainable and modern energy for all.” The interest in creating easy access to electricity and light in developing countries is to allow and improve social and economic development, thus pushing for an independent and self-sustained society. Not only is affordable and clean energy key for the development of a remote area but it is also for the well-being of its population, human welfare, and the generation of suffisable income to stay above the poverty line. [4][5] Electrification is one of the steps to start addressing fundamental issues present in many third-world countries, as its crucial asset in efficiently utilizing machinery, land and human capital. Many studies have reported the importance of energy accessibility as it is linked to economic development and as a productivity reinforcing factor. [6] Further studies show how other factors of influence, such as education, health, income rates and levels, and literacy, have a direct effect on the welfare of local and rural areas.

1.2 The Importance of Light

The importance of light and its possible health benefits are a perplexing topic to grasp, as its direct effects aren’t so evident. It is viable to offer another prospective by focusing on the consequences of poor lighting and glare such as, headaches, eyestrain, poor posture and resulting muscular pains (to see items), the possibility of injury by dropping items or failing to see obstacles, and after a prolonged period of time, mood swings and depression. [7] However, its perception allows only for a peek into the possible cascade of effects and causes of good and bad lighting, as seen in Table 1. Many research papers dive into the correlation of energy factors and economic factors, and how a simple nightlight can empower rural communities to work, study, clean, cook and do much more after dark hours. [8][9][10] Light is a key factor in many aspects of life, as it is a pillar in providing and ensuring an adequate quality of life; thus, aiding economic development. Very often when pushing forward electrification, the crucial factor is not the ability to provide remote communities with electrically powered technology but to provide them with a reliable source of light after dark. It must be mentioned that an increased access to electricity improves education, health and productivity but it also simplified house tasks, saved time for families and reduced the need and costs of non-safe fuels. [2]

Light has a direct influence in many aspects of our lives and it can be manipulated to alter experiences as It can greatly alter or only subtly affect everything we feel. Furthermore, the way its recipients experience, perceive and conceive light and colors, is also culturally specific. By acknowledging that the correlation between different cultures and their affinity for discerning from light to/and sight, brings into question the effect that technology has on remote societies.[11]

Thus, the color spectrum of the light must also be taken into account as it could affect the perceived and real value of the product, how it fits in culturally and which color of light the end user would be used to. The human body, in an evolutionary perspective, is more acclimatized with natural daylight as it matches closest with our visual spectrum, has the highest light levels for biological functions and provides the best lighting environment to perform activities in. [12][13]

For a clearer understanding of the repercussions of a non-adequately lit environment it is possible to focus on two main areas: the physiological and psychological impacts. Physiological impacts are perceived through the body which can include an unbalance in hormone and stress levels, inability to sleep comfortably (excessive daylight illumination) and changes in internal body clock. Psychological effects include the sensation of comfort and happiness derived by an adequately lit atmosphere.[14] Espiritu et al., 1994[15] found that deeper psychological symptoms derived from a regular exposure to deficient ambient illumination leading to atypical depressive symptoms such as increased appetite, weight gain and prolonged sleep. Another symptom related to light and light-exposure is Seasonal Affective Disorder (SAD) where earlier studies reported that introducing to the subject an increasing amount of bright light might ease the symptoms brought by the colder seasons. [16] Partonen and Lönnqvist, 2000[17] showed that an improvement in mood was apparent when, healthy adults, were exposed to bright light leading to believe that active people are positively susceptible.

PSYCHOLOGICAL IMPACT	LIGHTING EFFECT	LIGHT DISTRIBUTION
Tense	Intense direct light from above.	Non-uniform
Relaxed	Lower overhead lighting with some lighting at room perimeter, warm color tones.	Non-uniform
Work/Visual Clarity	Bright light on workplane with less light at the perimeter, wall lighting, cooler color tones.	Uniform
Spaciousness	Bright light with lighting on walls and possibly ceiling.	Uniform
Privacy/Intimacy	Low light level at activity space with a little perimeter lighting and dark areas in rest of space.	Non-uniform
Content retrived from IES Light Logic (www.ieslightlogic.com)		

Table 1: Psycological Impact of Light & Color

IES Light Logic (www.lightlogic.com)

1.3 Electricity & Power Grids

Generally, households find themselves in two situations: either they can access electricity but cannot afford it or they cannot access electricity at all. The cost of electricity was already found to be an obstacle in ensuring local electrification, however it is not the cost of electricity itself, even if relatively high, as other alternatives can be more costly overall, such as paraffin, oil and candles, but the cost that the final customer has to pay for the grid connection. Not only that, but rural micro-grid systems implemented in areas harder to reach, where oftentimes found semi/non functional states due to natural degradation, poor design and other technical factors, such as system overload due to theft and electricity tapping. [29] Trial projects of scalable power systems, such as only fossil fuel based, hybrid or completely renewable, seen in Figure 3, fall short of solving the problem due to their poor reliability, as specialized technicians were necessary as soon as something broke down. [44] Nonetheless, further studies show the need for

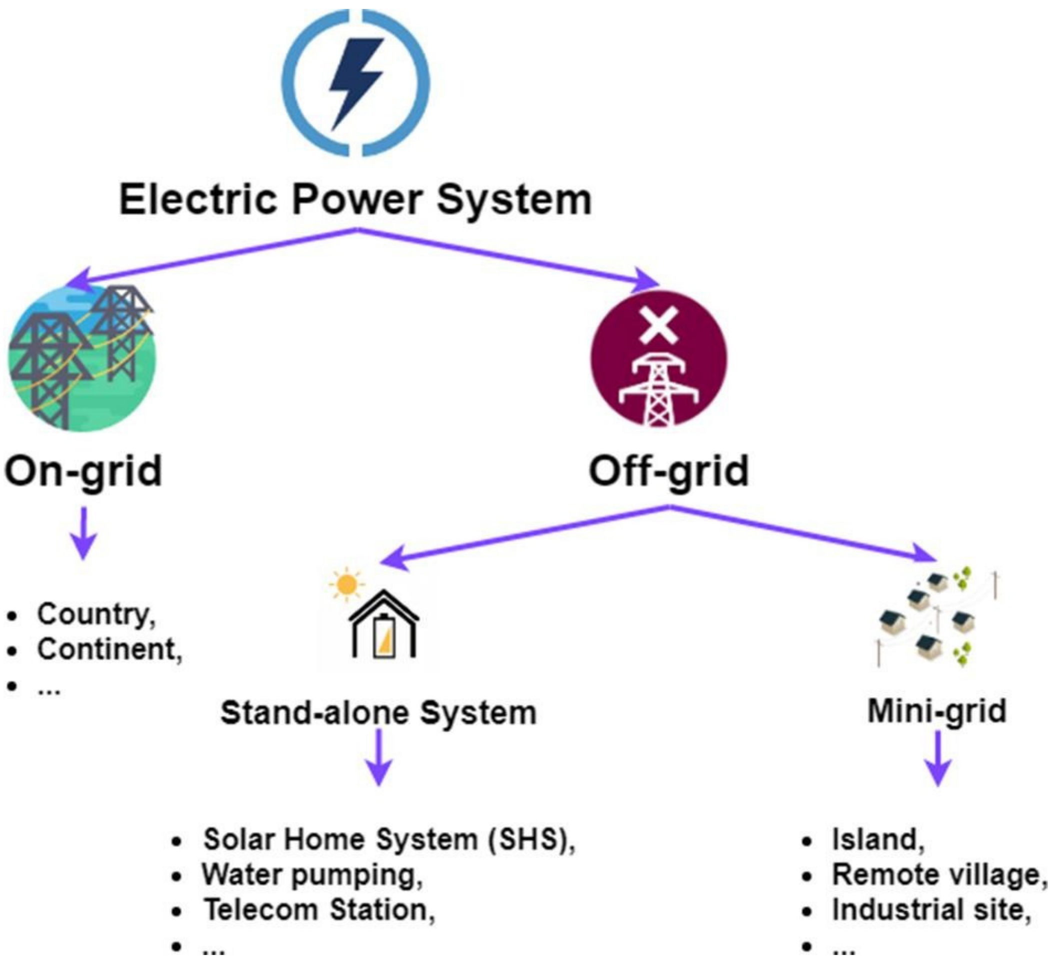


Figure 2: Classification of Power Systems

Khirennas, A., Talha, A., Kaabeche, A. and Bakelli, Y., 2020. Overview of fossil fuel-based hybrid power generation systems within mini-grids – The experience of storage-less PV system integration into three of the Great Algerian South mini-grids. Energy Conversion and Management, 221, p.113191.

a reliable and self-sustainable system that is adapted for the village characteristics in which it is placed, thus, a detailed study of the already established structure and system parameters is required. Moreover, the autonomy and overall reliability of the system is put to test when a component of the system fails or during natural disasters causing power outages, which underlines the necessity of a resilient and well designed power system. Another key point made clear is the importance of technology adoption. The proposed project must ensure the active involvement and embroilment of the target users to lay down the possible liabilities and short-comings. After the implementation of the project, its obligations and duties must be clear to ensure the maintenance, care and substitution of the elements in the system. The technological approval notion should be accompanied by social, environmental and health awareness related to the project together with infrastructure security and other critical issues [45][46]. The report of the SDG 7 forum mentions the importance of investment from the private sector allured by governmental subsidies or financial aids [29]. Many big investments come from private sectors but also from power nations investing backed by favorable promises and a steady GDP growth. [47][48] Nonetheless, it is important to mention that if it is not built a self-sustaining cycle [48], a project of such scale of electrification will take a lot of time and resources. [29]

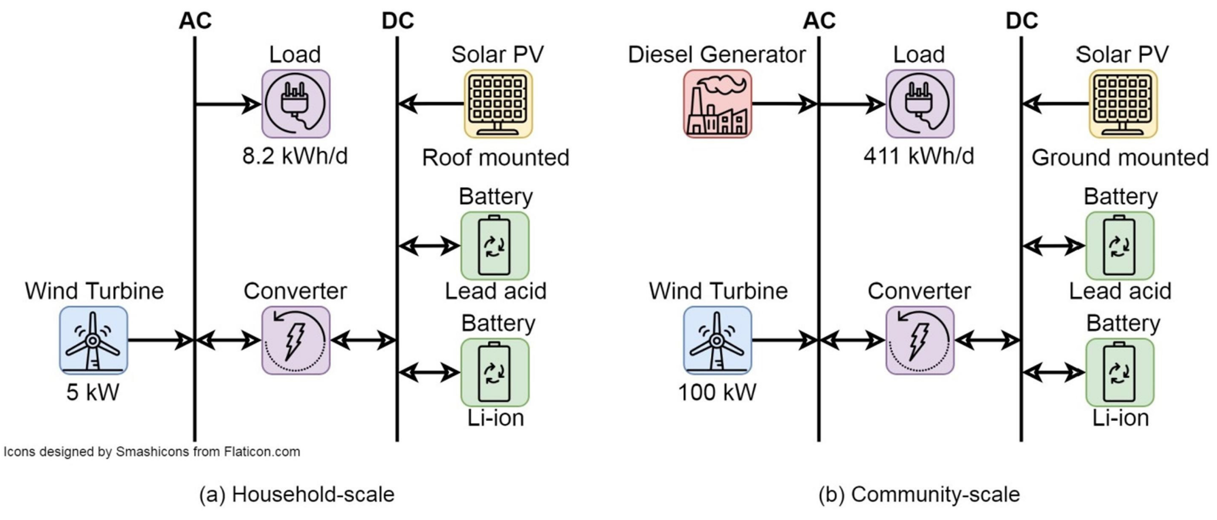


Figure 3: Hybrid energy systems for both Household and Community Scale.

Aberilla, J., Gallego-Schmid, A., Stamford, L. and Azapagic, A., 2020. Design and environmental sustainability assessment of small-scale off-grid energy systems for remote rural communities. Applied Energy, 258, p.114004.

1.4 Off-Grid Communities & Slums

Globally there are more than 1.1 billion people that are not able to link to their national power line thus, perpetuating the poverty cycle they are stuck to. A fundamental step to break the cycle is to have light after dark, as it catalyzes opportunity for improvement, education and health. Children will be more likely to stay in school if they are provided the chance to complete their studies after nightfall. Remote off-grid communities have used diesel oil-based systems to generate electricity. This implies that they greatly rely on artificial lighting through kerosene lamps, candles and wood. These practices lead to fire hazards and possible intoxication by the gasses. Nonetheless, increased technological options and lowered costs have resulted in the adoption of hybrid renewable energy-based systems over the fossil-fuel burning alternatives. Hybrid alternatives present advantages over older methods, as the system is scalable, reliable, cost effective and more sustainable. However, it was found that sometimes hybrid power systems fall short on reliability and their required maintenance. [18]

Figure 4: Example of Slum in South Africa

The Borgen Project (theborgenproject.com)

Due to the high population density in slums and sub-urban areas, it is very common that the housing situation is very crammed and built on top of each other, further limiting the access to daylight. Slums is a general term to define a crammed, compact and overcrowded settlement of houses that is ever growing in unmonitored and unregulated conditions sprouting in poor house quality, safety and residents' hygiene. Generally worsened by a lack of basic services All of these factors lead slum inhabitants to depend on unsafe and illegal work for living, such as precious waste salvaging. [19]

SSA has the highest proportion in the world of population, more than 70% of urban dwellers, that lives in slums. Slums are built with inadequate materials and poor joining techniques lead to high death rates, due to accidents, natural disasters and fires. Furthermore , slums are often located near factories, industrial areas and landfills resulting in increased hospitalizations and health emergencies for the nearby population. [20]

Figure 5: Example of unequal neighborhoods, Primrose and Makause, in Johannesburg, South Africa.

https://unequalscenes.com/south-africa

1.5 Risks & Hazards of Unsafe Electricity Access

In 2015 the IEA reported that by 2040 still 700 million people will lack access to safe electricity. [21] This data compels a worrisome view of SSA where the challenges to tackle this issue are due to an unreliable estimate of electricity demand, the power grid expansion in off-grid areas and non regulated revenues from unconventional settlements. [22] Nonetheless, the World Bank reports that in Sub-Saharan Africa around 50% of the generated electricity is stolen [35], for example South Africa loses yearly between 8 to 12 million Rand to electricity theft. Additionally the economic trickle down effect of such losses end up being increased costs for the end consumers.

Furthermore, the provided sub-standard service from energy providers creates a sense of mistrust towards them from communities, thus further intertwining the issue at the roots. As seen there is an array of complex situations that lead to energy theft, for example in Nigeria it depends on the political turmoil, in Brasil it is associated to discrimination whilst in Ghana it is related to poverty. This means that through the achievement of the 7th SDG and by providing clean, affordable and, very importantly, reliable energy, will prompt a reduction in energy theft.

By looking at statistics of how electricity is utilized, it is clear that as electricity is mostly used only for lighting, around 80% of it is used for light, shows how light is nearly a 'luxury' service as very few other electrical appliances are used. Commonly other fuels

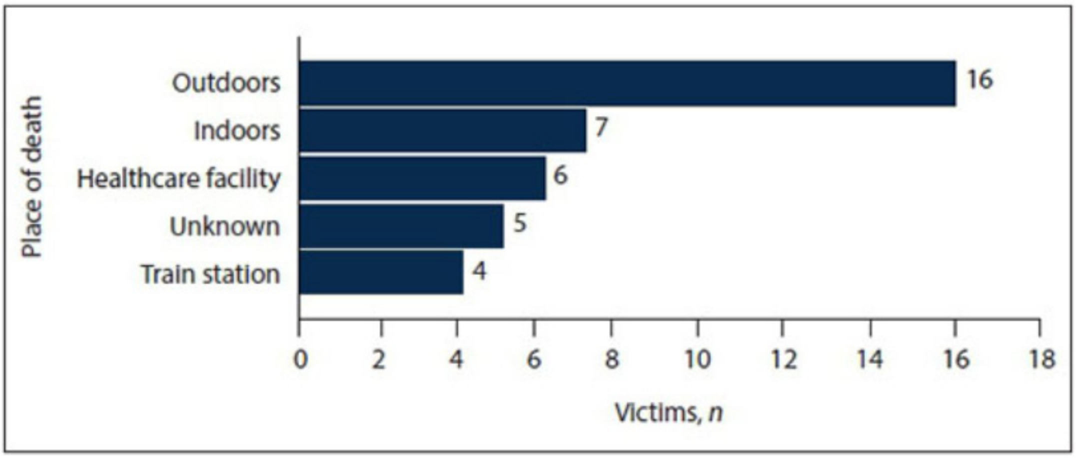


Chart 2: Showing the distribution of victims of electrocution according to place of death, Cape Town, SA.

von Caues, S, Herbst, C I, & Wadee, S A. (2018). A retrospective review of fatal electrocution cases at Tygerberg Forensic Pathology Services, Cape Town, South Africa, over the 5-year period 1 January 2008 - 31 December 2012. SAMJ: South African Medical Journal, 108(12), 1042-1045. https://dx.doi.org/10.7196/samj.2018.v108i12.13131 are used for cooking and lighting when the electricity isn't available or reliable, such as kerosene, wood, charcoal and gas.[22][23][24]

Energy poverty is not a direct consequence of electricity access but, as elucidated above, it is a mixture of issues related to reliability of the service and the ability to afford it. Non regulated housing, slums, often suffer the most from energy poverty which oftentimes drives to theft or non safe practices such as employing extension cords and, thus, creating consequent issues of lowered security and reliability, electrocution, as shown in Chart 2, and fire hazards, local power outages, surges and damage to electrical equipment, theft of wires and apparatus, with the gravest of all - higher costs than metered connections. These notions emphasize the broader issues rooted in energy poverty including a housing shortage for the always increasing in-migration, from rural to urban areas, and the government's failure in dealing with the growing number of workforce and the inability of the power system infrastructure to accommodate the needed improvements. [25]

This view only scratches the surface of the whole agglomerate of issues surrounding safe, reliable and affordable energy and its consequences and the lack of it on the energy poor population. Government investments and critical improvements on infrastructure, services and economic development programs were not well received and applied as they ostracize the share of the population living on non approved for human settlement areas. To conclude, easing access to electricity and power in slums will result in improving their condition economically, socially, their health and access to education but also will ensure the achievement of the SDGs.

The review above indicates that easing access for the slums to have power does not only ensure the achievement of SDGs but also improves both social, economic, health and academics of slum dwellers.[26][27]

1.6 Real Challenges to Reach full Electrification

Commonly, rural and remote communities have employed fossil-fuel-based systems to provide the necessary electricity. Such systems inadmissibly contribute to climate change and shortened life spans of the local population. Therefore, private investors, government bodies and institutions have gladly pushed the solar panel solution to address the matter at hand. In fact, the off-grid solar panel industry has grown into a 1.8 billion/year market, receiving worldwide investors, as its backing the Sustainable Development Goal 7. As R. Puliti: states "The off-grid solar industry is instrumental for achieving universal electricity access" confirming the Western world view of playing a fundamental role in bringing light in dim nations. To ensure that the 2030 agenda, that is about the sustainable development goals, can be achieved, in the next 15 years the evaluation of the sustainability of such systems is preeminent.

All-around help to grant sustainable development to these off-grid communities is growing but it is still inadequate, creating a stagnant situation for the population. Off-grid solar systems are a possibility, however, the costs of implementation are as high as the cost of maintenance and repair of the power grid. It is estimated that the solar programs cost around 1500$ per connection and 2000$ for rural areas.

This implies that a feasible and economically viable solar power plant isn't as realistic as it seems. Furthermore, a foreign-patented system will require foreign technicians and so on, increasing the costs and difficulty of maintenance through time. For hard-to-reach areas, oftentimes in sub-Saharan Africa, an improvement in the accessibility to light will cascade into a more promising livelihood for all the community. [28][29]

A few of the issues encountered when starting to plan a solar powered grid system are:

- The country's National Policies on the adoption of off-grid solar energy and possibly the time frame required for such installations. Some funding or subsidy is provided, such as the Sustainable Energy Fund for Africa (SEFA), which helps financially but not in the organizational area.
- Licensing Regulations that grant the existence of Licenses to generate, regulate and manage the distribution of electricity. For example if the electricity generated is for private use, for distribution or sale. Furthermore, precise guidelines for the implementation of off-grid self-sustaining solar systems are often missing.
- Financial Instruments ready to use when starting the project and if external sponsorship is available it will prove to be a crucial factor when starting this kind of grid development infrastructure.
- Social and Technical situations must be considered whilst starting a solar panel powered grid, as the current population will have to accept it, integrate it and then desire it to better their education, health and livelihood in general.

The increasing complexity of power-grid systems must be handled to ensure optimal power flow, maximize the seepage of renewable energy production and of its storage thus, to boost its scalability and appropriateness for the devised context. [30]

2. The Semiotic Perspective

The knowledge and understanding of the socio-cultural aspect are vital in both delivering a thorough and a well-recieved project. This chapters encircles the reasons and consequences of a mislead project and which are the most vulnerable and delicate points, of the project, for the end user. The necessity to grasp the social limitations and difficulties, sprouts from the human-level discrepances between the project's nation of origin to the project's targets. To broaden the view of such matter, different examples of pilot projects and their respective experiences are studied to draw a 'lesson learned' conclusion to, then, better this project.

2.1. Light

The introduction of a semiotic study, and therefore point of view, could be crucial for such a culturally sensible project. Semiotics is an approach to investigate the meanings of signs and thus it is a great tool to analyze an unfamiliar environment. Light and its shadows are embodiment of both meanings and signs wherefore it extends as an opportunity to strengthen the foundation of the project. This vision is suited to analyze lighting situations and in a semantic view also their perceived value both culturally and socially. Nonetheless, the view of the end user must also be considered by studying their expectations, understanding and future relation to the meaning created by the product. Other semioticians, such as Fontanille and Greimas, define semiotics as the study of complex signs, and their related meanings, as measure of the communication between the sender and the receiver. [31][32] Through the influence of linguistics, semiotics has evolved and has been adapted to describe visual aesthetics and communication such as cinematography, architecture and art. In this new modal view, light is regarded as a harbinger of information that is translated in an identity due to its linguistic outcome. Within this view, light is employed as a social construct, whereas perceived identities are indefinite and contingent. [33]

Looking at light as a smaller dimension of semiotics and placing more focus on the symbolism, posed by different light emitting sources such as the 'Vintage' light bulbs or LEDs, it is clear that inherent sub-categories exist. Nonetheless the ever growing light technology, as the new low-energy LiFi, will further expand its meta-dimension by considering light intensity, light spectrum, patterns and shadows created. These new aspects will affect the receiver by delivering deeper meaning but also the content. [34]. As underlined, light can be considered a complex semiotic agent, creating a dynamic objectivity which is able to influence, determine and define sense in objects and the surrounding space visible. Higher or lower luminosity, the location of the light, the materials and colors, are all aspects that bias the instinctive judgment and use, creating a game of individual associations and evocations. Light has always defined shape and material perception through light incidence modeling and giving meaning to material and form displaced in limited space. From this point of view the quantity of light is decided by how much of it is reflected and the quality of light is affected by how well the material reflects it. The game of shadows, created by the light, can be said to be a way to measure the passing of time, such as with daylight, and the geometrical depth of its surroundings. This means that light itself is nothing if not placed in surroundings, that its meaning comes with the sense of the relationship between the light bulb, the sender, and the object/space shone upon, the receiver. [35] By switching focus to the qualitative aspects of lighting, one can grasp the benefits at an individual level. Light quality benefits well-being, socio-economic aspects and aesthetic communicative elements. [36]

Case studies of semiotics of light have shown how to reach a desired outcome by placing a focused interest on psychological effects of proper illumination, delineating the relevance of a semiotic perspective.[37][38] Moreover, historically, cultural phenomena have greatly influenced the meaning of light through time and its relation with users. Thus, semiotics can be employed as a tool to counteract divergences and confusion that is created by design and naïve functionalism by clarifying interpretational propenderancies reminding to place the self at the core. [39][40] Kelly, 2017[41], gives a great conclusion, stating that semiotics, a qualitative method, can be adjoined to quantitative research to properly prepare it or to be able to explain it subsequently.

2.2. Semiotics in the Field: Zimbwean Bush Pump

De Laet and Mol, (2017)[42] raise an interesting point by analyzing the Zimbabwe Bush Pump, which is a 'lever activated lift pump mechanism'. Its fame does not come from the hydraulic system but from its capacity to pump water from 100-meters-deep wells using half the energy. Nonetheless, the study encircles the specific quality that attracts users to the Bush Pum; its fluidity. Its fluid nature comes from a so-called 'advanced simplicity', as its final functionality depends on its adapted variations for the different surroundings, for it can be considered a 'Hero', as it 'saves' the user in nearly any situation. The heroic Bush Pump acclimatizes to every situation, flowing and evolving into the milieu. Furthermore, they state that the pump not only is a source of clean, fresh water but also of Health. This shows that underlying implications are always present in an humanitarian project and how other aspects must be taken into account, culture and the local values will affect the impact of the delivered project.

*The real demonstration that the Zimbabwe bush pump has real effect on the community is by showing its '***fluidity'** *of being adapted to different situations and needs. By having* *the resource of '***bricolage'*** which allows the transition of the pump from a simple necessity to a kind of 'ritual' also by having the possibility of adding colorful signs and patterns it really starts creating relationships and rapport inside the community. [42]*

2.3. Semiotics in the Field: De-Scription of Technical objects

It is crucial to discuss the relationship between human and non-human actants and how real technical objects help create a heterogeneous structure between all of them. In the case of designers and technical objects the bond is even more present, by delineating that the actants that are imagined for the object are also related to the actants that exist in reality, as a result of decisions made by the designers. The design, or plasticity of the object, is derived by assumptions made by designers when confronted with end users thus, bounding different competencies when a final design is drawn. This can be translated into designers creating 'scientific' hypotheses to categorize and make up the world where their object is to be placed in. The balance lies between the designer, the designer's perceived user and the real user therefore, as stated by M. Akrich (1992) [43], between the "the world inscribed in the object and the world described by its displacement".

2.3.1. The Photoelectric Lighting Kit: How to produce a Non-User

The Photoelectric Lighting Kit is used as an example of missed user and consequent design, which is closely relatable to this project's end goal, thus accentuating the importance of a semiotic understanding of the relationships involved in designing an object for a society, culture and tradition different to what the author is used to.

The French government wanted to improve the market for their new photoelectric cell industry, thus delegating a design team to create a photoelectric kit to be sent to developing countries.

The limitations, necessities and constraints were ideated by the designers, and therefore, as a function of their position and perspective. The components at play were few, a battery, LED lights and a solar panel however, their role in the field was different. Each one of them is crucial and necessary for the lighting kit to work, however the previous knowledge that the end user had on them differed greatly. The battery is a more common product, and overall well understood, but the solar panels and LED lights could be considered completely foreign to the target users. Furthermore, difficulties started to arise when the pre-imposed limitations of the kit affected its true acceptance and adaptability to different scenarios. The fixed wiring length, the non-standard electrical plugs and the impossibility of finding replacement for any of the parts, as not available in the local market, doomed the user to lose the control over the installation of the lighting kit. The user was made dependent on the contractor that installed the kit and could not rely on local electricians, as they would only damage the kit due to being untrained in repairing and maintaining them.

By confronting the real final user of the kit and the perceived projected user of the kit, the differences and similarities appeared. The projected user, created in laboratory conditions was much different, in terms of the social and technical actants, than the real one, nonetheless, this outcome was a result of technical studies on the possible influence that the end user would have on the kit. An example is that the kit runs on direct current instead of alternating (DC is delivered by solar panels) furthermore watertight batteries and non standard connections were implemented to reduce users interference and disruption of the kit, to prevent damage. Also the wire length was fixed to reduce losses and improve performance, meaning that overall the user was cut off from any possible appropriation of the product, both culturally and socially. This point leads to believing that the end user was not the ‘real’ end user but the governmental donating agency thereby proving that the real end user was a facade for promoting and marketing French photovoltaic panels.

The goal of the designers was to create a ‘foolproof kit’ that would not be tampered with, that could not be repaired without their intervention and that could not be fully incorporated into an everyday lifestyle as it was perceived as an outsider. Thus, the technical object indefinitely picked out its actants and their interactions, not the other way around. *A question arises:* **How is it possible to adapt foreign technology to cultures and societies that are distant from its origins?**

2.4. Reinventing & Reshaping Technical Objects

If a generator, the source of electricity and life in a community, is taken into consideration it is possible to identify its actants as a relationship between the different actors that revolves around the relocation and housing of the generator inside the community. The real difference that a generator poses against a photovoltaic kit, is its relations between users, inventors and distributors. The kit was a function of climate and installation; thus, submitting the user to arbitrary individuals and natural forces. Instead, for the generator, the subjects involved, the investors, the owners, the users,the renters and the transporters, marked the frontier of communal solidarity and compassion, as the work of a single individual could not enrich the whole community. The fluidity of usage of the generator, therefore a technical object, mediates the relationship of the user to the real world.

In other words, electricity and the presence of its infrastructure, allow for rural communities to ‘legally’ exist in economic terms. Meaning that as the government is able to track electricity consumption, and thus creating power lines, and in consequence marking public and private owned land, it would enable them to exclude traditional representations of the village. Electrification is the first step towards modernisation as it builds the foundation for other utilities to sprout. However, by allowing state owned infrastructure to take place on the communities’ land, it meant that also a fair share of their independence and freedom would be extirpated. The electrification deal is extremely allouring to remote villages, and can be seen as a sign of progress, and, consequently, recognises individuals as citizens, as their relationship with governmental authorities is rooted.

As electricity and electrification rates are a sign of progress and modernisation the lack of it implies the opposite: low hygiene, education and standards of living. This transforms the relationship between the technical object, electricity and its access, and the user creating a kind of ‘Social Control, enhanced by electricity meters and connections. The methods of electrical consumption regulation, somewhat ‘groomed’ the end user, through a reward-punishment process, to utilize the object at its theoretical full potential. Nonetheless, the fiasco of the object to be accepted by the community, from the designers point of view, is not because of the object that failed (technically), but because it was improperly used (socially). However, from the end user point of view, the social misuse was due to the unshakable fact that it was misconceived technically. Potentially, the real conclusion is that the users were considered as a mediation point between the manufacturers and the government, where technical objects are a political bargaining chip allowing them to shape other social factors and relationships. [43]

Figure 6, shows simplifications of the involvements of different actants and actors in the play out of introducing a technical object in a foreign culture and society.

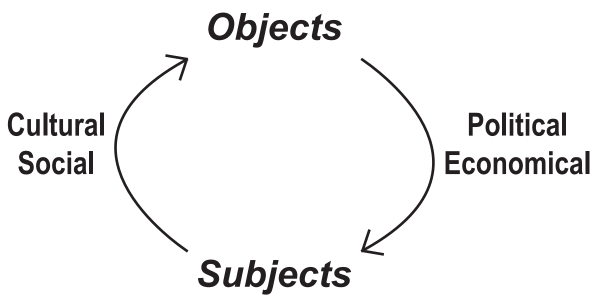


Figure 6: Summary of the relationships between the Object & subject with their influencing factors

-

3. Traditional Lighting

After having described the social and cultural aspects of the project where the importance of the target users and their perception of the project are detailed. Therefore, it is key to integrate the discoveries into further research and delinate the limitations of them. The previous research showed how a wrongfully inserted project can do more harm than good, thus the basis of lighting sources and how the poorest uptake indoor lighting is necessary to fully grasp both the competition and the potentials of other lighting products. Case studies will be presented to compare the differences and similarities of various products, and how well they perform under certain specifications. They will be used to draw a basline for the project to develop on.

3.1. Conventional Solutions

In rural regions of SSA traditional energy solutions span from candles, kerosene and hurricane lamps. The lighting quality and efficiency is low, furthermore they are linked to respiratory issues and overall 'black carbon' pollution. Kerosene lamps prevail over the other traditional energy sources, such as candles, in nearly all non-electrified parts of the world. Less polluting options for achieving electrification are micro-grid systems, Solar Home Systems (SHS) and, generally, portable solar lamps but as previously described they also bring further issues as repairs, maintenance and safe use. However, some studies have focused on the poor disposal of the batteries utilized in solar lamps and their effect on the health of the community. As seen in Table 2, most households utilize kerosene lamps, except Zambia and Senegal where candles are preferred.

	Population without electricity, in %	Share in total lighting cost among non-electrified households, in %		
		Kerosene	Candles	Batteries
Benin	75	87	5	7
Burkina Faso	85	81	15	4
Ethiopia	83	77	8	14
Ghana	40	90	4	6
Kenya	84	89	4	6
Mozambique	88	81	15	4
Rwanda	95	83	13	4
Senegal	58	17	81	2
Tanzania	86	78	17	5
Zambia	82	17	81	2

Table 2: Lighting sources employed in household in SSA

UNEP/GEF, United Nations Environment Programme and Global Environment Facility (2017)

The luminosity and brightness performance of lamps, candles and mix solar-battery lights is variable and non-constant, as it can depend on how they are made, thus affecting the final lumens emitted. [49] A simple comparison of these light emitting sources can be seen in Table 2, where different real life photos are shown.

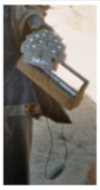
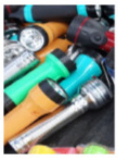
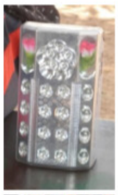
	Tin wick lamp	Glass cover hurricane latern	LED lamps powered by non-rechargeable batteries			Pico-solar photovoltaics LED task lamp
			Single or multiple diode hand-crafted light	LED Flashlight	Ready-made battery-run LED lamp	
			 		 	
Energy carrier	Kerosene	Kerosene	Dry-cell batteries	Dry-cell batteries	Dry-cell batteries	Solar (stored in rechargeable batteries)
Luminous flux (in lumen)	11	8–82	~10	10–150	10–150	25–200

Table 3: Range of products of typical light solutions

Bensch, G., Peters, J. and Sievert, M., 2017. The lighting transition in rural Africa — From kerosene to battery-powered LED and the emerging disposal problem. Energy for Sustainable Development, 39, pp.13-20

As seen from Table 2, the luminosity greatly varies not only from solution to solution, but even between different LED light options. The pictures present in the table show hand-crafted battery powered lamps that use different amounts of diodes thus varying the output light. LED lights emit a more direct kind of light compared to light bulbs that radiate warmer ambient lighting.

3.1.1 Candles & Kerosene Lamps

Candles have been employed by humankind for centuries, starting from tallow candles made from animal fat, and can be considered one of the most traditional lighting methods. However, the use of candles not only does it not provide a sufficient amount of lighting necessary for reading or other night time activities, but it can also be a cause of fire hazards. Hardly any of the traditional energy sources provide the basic 300 lux needed for reading as candles provide around 1-5 lux whilst kerosene lamps from 10-80 lux as seen in Table 2.

Candles have been reported to be used as a source of light in one-fifth of households without electricity mostly due to their limited use for cooking or other purposes and also their lower average cost compared to kerosene and batteries, the two most common sources. However, it is important to keep in mind that different regions employ different light sources at different percentages of use and for different amounts of time, thus making it complex to paint an image of how much is each energy source used. [50]

Kerosene lamps can greatly vary from home made with a tin can to store-bought kerosene lanterns. Both urban and rural households use kerosene lamps for lighting purposes as its use was found to be correlated with the user's income. Meaning that educated and higher earning individuals will be more aware of the benefits and life improvements of clean sources of energy. Kerosene lamps are used in most households as a primary or secondary source of light, preferred over solid fuels, but income still plays a vital role in determining which energy source to prioritize. Furthermore, kerosene lamps are a cause of concern for the health of the user increasing the risk of severe health effects. Reducing the exposure to these lamps for 48 h lessening the intake of black carbon by 50-70%. [51][52]

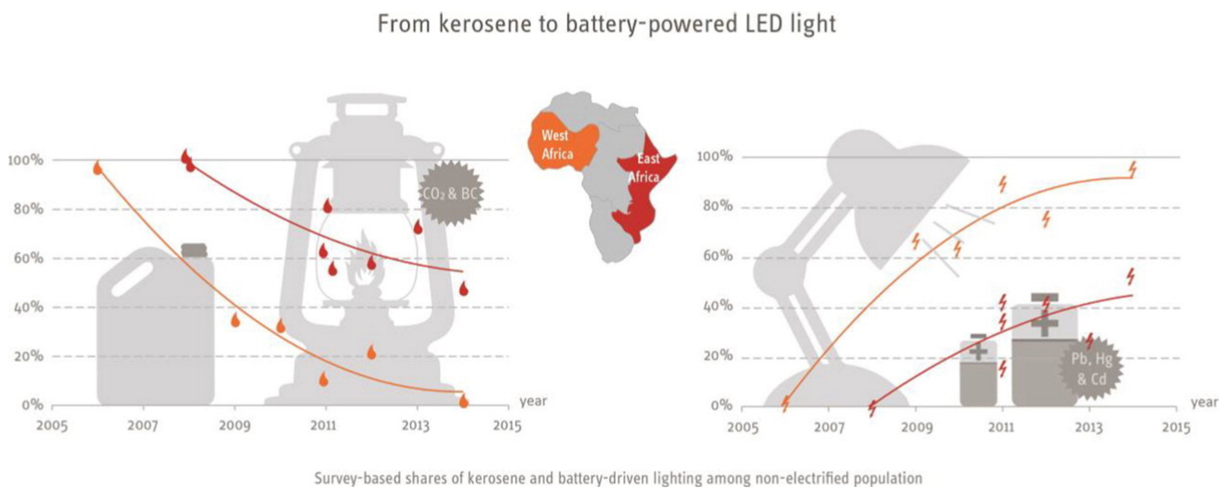


Chart 3: Range of products of typical light solutions and their percentage use.

Bensch, G., Peters, J. and Sievert, M., 2017. The lighting transition in rural Africa — From kerosene to battery-powered LED and the emerging disposal problem. Energy for Sustainable Development, 39, pp.13-20.

3.1.2 LEDs, Solar & Battery powered Lamps

As it can be seen above, kerosene is the most common light source, as it is easy to find, use and is relatively cheap. However, in recent years the reality of solar lamps and LEDs is growing stronger. The price of Light-emitting diodes is lowering and their efficiency improved. LED lamps powered by single use batteries are more common and easier to find, which consequently leads to a huge consumption and waste of batteries and electrical components. Many studies claim that most of the rural communities do not possess advanced technology, the only exception being smartphones. Other pieces of technology were found to be individual electricity resources such as hand-built solar systems, repurposed car batteries and old diesel generators. These methods used for generating a 'steady' stream of electricity are of curious nature, as one can see that they are oftentimes reused and recovered electrical waste themselves, coming from junkyards or old industrial equipment. [49] As seen in figure 6, the transition to solar powered light is happening but at a very slow pace.

The biggest disadvantage for solar technology is still its cost, even though it's lower than the past years (around 50-60 $ for a solar lighting system), it is still too high for the vast majority of the poverty-stricken Third World. [53]

The cost factor for solar lamps is of key importance but users are ready to pay a higher price for added value, such as solar lamps with incorporated radio. Communal solar charging stations can be thought to be an answer for the poorest of the community, as they would be able to charge their battery powered lamps paying the same amount as for kerosene.

Another crucial aspect for solar powered light is the system reliability and a mechanism that can ensure long-lasting service (usually 5 years) and ease of servicing and maintenance, if required. Moreover, how they are employed, their use and abuse will have a direct effect on their trustworthiness. Examples of LED lamps and solar powered lamps can be seen in Table 2. [54]

3.1.3. Architecture & Natural Lighting

For populations that live in arid and hot regions of the world, it was natural to adapt to such conditions, which have led inhabitants to change their way of life to acclimate to the thermal discomfort. The methods employed by these communities to counteract heat and sand storms, dry winds and dune sands, are in the field of playing with lights & shadows in architecture. For example, for centuries have Iranian architects and engineers studied the light patterns, wind flow and night humidity to keep a good level of thermal comfort inside houses. The Iranian climate is relatively similar to the SSA weather conditions. By mastering the ability to work with nature instead of against it, Iranian architects were enabled to minimize the amount of artificial lighting and cooling required.

It is important to mention how architecture plays a role in reducing energy consumption, as difficult climate challenges push for ingenious solutions. Architects using the geographical features and the sunrise/sunset locations were able to greatly enhance the natural lighting and cooling properties inside the house. [55]

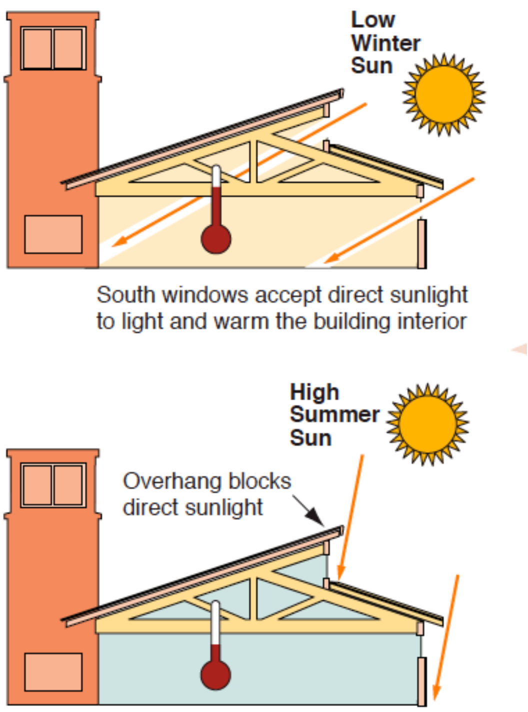


Figure 7: Passive solar design shwoing the height of the sun during winter and summer

https://engineeringdiscoveries.com/orientation-of-building-with-sun-purpose-and-factor-affecting/

Furthermore, light can be considered as an agent of comfort, transmitting symbolic concepts, beauty, patterns and overall space variety. Effectively, in hot arid countries such as Iran, light comes from windows, vertical walls and 'roof-lights'. For example, North facing rooms would get warmer in winter by receiving more sunlight, whilst in the summer the South rooms would be cooler as less sunlight would hit/shine on them. Examples of these phenomena are shown in Figure 7 & 8. Sun's angle, the window's height and width, would affect the resulting sunlight received in the room, hence showing how different factors can determine how much natural light one can exploit. [56]

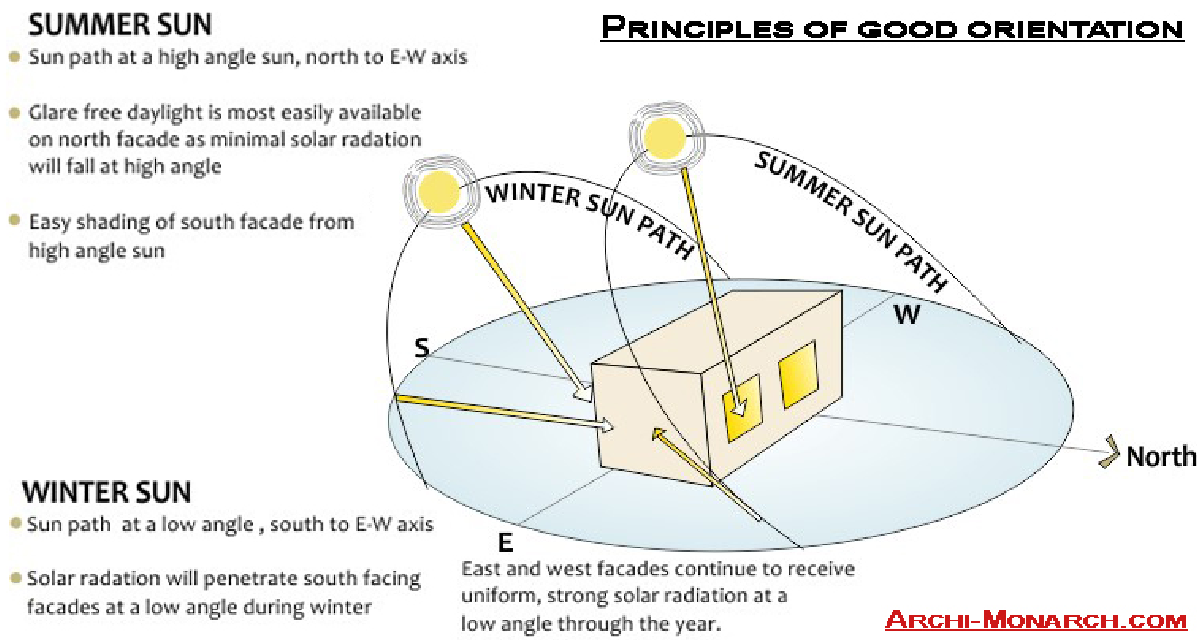


Figure 8: Shows the effect of the sun's orientation on different rooms of the house and thier windows

https://archi-monarch.com/building-orientation-for-passive-design/

3.2. Case Studies

It is important to utilize case studies in this project not only to grasp what has already been done to approach the issue but also to be able to compare different outcomes based on a standardized form. For this analysis the case studies will have a wide range as the topic under scrutiny offers different solutions. Case studies are a great opportunity to visualize shortcomings and possible improvements of projects that can be factored in this project to enhance its desired impact on end users. For this project, the case study will assess the products aimed at the end user, the materials and components it is made of, physical attributes such as weight and dimension, the overall costs, the technologies employed, the focus and interaction of the product and its replicability. All these factors are important to judge how well the product performs against the constraints of this project. Some basic information will be extrapolated to better place the product in the market and its aimed goals and values. Due to the DIY nature of this project the variety of projects being chosen to be analyzed and compared will all have similar functions. Furthermore, these case studies will reveal points of strength and weakness of each product, underlining how some features can be extrapolated and utilized in my proposal.

3.3. Case Studies Form

Case Study Form

Launch Year

Product Name & Description

Picture of product

User

Cost

Materials/
components

Technologies

Physical
attributes

Interaction

Focus

Replicability

Advantages

Disadvantages

3.3.1. Case Study: Light Pipes

Case Study Form

Launch Year 1850

Product Name & Description

Light Pipes or Tubes is an innovative light transport technology that with a light collector dome it transfers light through a reflective mirrored pipe into different rooms. The natural sunlight is transported and refracted out of a glazed light diffuser for a length of about 12 meters.

User: Used in office/private buildings to allow employees to receive more sunlight during the day.

Cost: Self installation: 200-400$ Installed: 500-1000$

Materials/ components: Composed of a clear dome, sealed air pipe with mirror finish and a final dome light diffuser

Technologies: The technology emplyed is an internal refelctive finish, commonly aluminium or reflective plastic

Physical attributes: Weight and size depend on light travel distance and pipe diameter and use.

Interaction: The light pipe is fixed and most times dosen’t need interaction. Some modern ones can be ‘closed’.

Focus: The focus of this product is to channel light inside to ridirect it at will.

Replicability: Light Pipes are a simle but ingneious idea of ridirecting light only with reflective tube and plastic domes,

Advantages

- Enhancecs the amount and quality of daylight inside a buiding
- Reduces the need for artificial lighting and energy consumption
- Improves user comfort and pructivity
- Couples well with design aesthetics
- Requires a small roof space

Disadvantages

- Dependent on weather
- Littile control over amount of light recieved
- Requires roof access, not for apartemnet complexes
- They require maintenance and if poorly installed might get roof leaks

3.3.2. Case Study: Light Shelves

Case Study Form

Launch Year 1950

Product Name & Description

Light Shelves are one of the simplest light guiding systems in the market. The shelf distributes daylight inside a building by re-direction and diffusion in an area of around 8-10 meters.

User: Used in office buildings to allow employees to receive more sunlight during the day.

Cost: Cost is around 100$ for a full light shelf system and installation.

Materials/ components: Composed of support component, generally plastic, held by metal hinges, covered by reflective side.

Technologies: The technology emplyed is a refelctive coating, commonly aluminium or reflective plastic layer

Physical attributes: Weight and size depend on window dimension, average is 60x40cm for around 1.2 kg.

Interaction: The user has the choice too have the shelf open and reflect light or closed and become a curtain.

Focus: The focus of this product is to direct and diffuse light inside an enclosed space.

Replicability: Light Shelves are of wite simplistic design and could be replicated with common everyday materials.

Advantages

- Enhancecs the amount and quality of daylight inside a buiding
- Reduces the need for artificial lighting and energy consumption
- Improves user comfort and pructivity
- Couples well with design aesthetics

Disadvantages

- Better suited for mild climate instead of hot and dry ones
- Require high floor-to-ceileing hight
- Light shelves must be appropiate for the windows
- They require maintenance

3.3.3. Case Study: Solar Bottle Light Bulb

Case Study Form

Launch Year 2002

Product Name & Description

Bottle Light Bulb is an environmentally firendly, zero emission alternative to traditional light sources or electricicty that is perfectly adapted for electricity poor countries. The project has been taken up by a few NGOs as it utilizes waste materials giving them new purpose.

User: Used small mixed material houses of slums or rural communities to light windowless rooms.

Cost: Mostly self-installed the materials are nearly all salvagable and the cost hovers rounf 1-2 $

Materials/ components: Composed of a plastic bottle filled with water and chlorine fixed directly in the roof.

Technologies: The effect of refractions and Snell's Law allow the outside sunlight to be refracted inside the bottle thus, the house.

Physical attributes: Weight and size depend on size of bottle used but generally around 1.5-2 kg.

Interaction: The solar bottle bulb is fixed in the ceiling and dows not require interaction.

Focus: The focus of this product is to channel light inside the bottle and ridirect it inside the house.

Replicability: The bottle bulb is a simple and easly repitable project, allwoing its wide spread and popularity.

Advantages

- Enhancecs the amount and quality of daylight inside a buiding
- Reduces the need for artificial lighting and energy consumption
- Improves user comfort and pructivity
- Requires a small roof space
- Has 360° lighting
- Creates no heat, no fire hazards
- Cheap and easy to locate materials

Disadvantages

- Dependent on weather
- Littile control over amount of light recieved
- Requires roof access, not for apartemnet complexes
- They require maintenance and if poorly installed might get roof leaks
- Durability depend on water and chlorine, quality of roof and bottle

3.3.4. Case Study: Little Sun - Solar Lamp

Case Study Form

Launch Year *2002*

Product Name & Description

Little Sun Solar Lamp is a solar lamp designed by Olafur Eliasson to adress the 7th SDG, about energy and electricity. The design is meant to be a solar powered solution to the electrification access issue.

User: Intende for rural or sub-urban users that lack safe access to electricity. Can be used both by adults and children.

Cost: Sold by the UN for around 25 $, possibly can be sold at less for higher quantities.

Materials/ components: Composed of a plastic shell (ABS), a LED light, light diffusing lens and a solar panel.

Technologies: The Little Sun utilises a small solar panel to charge the battery, max average 27h of light. The solar lamp is waterproof and the battery's life span is 5 years.

Physical attributes: Weight and size are 12 cm diameter x3.2 cm height for 96 grams.

Interaction: Little Sun only requires one botton push interaction to be used.

Focus: The focus of this product is to provide a 'cheap', movable solar light for poverty-striken populations.

Replicability: Little sun can only be produced with modern machinery and technology and the design is patented.

Advantages

- Enhancecs the amount and quality of light inside a buiding and at night
- Reduces the need for artificial lighting and energy consumption
- Water resistant, ISO certified
- Battery lifespan 5 years (if used properly)
- Creates no heat, no fire hazards
- Full charge in 5 h

Disadvantages

- Dependent on weather
- Produced abroad with modern tech, requiring western patent and knowledge
- Cannot be rapaired or mainteined
- Reliability depends on use

3.3.5. Case Study: Summary

Through the analysis of the case studies it was possible to identify key aspects and features that have allowed these projects to shine in their respective markets. These products come with different costs, both for materials, design and installation, but all use a key aspect: sunlight.

A summary of their features and innovative features are presented below to have a clear set of comparison available and to better grasp the opportunities at hand. Table 4 shows a summary and analysis of the preferred projects using the colour legend of Table 5.

N°	Innovation Feature	Advantages	Tech Level	Replicability	Phenomena
1	Mirrors	Redirect/Channel/ Focus light	Low	Med-Low	Reflection
2	Dome Shaped Aperture	Maximise sunlight channeled	Med-High	Med	Light Refrac-tion
3	Total Inter-na Refelec-tion	Maximise light transport	Low	Med-Low	Snell's Law
4	Deisgn for durability	Good cooling, solar panel and led placement	High	High	PV

Table 4: Shows the summary and comparison of the analysed case studies-

Colour	Meaning
(green)	Good and/or interesting opportunity
(yellow)	Interest but furthere developent/study needed
(red)	Interesting but compex

Table 5: Shows the colour legend for the summary above, and the ones in the future chapters.

4. User Definition

To develop a good understanding of the user, its behaviour and its customary habits in respect to light, an in depth study of the target consumer is necessary. In this chapter context and performance are defined and studied to graps the real needs that the project encounters Through questionnaires and interviews extremely valuable information is drawn which has also allowed to create a family persona, as an example of who will be impacted by this project. This chapter shows the close relationship between the use of electricity and kerosne lamps, by facing the issue in a broad way and therefore favouring a neutral point of view on the matter.

4.1. Context Analysis

For this thesis, South Africa will be employed as a pilot country to 'represent' the rest of the Sub-Saharan regions. It must be noticed that all countries that are part of the Sub-Saharan zone have very different demographic, economical, political and technological achievements and issues, thus the selection is difficult and only one country cannot represent the whole. Nonetheless, South Africa has been through an early, around

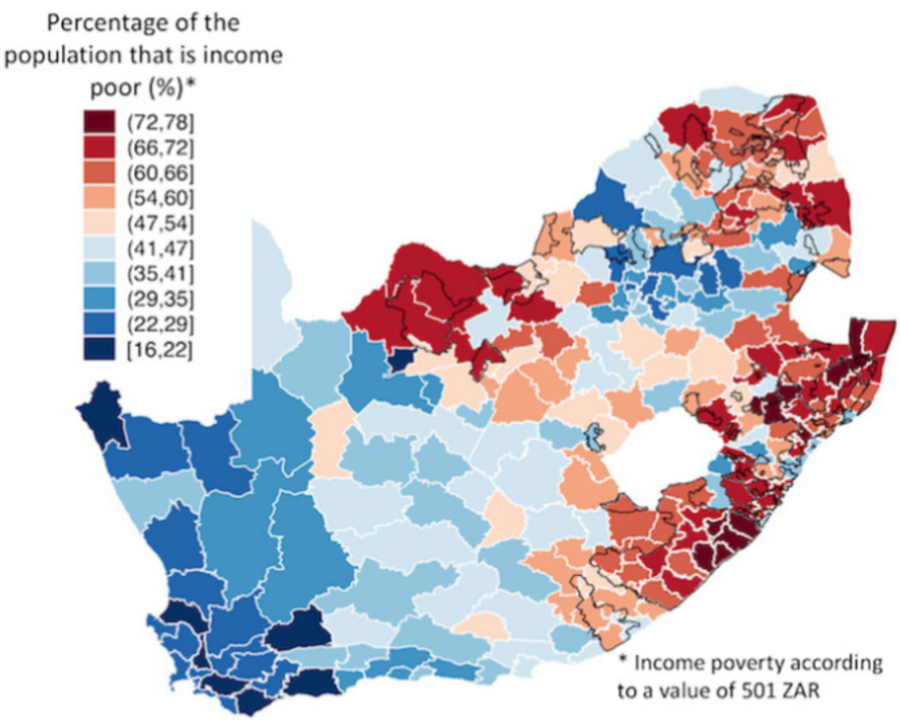


Figure 9: Shows the patterns of poverty across South Africa's Municipalities (2011)

David, Anda & Guilbert, Nathalie & Hamaguchi, Nobuaki & Higashi, Yudai & Hino, Hiroyuki & Leibbrandt, Murray & Shifa, Muna. (2018). Spatial poverty and inequality in South Africa: A municipality level analysis.

the 2000s, economic growth after the apartheid which crashed to nearly zero in 2008 derailing infrastructure and electrification projects that were meant to connect to the electricity grid more than two million people. Figure 9 & 10 give demographic and income information about SA.

In 2008, South Africa, recorded the worst energy crisis leading to urban inhabitants to have limited access to electricity during the day for months and months. Eskom, SA's main electricity provider, undertook massive infrastructure projects to improve the grid and its plants to try to satisfy the growing energy demand. The projects' progress is extremely slow and blackouts continue, even in the capital, up to this day.

Rural, semi-urban and urban areas suffer from this issue, accentuating the core problem of South Africa's electricity grid and infrastructure. Urban slums are characterized by the lack of basic services, electricity access and overall the opportunity for development. These communities living in non-regulated areas, also called 'compounds', are generally

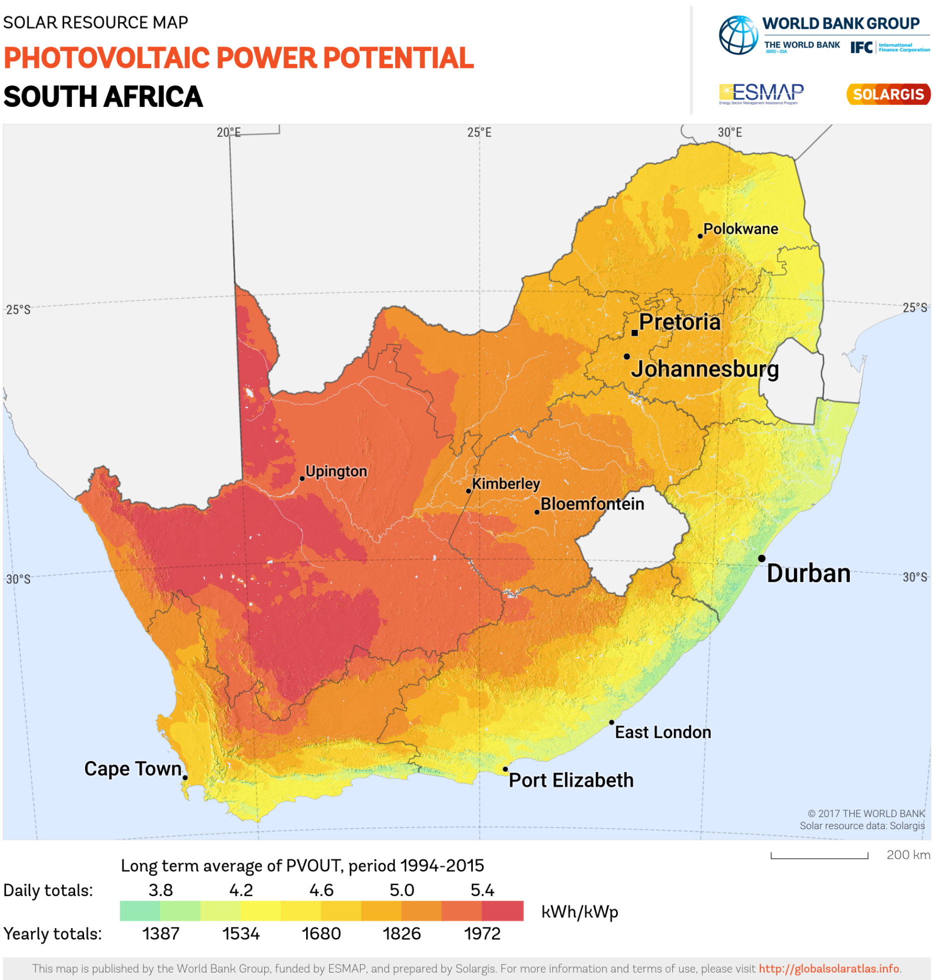


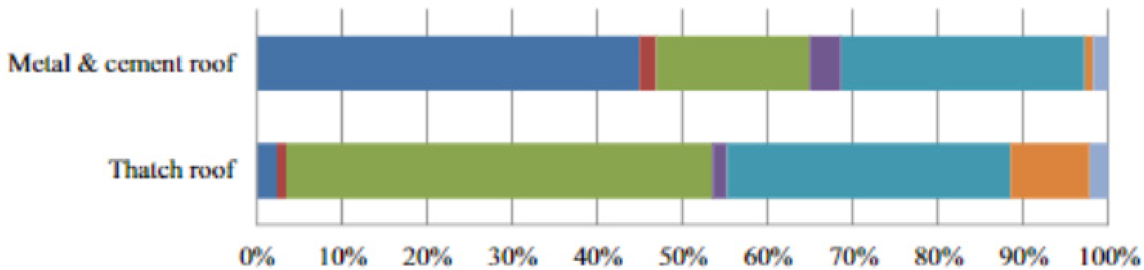
Figure 10: Shows the PhotoVoltaic power potential and the total annual irradiance per area

2020 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis.

excluded from running water, sewers and electricity. Moreover, if electrical access is available its high price and low reliability steer away consumers, making them turn to traditional lighting sources instead, such as candles and kerosene lamps. These lighting sources are used both during the day and during the night, as most houses in the compounds do not have windows or cannot get access to natural sunlight at all. [57]

4.2. Performance Analysis

This project's goal is to develop some kind of ambient light, thus it is crucial to determine the basic aspects and performance of already in use products and focus on their characteristics. The products will be compared on the amount of illumination, runtime (fuel or battery) expected lifespan and possible hazards. These factors are important to have a baseline guide to build upon, however the most vital one is illumination, typically measured in Lumens or Lux, that quantifies the amount of light received on a surface depending on the distance. Ambient lights are usually measured in lumens, as the total of visible light in all directions. [58] The two are linked by the expression of their relationship in an equation: $1\ Lux\ (lx) = \frac{1\ Lumen\ (lm)}{Meter^2}$



	Thatch roof	Metal & cement roof
Electricity	2.3	44.9
Solar	1.1	2.0
Battery	50.1	18.0
Candle	1.7	3.7
Kerosene	33.2	28.7
Solid Fuels	9.3	0.9
Others	2.2	1.8

Figure 11: Percentage of Households by sources of energy, as measured by types of roofs.
Rahut, D., Behera, B. and Ali, A., 2017. Factors determining household use of clean and renewable energy sources for lighting in Sub-Saharan Africa. Renewable and Sustainable Energy Reviews, 72, pp.661-672.

It has to be denoted that an ‘adequate’ light emission is dependent on diverse variables, such as the typology of task to be performed, the surrounding conditions and the user itself. Thus it is necessary to establish a baseline product to be able to use as minimum requirements. The most common lighting source are kerosene lamps, which can differ from hurricane lamps and kerosene wick lamps and affect the resulting illuminance, that emit around 15 lumens. Table 6 shows the comparison of different light sources, whilst Figure 11 shows the relationship between types of roof and how it relates to the use of lighting sources.

Light Source	Type	Wattage (W)	Lux (lm)	Lux Efficacy (lm/W)	Life (h)	Color Temp. (K)
Candle	General	-	5-15	-	340g=60-80h	2500
Incandes-cent	General	60	730	12-20	740-4000	2700-3200
Fluorscent	CFLs	36	2850	60-100	10 000-30 000	2700-7500
High intensity Discharge	Metal Va-pour	80-110	3000-4000	40-150	10 000-20 000	2800-5000
LEDs	Light emitting diodes	5	300-450	90-130	50 000-100 000	3000-8000

Table 6: Shows the summary and comparison of the analysed case studies

Flesch, P., 2006. Light and Light Sources.

The relationship seen in figure 12 can clearly show how solid fuels are used in poorer households (thatch roof) while for richer households (metal and cement) electricity is the main light provider. Furthermore it’s noticeable that both groups still employ kerosene lamps as a source of light independently on the income. To obtain around 4h of light everyday for a month, found to be the average amount used during night time activities, one utilizes around 3 liters of kerosene.[59] The average citizen in South Africa works around 45 hours a week, 195 h per month, but these are ‘standard’ working times do not comply for peri-urban and rural inhabitants who are part of the informal sector in which the majority of the available work is non-regulated and non-taxed, commonly also dangerous and hazardous. Generally during the day, in a household family, the man is out working whilst his partner is cooking and taking care of children. This implies that some kind of energy source is used for light most times and another is used for cooking. Research has shown that when electrification reached the poorest rural and semi-urban populations it was mostly used for lighting and not cooking, leading to the logical conclusion that the availability of electricity cuts in half the consumption of solid fuels sources, such as kerosene or wood. Thus, cooking and lighting are the two main sources of pollutants, health issues and fire hazards in the poorest homes and tackling the lighting source issue and unreliability will trickle down to reduce the need for kerosene for cooking and lighting.

An instinctive solution that comes to mind whilst thinking upon light, is to use battery powered torches, even solar ones, however it has been reported that low cost lights, that come from China, have flooded the African market creating an experience problem: African customers are now skeptical and suspicious of circuit based products. The wave of technophobia has killed years of slow electrification expansion and the adaptation of alternative technologies that aimed at reducing kerosene and solid fuel consumptions. [60]

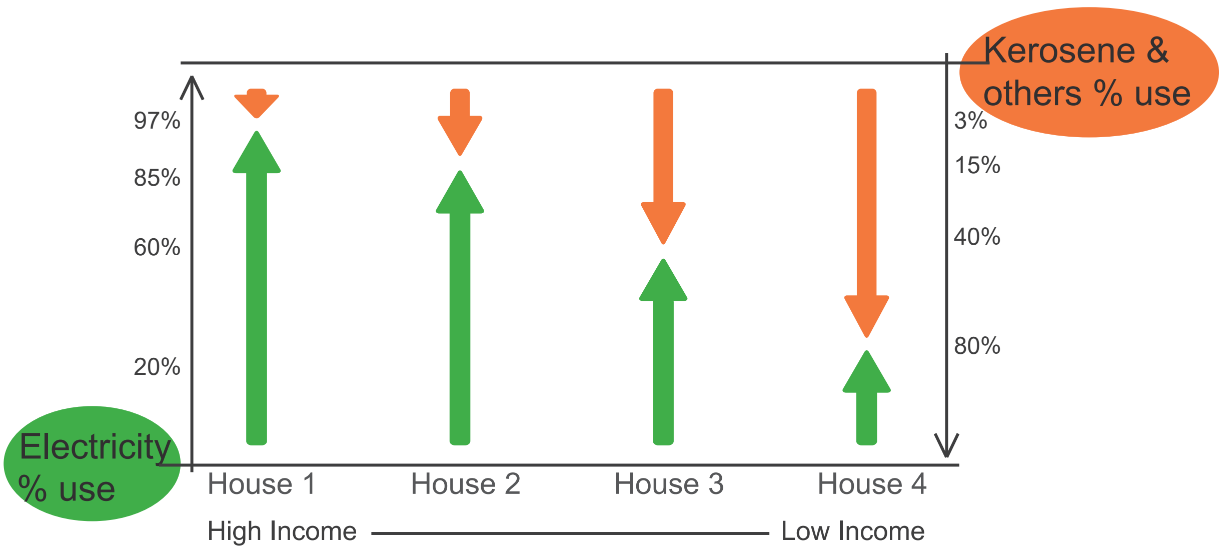


Figure 12: Difference in electricity and Kerosene usage depending on Household income

Data taken from: (Rahut, Behera and Ali, 2017)

4.3. User Questionnaire & Interviews

Due to the nature of this project and the reality that it is to be developed in a foreign country, culture and society, it requires a well defined and understood end users. Two different types of user information collection methods are employed: Online questionnaires and in person interviews. The online questionnaire is created to make a quantitative approach at the issue by diversifying the user range and collecting basic information. This will be used as a basis for developing the product specifications and limitations, however, the face-to face interviews will be adapted to record qualitative data, as it easier to extrapolate necessary answers and insights.

4.3.1. User Questionnaire

The user online questionnaire is composed of around 26 questions aimed at identifying materials, needs, uses and socio-cultural aspects related to light. It can be seen in the appendix A. The questionnaire is a pilot study, due to the difficulty in gathering subjects for the questions, to understand details and non-obvious facts that only inhabitants of the Sub-Saharan regions could know. It is aimed to stimulate and extrapolate key information, from 10 different subjects, both qualitative and quantitative. The questions are divided in three categories: About the subject (who is filling the questionnaire) as general data, about their knowledge on slums and sub-urban dwellings and finally on how they relate to light.

Below are key information and facts extrapolated from the questionnaire.

The majority of the people that have replied are between 18-50 years of age with a good mix of male and female subjects (around 50/50). They were from: Senegal, Nigeria, Zambia, Zimbabwe and South Africa. The variety of countries of origin is good to understand how the Light and Electricity issue is perceived in different cultures and traditions. None of the people that have answered found the living conditions in their area ‘splendid’, the majority (half) found them to be ‘good’, whilst the rest opted for ‘OK’, ‘mediocre’ and ‘poor’. This shows how different living conditions can be similar for users that live in cities or close by. When asked how easily they could access basic services, most questioned subjects in the group of ‘somewhat easily’ with a few of ‘very hard or hard to reach’. One interesting aspect is that all of the people that answered are or have been or lived in rural communities or informal settlements. When asked where, a user answered Zaria, which is one of the prominent cities in Nigeria, demonstrating that poverty and urban dwellers are a reality that even bigger cities face. Another person stated the communal region of Somerset West close to Cape Town showing that informal settlements are closer to the center of big cities. Furthermore, as seen with the examples before, all the participants of the questionnaire stated that the informal settlements or rural communities they visited were in or next to 'very busy' or 'busy' city/ township. An estimate of 4+ people live in a house in rural communities, with around 2 rooms. The presence of electrical infrastructure was denoted in some communities but it also brought the dangers of live wires, cable theft, and increased Load Shedding. Other difficulties have been mentioned such as traveling long distances, also perilous due to criminal gangs and wild animals, to access electricity to charge portable devices, such as smartphones. Recycling and waste management is reported scarce with half the users not utilizing it or just some version of it. Shown in Chart 4, are the percentage results of the user that confirmed the presence of waste/rubbish in their community. Due to that, all users reported that the most common waste were plastic bottles, plastic bags, glass bottles and metal scrap.

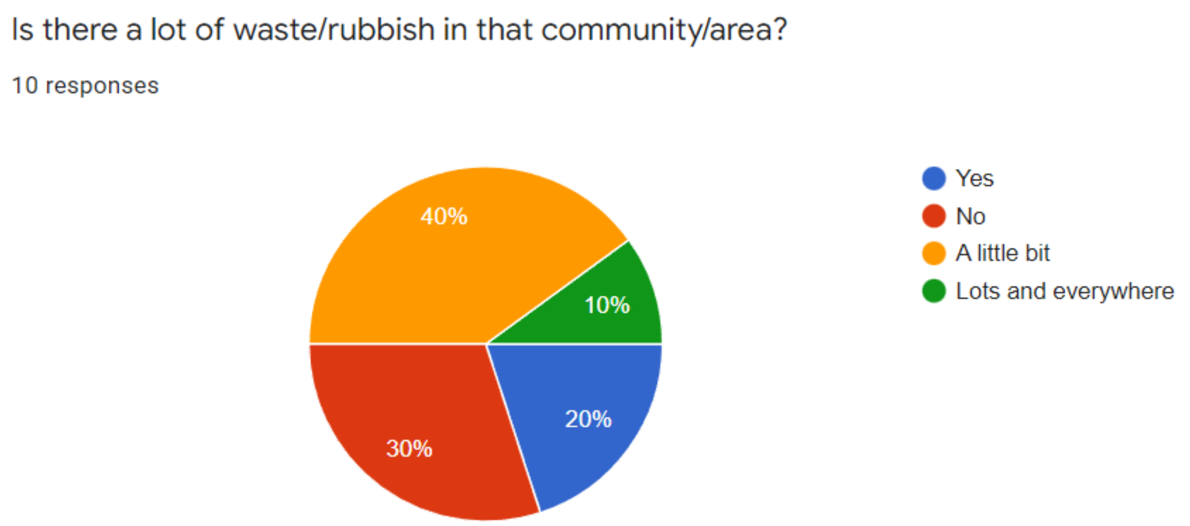


Chart 4: Percentage results of the subjects that reported on the waste/rubbish in their area

When asked if they knew of or had seen phosphorescent products, only half of the participants answered positively. An interesting point is that many use electricity for lighting, nonetheless others are using candles and kerosene lamps. Subjects have also reported that most of their energy source consumption for lighting happened at night/ evening and during the day was limited or absent thanks to sunlight. Users reported an average of 2 h of artificial light during the day and around 5 or 6 h of light during the night. This goes to underline the importance of a night time solution to electricity issues. The answers given for how often and for how long they are left without electricity are eye opening: most of the load shedding happens in the daytime, when demand is at peak, for a few times a day, several times a week for 2-4 h. In a month it is estimated that they 'lose' access to electricity for 48h total. Cost of electricity varies greatly, in some countries it can be more than 600 R (South African Rand) equalling around 35 euros. For rural communities, where electricity access, if granted, lasts only 4 h a day the cost is lower, around 300-400 R.

Finally many users found that light, in their communities and rural communities, is a real need, nearly a luxury in some cases, and that DIY products, of low cost (1-3 $), would be a feasible solution to tackle the electricity crisis. A sumary of the information obtained is presented in Table 7.

Summary of Key information Aquired		
Info	**Why**	**Relevance**
Living Conditions	Only about half of the users recorded a 'good' level of living conditions.	Living conditions are closely associated with physical and mental health, economic stability and overall happiness.
Basic Servicies	To understand access to base level services, such as health-care, public infrastructure and education.	It is key to understand the avail-ability of shops, infrastructure, material and other tools that will be required to build a DIY prod-uct.
Informal Settle-ments & Sub-Ur-ban Dwellers	To see how many and where users had seen/came across these types of settlements and what they know of them, as how many people live in a house.	To understand where they could be, and to validate previous claims, and have real geographi-cal examples of them.
Electricity & Waste Manage-ment	To have an idea of the situa-tion regarding waste and how electricity affected the com-munity, their dangers and the most common waste objects.	Both waste and electricity affect the community as it was found that recycling is hardly present and new electricity infrastructure augmented the already present load shedding.
Phosphores-cence & Light Sources	To understand the relation between users and their light. How they manage it, where it comes from	It was found that more people had used a kerosene lamp than seen/interacted with a glow-in-the-dark product
Light & Costs	To grasp the real require-ments of the users, their needs and how light has/is/will affect the community	Understanding the real need for light during the night, more than during the day. As it was found the majority of the users employed electricity, candes and kerosene lamps at night be-tween 2-6 h each night.
DIY & Handiness	To evaluate the level and capability of the users to rep-licate a DIY project of low-me-dium-high difficulty and under-stand if they would be able to make it.	Necessary to grasp level of knowledge on the materials and technologies, their perceived cost and possible difficulties they might encounter.

Table 7: Summary of the Key information collected

4.3.2. User Interviews

The user interviews are carred out face to face, whithout following a specific script.

The subjects are filled in with the details, goals and prospects of the thesis, and are questioned on their knowledge of electricity, powergrids and powerlines, their own experience with kerosene lamps and the dangers thereof. Furthermore, they are allowed to express any thought, idea or advice that they deem appropiate for the tesis.

Nonetheless, questions about light and their cultural/socail relations are proponed, but generally found hard to get similar answers.

For the privacy and safety of the subjects interviewed, only their initialy will be shown and segments of the interviews reported, moreover many did not want to be recorded for personal reasons.

INTERVIEWEE N°1 - O.M.

When questioned about electricity:

"*Electricity is beneficial but soon becomes a problem when it starts to be stolen, through unsafe illegal connections, and soon enough it will start to overload the power line*s."

Questioned about the conditions in the infrmal settlements:

"*The slums are very clustered, many people (5ish) live in cramped spaces and when it rains everything becomes muddy and unhygenic. There is rubbish and waste everywhere on roads, some is due to the thatch/tin shaks that break or loose piecies when its windy or there is a storm.*"

Questioned about waste and recycling:

"*There is plenty of tin and alchol bottles, journal paper, plastic waste is the most common. The problem is the recycling is nearly inexistent and people do what they can - burning trash is most common*"

When questioned on electricity costs and blackouts:

"Electricity is relatively expenive - paid in 'units' - 2 euros=18 units= around 2 days of electricity. The electricity goes first to the richest part of town, as the poorest view it as a luxory. There's also the possibility to buy electricity from the black market".

When questioned upon light and its color:

“*Light depends on the individual, families maybe prefer white light, but generally it is not of great importance the color of light but more that it is available.”*

INTERVIEWEE N°2 - S.B.

This subject was older and gave very interesting advice on how fast the energy industry grew and how it affect the locals.

When questioned about electricity in general:

“10/15 years ago, there was nearly no electrical power lines and infrastructure. People lived very simple life with candles and firewood. The advent of electricity changed the way people lived, difference of waking up at sunrise and bedtime at sunset, and how they approached light. Now we live for electricity, and whom cannot pay lives without.”

When asked about rubbish and waste management:

“in my city, now there is waste ‘recycling’ but before there was also less plastic and imported product waste. It is because of these inports that the recycling process is built. But generally it is not much different from a small european city.”

When questioned about light:

“In europe its normal to have light, not even thinking about it. In africa light is, for those who have less, a need or nearly a problem.”

INTERVIEWEE N°3 - K.B.

This subject , who was a young adult, was a bit reluctant to be interviewd but realeased some very interesting point of view. Instead of commenting and answering the questions about the thesis, he/she only expressed an overall opinion upon the project’s goal and target users.

When asked to comment on the project’s idea and innovation:

“*African governments eliminate people who come up with alternative solutions to any socio-economic problem. When your thesis is done, go knock at the doors of SA’s state power utility, present your innovative ideas & let’s see if you will stil be alive within a month.*”

When asked to comment on the previous comment:

"I fully understand your perspective. We are currently experiencing load-shedding in a country that has abundant supply of coals & sunny days. ANC in state is intending to reverse us back to the dark ages. Eskom is managed by stubborn bureaucrats, who are just there to embezzle SoE finances. There is no cutting edge research into futuristic, sustainable power supply within eskom. Who will Disrupt this dinasour corporation?"

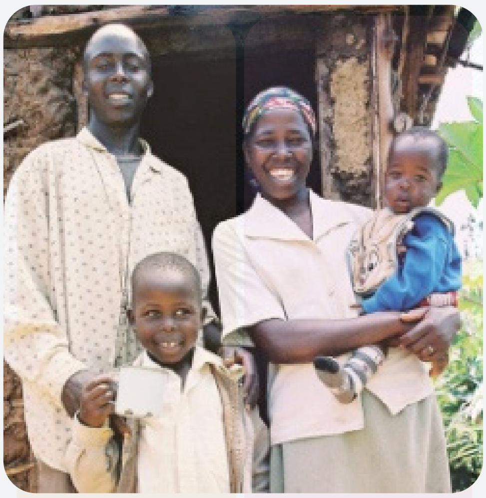
TO CONCLUDE

After these three very different types of interviews and subjects, many points come to the surface.

1. They are somewhat proud people and sensitive about the topic
2. The situation in Africa, overall, has improved over the years but is still being led by poiticians and bureacrats that cannot see the potential
3. Eskom has the monoploy on Africa's electriccity and is not liked by everyone
4. The issue of light is a recurring problem and has imporved very slowly
5. Waste and recycling management is resent but still lacking to support the required amout of rubbish present
6. Waste and materials are ready available, in sub-urban areas
7. Electricity is viewd as a need, but sometimes as a risk or problem

4.4. Family Persona

After gathering information directly form the subjects a family persona is created to rapresent the target market of this project. Through the studies presented in 4.1, 4.2 and 4.3, the information was gatehred and transformed into the needs of a simulated family. It is important to visualize how the information collected traslates to specific needs and requirements of a family.



Dlamini Family

The Dlamini family lives in the out skirts of Pretoria, in a peri-urban informal settlement. The father, Lethabo, works partime in a shop from dusk to dawn most days. The mother, Amahle, cares for the children and the house whilst Lethabo is at work. She endulges in cooking and cleaning activities but also worries about providing the best future possible for her kids, Enzokuhle and Lubanzi. The family leaves close by a city but they have little basic servicies available, however, they can easly get access to basic tools and materials. Their house is a simple two room shack and metal roof made from salvaged material.

Lethabo
Father
29 years old
Manual Worker
Pretoria, SA

Amahle
Mother
26 years old
Housewife
Pretoria, SA

Enzokhule
1st Child
8 years old
Student

Lubanzi
2st Child
2 years old
Child

Energy Needs

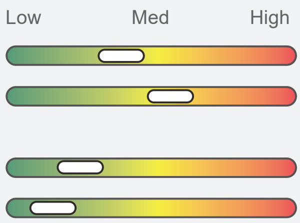
- Light 8 h in total (4h during the day, 4h during the night)
- Cooking 4 h a day
- Cleaning 2 h
- Extra 1/2 h

- Indoor activities 4h (2h day, 2h night)
- Education 2 h
- Extra 2

Expenditures ($):

Lighting
Elecrticity
Kerosene

Cooking
Firewood
Kerosene



% of Income:

Total Avg. - 2500R
Electricity - 25/35%
Kerosene - 20/30%
Firewood - 5%

Family Goals

1. Reduce expenditure for light
2. Improve health and safety for the family - less fire hazards and pollutants created by fuels
3. Find safe possibility of night reading - starting from their children's education
4. Dependable and simple solution for day-night lighting - cost saving
5. Save money for future expenditures, issues or opportunities
6. Invest in their children's education by buying books and school supplies

5. Research Findings

From the research carried out the key points on which the research will contiue are:

- Scientific understanding of the phenomena that employ the sunlight
- In deapth product understanding and analyisis
- Night light solution and Study

A conclusive summary of the lesson learned are presented below to recap what has been understood from the previous chapters.

5.1. Key Findings

Through the study of products, infrastructural agencies, governmental bodies and local resources, a general view of the future work and research is generated. The problem analyzed is not only real and looming over South Africa but also all over Africa. Power outages, black outs and overall low rate of electrification have created a cycle of poverty that cannot be easily halted, because the local authorities have largely failed in tackling the problem at the source and have been misled by political and financial gains.

The most intuitive solutions, such as solar panels and rechargeable batteries, have a limited effect due to the difficulty of adaptability of their systems and the issue of foreign products and technology requiring foreign technicians and electricians.

A simplification of the available options studied and analyzed is shown in Figure 13, where the use of solar energy is of notable nature.

Through the semiotic analysis carried out to better understand the impact of foreign projects upon culture, societies and traditions, it was understood that a proper project must consider and understand the relationship between the end user, subject, and the product, object, and how these factors play out both for the individual and the community.

By empowering individuals to create themselves their much needed non-harmful light source, it is possible to say that they create their own future. By understanding the project, the process, the benefits and science behind it, they can also further adapt it to other needs such as cooking, water and overall save money and resources that can be used in other aspects of their life.

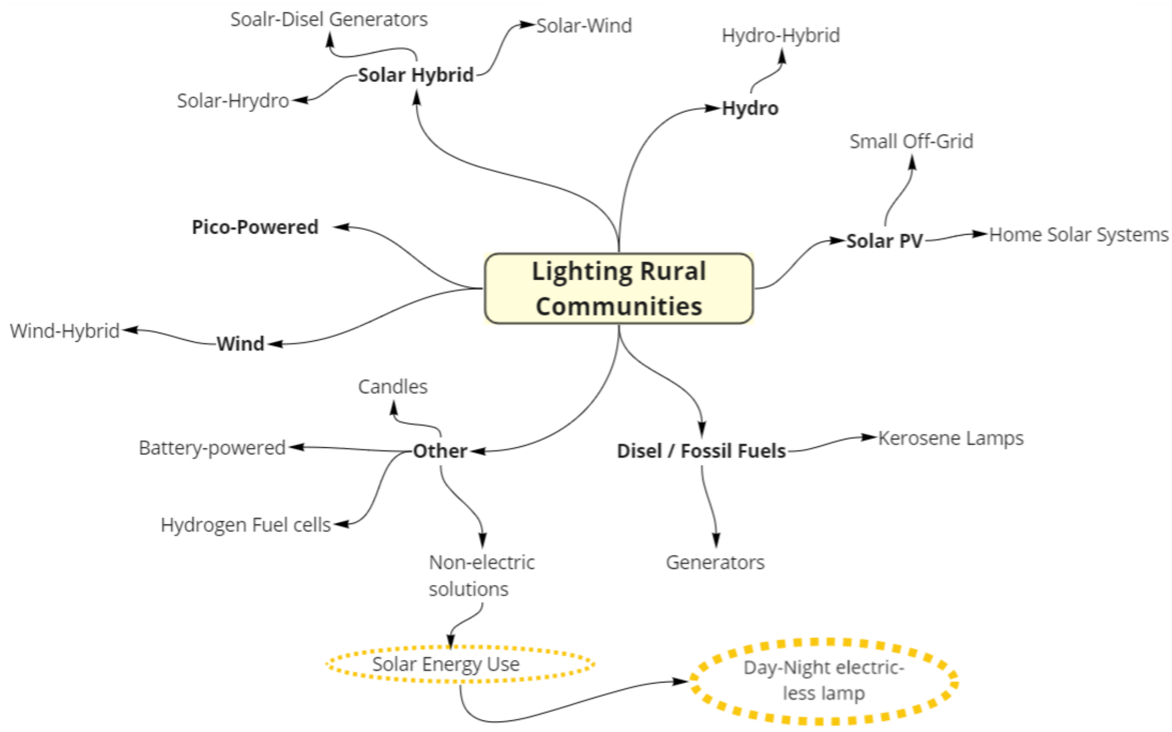


Figure 13: Shows proposing all found Lighting alternatives, underlining the final choice

5.2. Key points to Solve

The generalities of the project have been understood and recorded however, further details must be scrutinized to ensure a clean and just delivery of the final product.

Nonetheless, it must be said that technology cannot be excluded completely, such as solar panels, batteries and LEDs, thus further in depth research to grasp their real validity for this project is required.

Below, Table 8, shows further key points of interest and necessary research drawn upon the user research and questionnaires.

What is to be researched	Why	Its Importance
Science behind light transport	To ensure efficiency and efficacy	Deliver a through-and-through project
Existing products for light channeling	Investigate possible opportunities and solutions	To ensure the best lighting outcome
Night time lighting opportunities	To investigate what methods would be most appropriate	To face the lack of simple, costless, night lighting
Lenses and Screens	To understand if there is a real opportunity in this field	Lenses and screens are key for light diffusion and concentration
DIY PV solar cells and Panels	Understand possibility of hand-making solar cells	Project must empower user to make own light source

Table 8: Summary of the Key information collected

6. Further Research & Alternative Light Solutions

This DIY project requires a great deal of research as its simplicity and physical restraints limit it to study in depth scientific and physics phenomena that can enhance the illuminance outcome. The experimentation, testing and development of this project will follow the studies presented below on how to magnify and utilize at best what is provided by the natural sunlight. It is a necessity to evaluate the feasibility and reality of the presented scientific phenomena to be then applied to the project.

6.1. Total Internal Reflection, Refraction & Snell's Law

The most common and basic light physical phenomena is the theory of refraction of light rays. Light acts as both a particle (photon) and wave. Refraction works when light passes from one media to another, such as air and water. This theory is utilized in the previously mentioned Solar Bottle Lamp project, where light is 'channeled' in the water filled bottles, placed in the roof, and because of two fundamental optical effects: Total internal refraction and Snell's Law. Light rays penetrate the bottle and due to the different densities of the media, it 'bends' allowing a greater stream of rays to reach the bottom of the bottle, thus, more light enters the room. This is explained by Snell's Law: "the relationship between the path taken by a ray of light in crossing the boundary or

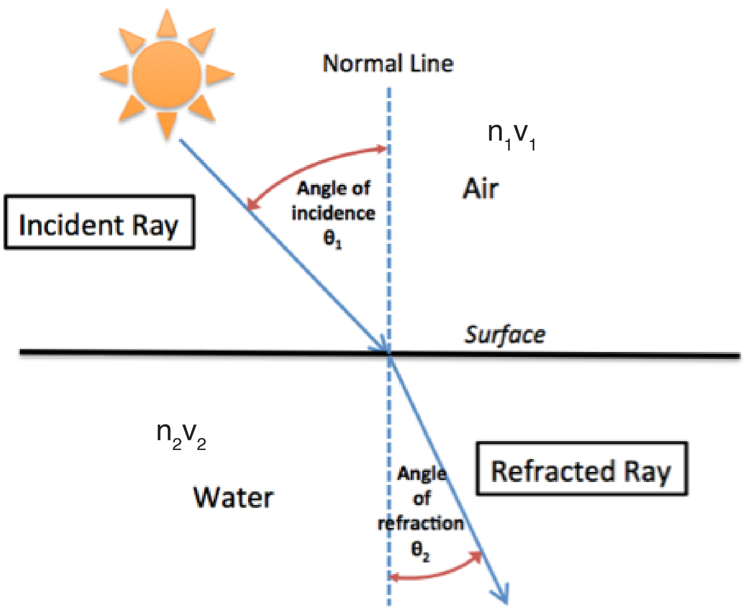


Figure 14: Rapresentation of Snell's Law

(study.com)

surface of separation between two contacting substances and the refractive index of each."[61] Snell's Law is rapresented by Figure 14.

As light going through air encounters a denser media, such as water or glass, it slightly deviates direction due to the change in refractive index (n). Figure 15 depicts the aforementioned phenomena, as the light ray 'shifts' to a lower angle of refraction. Due to the differences in densities of the materials the velocity of light will be affected and, thus, the refractive index, as its calculated by n=c/v, rearranged as v=c/n , for different materials. Snell predicted that the velocity over the sine of the angle would predict the resulting deflection of the light ray by saying $v_2 Sin_2 = v_1 Sin_1$, where v_1 and v_2 are the respective velocities, and by substituting in v=c/n and deleting 'c' to obtain:

$$n_2 Sin\theta_2 = n_1 Sin\theta_1$$

Where θ_1 and θ_2 are the angle of incidence and refraction.

To continue on the explanation on how the solar bottle works, the light enters the bottle and reflects inside of it. The key effect of reflection is that, as light passes through two transparent media, as in air and water, light is reflected, with a slight loss, but as the light ray's angle increases it will soon reach the Critical Angle and achieves Total Internal Reflection.

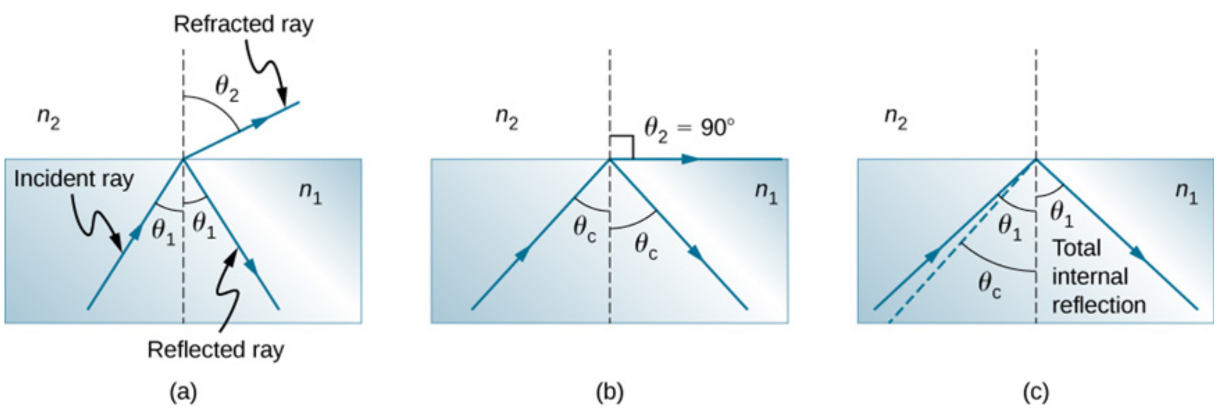


Figure 15: Showing (a) refraction of incident ray, (b) the critical angle and how its obtained and (c) the effect of Total internal reflection

Buphy.bu.edu. 2022. Refraction, Snell's law, and total internal reflection. [online]

It is to be noted that total internal reflection only works when the light is emitted already inside a denser media, as it starts in water surrounded by air. Figure 14 shows how the critical angle is reached, by increasing the incident ray until the refracted ray has a 90* angle, thus, when $\theta_{1incident} > \theta_c$, total reflection occurs. [62]

6.1.1. Real Life Application: The Solar Bottle Bulb

In the case of the Solar Bottle Bulb, the bottle acts as a 'lens' for the sunlight, capturing and redirecting it, through the previously explained effects, the light is reflected and refracted inside the room at 360°.

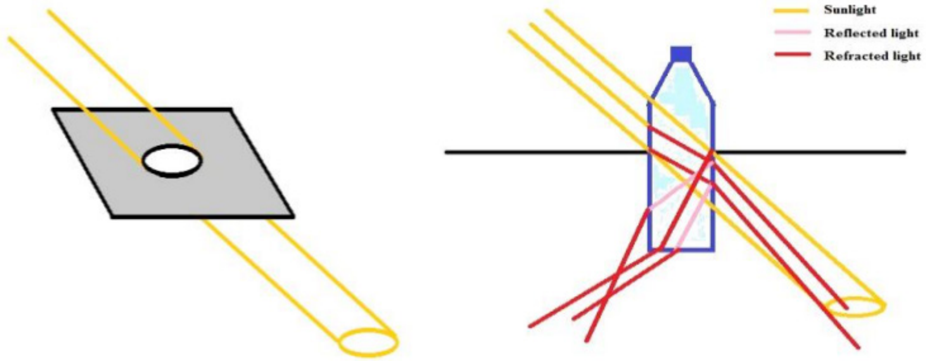


Figure 16: Illustrating how much sunlight is captured, using the Solar Bottle Bulb and not

Wang, C., Rahim, F., Yusoff, N., Rahman, H. and How, V., 2015. Critical View on Daylighting Through Solar Bottle Bulb. Building Research Journal, 61(2), pp.115-128.

Figure 16 shows the effectiveness of the solar bottle bulb in capturing more light, not only by having a greater collection surface area, but also by utilizing the previously mentioned effects. To better understand how truly effective this project is, a table for comparison against the normal light bulb is shown in Table 9, and in Table 10 its advantages and short-comings.

Solar Bottle Bulb	Conventional Light Bulb
Reflective/Refractive light output: around 60W on a clear day Light propagates 360* for 40m2 Low heat produced No pollutants produced Low costs Saves on electricity and solid fuels	Carbon footprint: 0.45 kg CO2 Heat by the light: 90% of power consumed emitted as heat energy Usage: 50 Watts run for 14 hours a day Electricity consumption: – approximate 0.77 kg CO2 per kWh – 16.17 kg CO2 per month – 200 kg CO2 per year

Table 9: Comparison between the Solar Bottle Bulb and the conventional light bulb

Wang, C., Rahim, F., Yusoff, N., Rahman, H. and How, V., 2015. Critical View on Daylighting Through Solar Bottle Bulb. Building Research Journal, 61(2), pp.115-128.

Advantages	Disadvantages
Natural light color No glare Cheap and easy to find materials No pollution (even upcycle trash) Easy fix and maintenance Reduces fire hazards No running costs	Durability is dependent on use and prior material integrity and quality Must be monitored Only during day time Not as effective in cloudy day

Table 10: The advantages and disadvantages of the Solar Bottle Bulb

Wang, C., Rahim, F., Yusoff, N., Rahman, H. and How, V., 2015. Critical View on Daylighting Through Solar Bottle Bulb. Building Research Journal, 61(2), pp.115-128.

These two tables demonstrate the validity, feasibility and opportunity for improvement of the Solar Bottle Bulb project.

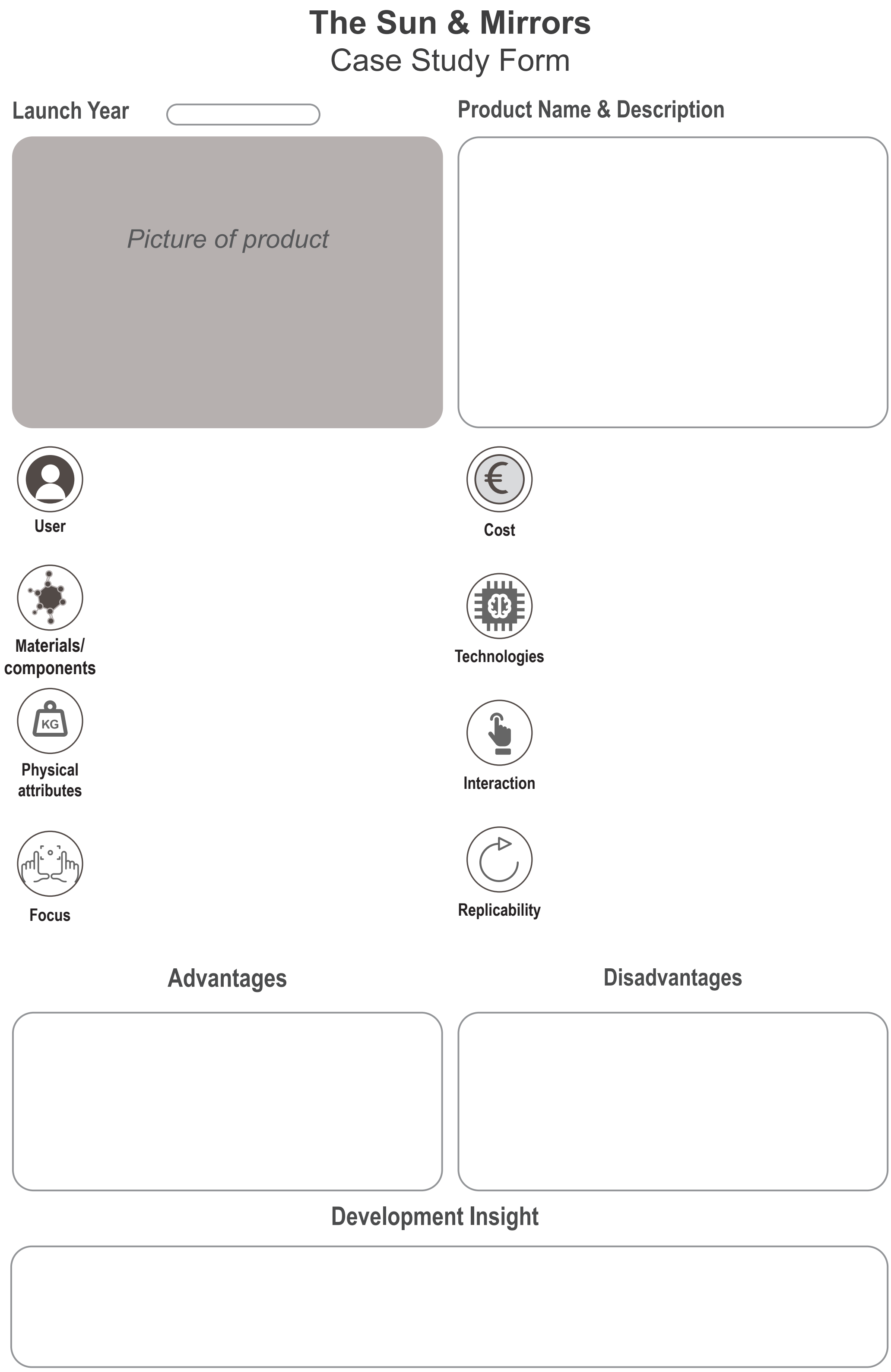
The effect of light refraction, reflection and snell's law are applied in other products such as light wells, light pipes, dome skylights and solar cookers, all functioning without the use of electricity. It is of interest how other effects, such as the heat created, can be employed to make this project more complete. [63]

6.2. The Sun, Mirrors and Reflection

During our everyday routine we come across a variety of mirrors, from more apparent ones like the ones in our homes orto some unexpected ones, like car mirrors. But their value is not limited to those uses, as they can also be found in space telescopes and even to see even the smallest cells, with a microscope. The true power of the mirror is its ability to nearly perfectly reflect light. For its application in this project, a mirror, or highly reflective surface, will prove key to enhancing the ability of the sun to light up a house. By channeling and reflecting natural sunlight, it is possible to receive a full spectrum of light, from the warm infrared waves to the beneficial UV radiations (to be noted that they are harmful in high quantities), which positively affect the mood and creates vitamin D in our body. Mirrors can be employed as simple light reflectors, such as if you place them outside and point the sunlight inside your house, but through a series of modifications it is possible to obtain a better effect, such as for light shelves and pipes. There are a series of products that employ the sunlight and/or mirrors to create an enriched result.

For this reason a series of sunlight using products will be explored and compared to better grasp their advantages and possible uses/inspiration.

6.3. The Sun & Mirrors: Case Study Form



6.3.1. Case Study: Solros

The Sun & Mirrors
Case Study Form

Launch Year 2018

Product Name & Description

Solros is rervolutionary system that through the use of a sun collector, or concentrator, it channels sulight through fiber optic cables to be able to deliver it to darkest rooms in your house thorough a Luminaire, a light diffuser. Solros follows the sun for a full day worth of light.

User: Intended for anyone that requires basement lighting and has easy acces to the rooftop.

Cost: Complete installation for around **4500$**, Concentrator sold for **1800$**

Materials/components: The 3 main components, Concentrator which is a concave mirror, the Light cable, which is fiber optics, and the Luminaires which are lenses.

Technologies: Solros uses technology and algorithms to trace the sun, an app to controll it. The true innovation is the concave sunlight collector that reflects and focuses it inside the optics cables.

Physical attributes: Solros concentrator:
13557x575x720 mm (HxWxD)
15 kg

Interaction: Solros is controlled via the app and can be installed by any '**handy person**'.

Focus: To collect and ridirect sunlight inside the house, easy to install and aimed at, mostly, well-off city folks.

Replicability: Solros is only produced by the company, and has limited market penetration at the moment.

Advantages

- Utilises natural sunlight
- Very little light is lost
- Relativley easy installation

Disadvantages

- Cloudy days and night not in use
- Quite expensive, even for function
- Installation requires a medium level of handyness and expertise in placing fiber optic cables

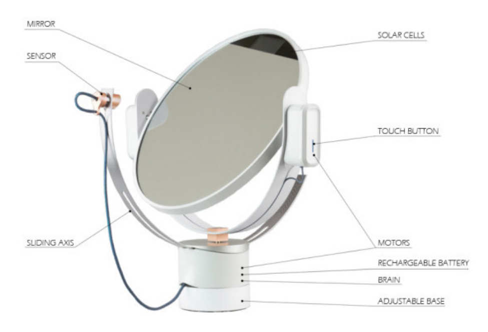
Development Insight

- **Concave mirror** allows for focused collection of light from a larger area
- Follows the sun light
- Utilises glass and plastic fiber optic cables to channel and direct the collected light

6.3.2. Case Study: Caia (Selenca)

The Sun & Mirrors
Case Study Form

Launch Year 2016



Product Name & Description

Caia illuminates the rooms where its placed, redirecting the sunlight with its flat mirror. Caia follows the sun during the day making adjustments to always have the best lighting results. It doesnt need external power as it draws its energy from its pre-installed solar cells.

User: Intende anyone that lives in **cities small apartments** and does not receive enough sulight. Most of the time indoors.

Materials/ components: Most of the external shell is in aluminium, few plastic covers, the mirror, solar cells and sensor. Internally there are the battery and ‘brain’.

Physical attributes: Around 500x500x 150(HxWxD) 3-5 kg - consumption of 10 W

Focus: To detect and redirect the sunlight inside a dark room by remembering an indoor location chosen by the user.

Cost: Non-final cost 300 $, still has to be placed in the market.

Technologies: Caia constantly takes light intensity readings using her sensor array. Once you aim the pointer where you want to redirect sunshine, Caia’s proprietary algorithm uses the light intensity values to position her motorized mirror at the correct angle of reflection to illuminate your chosen indoor spot.

Interaction: Caia is equipped with a tuch button that is used to turn it on and choose where to ridirect the light.

Replicability: Caia is a highly engineered product that relies on different technologies. It consists on many components and piecies of hardware.

Advantages

- Utilises natural sunlight
- Very little light is lost
- Relativley easy installation
- Flat mirror - no fire hazards
- No extra power needed- solar cells present

Disadvantages

- Cloudy days and night not in use
- Quite expensive, even for simple function
- High costs relatively low rewards
- Lots of tech for a moving mirror

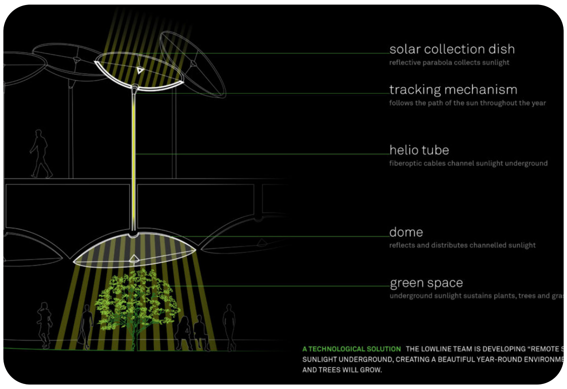
Development Insight

- **Flat mirror** to reduce fire hazards
- Follows sun
- Redirection and reflection of sunlight - reatively simple effect

6.3.3. Case Study: LowLine

The Sun & Mirrors
Case Study Form

Launch Year *2009*



Product Name & Description

LowLine is an innovative new project currently underway that will transform an abandoned trolley terminal into an underground garden through the use of advanced solar technologies. This technology would transmit the **necessary wavelengths** of light to **support photosynthesis,** enabling plants and trees to grow.

User: Intended to bring natural solar light in dark underground areas by collecting and redirecting sunlight to create a natural ecosystem underground.

Materials/ components: The aboveground part is a sun collector made form a concave screen protected by a infrared shield. Then the light is transporeted by tubes with focus lenses and then diffued.

Physical attributes: Caia:
Around 1000x1000x 1000 mm(HxWxD)
10/15 kg

Focus: To create a "remote skylight" only utilising the natural sunlight.

Cost: Never entered market, in 2018 project halted.

Technologies: Sunlight passes through a glass shield above the parabolic collector, and is reflected and gathered at one focal point, and directed underground. Sunlight is transmitted onto a reflective surface on the distributor dish underground, transmitting that sunlight into the space.

Interaction: Very little interaction is required to allow LowLine to function, except installation.

Replicability: The technlogy behind LowLine is quite simple, however, advanced manufatruing techologies and experitse are required for all to function.

Advantages

- Utilises natural sunlight
- Very little light is lost
- Infrared radiation shield
- Concave mirror with prism focusing
- No extra power needed

Disadvantages

- Cloudy days and night not in use
- Quite expensive, even for simple function
- High costs relatively low rewards

Development Insight

- **Infrared radioation shield** to reduce heat but allow UV radiation for plant growth
- Light channelled through tubes and lenses

6.3.4. Case Study: 4Life (SolarSack)

The Sun & Mirrors
Case Study Form

Launch Year 2010

Product Name & Description

SaWa (SolarSack) innovation lies in its human-centered product design using a bottom-up approach. This approach ensures it is widely adopted by the users in context. **The SODIS process** removes harmful pathogens by harnessing UV-rays and heat from the sun. UVA forms Reactive Oxygen Species in the water that play a critical role in deactivating the microorganisms. UVB directly damages the organism's DNA and RNA.

User: Anyone that requires clean water can use the simple sodis process to clean it. Mostly for underpriviledge areas.

Cost: **1-5 $** total costs of delivery and transport may vary the final cost.

Materials/ components: SaWa is made of soft plastic, such as PTFE, and can easly withstand the sun, possibly a UV stabilizer. Other plastics can be used too, as HDPE, but UV radiation breaks the chains after som etime.

Technologies: Uses the Solar Disinfection effect where the UV radiation, over time, kills bacteria and any DNA of anything present in the water.

Physical attributes: LowLine collector:
Around 600x400x 100(HxWxD)
0.7 kg epty4.7 kg full

Interaction: SaWa is simple, the user fills it with murky water and then the sack is palced on the roof. It has a handle for carrying and a hole for stoarge.

Focus: Utilise the Sodis to clean water. A full sack **(4l) is cleaned in 4 h**.

Replicability: The process behind SaWa is highly replicable, however, the product designed and manufactured to be cheap and sent as humanitarian aid to clean water-poor communities.

Advantages

- Utilises natural sunlight
- Relativley easy to use
- Cleans water in 4 h during a sunny day
- Cheap
- SoDis Process higlht replicable

Disadvantages

- Cloudy days and night not the best
- Manufacturer advises 500 uses = 6000 l of water purified
- Requires to be sold and distrubuted from abroad

Development Insight

- **The use of the SoDis process to clean water - natural process**
- Clever use of materials and design

6.3.5 Case Study: Sun Stove - SunFire Solutions

The Sun & Mirrors
Case Study Form

Launch Year 2015

Product Name & Description

The ***Sun Stove*** is a Slow Solar Oven produced from recycled plastic.
Solar Ovens allow light into the oven chamber trapping heat in the same way as a Green House does for plants. SunStoves take about twice as long as conventional ovens but dont need adjusting to the sun. Never worry about burning food or switching the oven off again.
Simple, easy and VERY, cost effective.

User: Anyone can use the Solar Stove, all is required is a nice sunny day and plenty of time.

Cost: 875.5 R (ZAR) equals to around 51.5 euros.

Materials/ components: Injection moulded, recycled plastic box, glass fibre insulation, heavy duty aluminium reflector sheets, and Perspex lid

Technologies: Solar cooker has a reflective inner surface and perpex lid to trap solar radiation and can reach 124°C. Can bring water to the boil in 60 minutes. Safe and easy to use

Physical attributes: Weight: 4.3Kg
Dimensions: 780mm x 360mm x 580mm

Interaction: Very safe and light, needs little supervision, unattended cooking possible, food doesn't burn or boil over.

Focus: To use the sun's heat to cook, as a slow cooker, without risks of fire or burining food.

Replicability: The idea behind the Sun Stove is sulight reflection and redirection to concentrate it on the cooking pot. It uses mirrors to focus the light.

Advantages

- Utilises natural sunlight
- Easy to use
- Safe, no risk of fire hazard
- It's made and distributed already in South Africa

Disadvantages

- Cloudy days and night not the best
- Requires lots of time to cook or boil water
- Its a bit expensive for lower income groups

Development Insight

- **Clever use of sunlight** for cooking and daily purposes
- Can be used to clen water
- Extremely easy to use

6.3.6 Case Study: Key Innovation Summary

In the above analyzed case studies different methods, physical phenomena and materials are employed to achieve a certain goal: use the sunlight and its physical characteristics to cook, purify water and as a light source. The key innovative features and their advantages are listed and compared to better grasp what could be implemented in this project. Each feature is described against three characteristics: technological level, its replicability and the physical phenomena that makes it possible. This comparison helps understand how suitable for this project they are and how easily they can be adapted by different users.

N°	Innovation Feature	Advantages	Tech Level	Replicability	Phenomena
1	Concave/flat Mirrors	Redirect/Channel/ Focus light	Low	Med-Low	Reflection
2	Follow the sun's movement	Maximize sunlight utilized	V. High	V. Low	Light Refrac-tion
3	Infrared radia-tion shield	Reduce heat transported	Med-High	Med-Low	Snell's Law
4	SoDis Process	Naturally clean water	Low	High	PV
5	Solar Cooking	Simle and Safe cooking method	Low-Med	Med-High	Heat Radia-tion

Table 11: Shows the summary and comparison of the analysed case studies

It is possible to further draw conclusions from Table 11, such as that mirrors can be employed in different shapes and sizes to obtain different effects as simple light reflection for light purposes but also for their ability to transfer the full light spectrum, both heat as infrared radiation and UV radiation. Furthermore, radiation can kill bacteria and microorganisms due to the presence of UVA generates reactive oxygen species that gradually deactivate microorganisms and UVB directly impacts the DNA and RNA of the organisms. [64] This goes to show the extent of the possibilities that are available to utilize the sun's energy and light and employ them in overall simple but effective projects. The true conclusion to take in this aspect, is that even with a simple mirror, plastic bag or bottle one can help themselves without the aid of expensive designs, materials and manufacturing processes.

6.4. Luminescence, Fluorescence & Phosphorescence

The three above 'glowing light' reactions and phenomena are somehow similar however, they sprout from different physical mechanisms' effects. The importance of these outcomes for this project is derived from the issue of providing light during the night without the direct use of electricity. This implies that the simplest solution, solar panels, will not be considered as a first option due to its very technical nature, cost and difficulty to maintain and repair them without trained technicians.

Nonetheless, Luminescence is described as any emission of light, as in electromagnetic waves, from a substance, not arising from heat. The process of giving off light.[64]

Luminescence can be classified and differentiated by the energy source that triggers the luminescence process. A general overview of the distinctive traits of luminescence are provided in Figure 17, where many of the mentioned phenomena have key scientific and industrial applications.

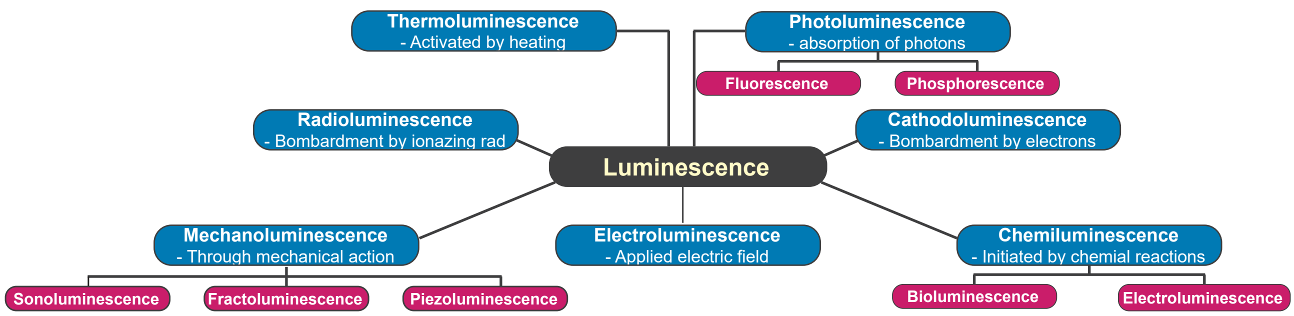


Figure 17: Types of luminescence and their perspective energy sources

Fluorescence, Phosphorescence and Photoluminescence Differences (edinst.com)

Many of these effects are very useful in manufacturing and commercial applications, whilst photoluminescence, fluorescence and phosphorescence can be found and seen in everyday objects.

To put it in simple words photoluminescence is when a substance glowing effect is triggered by light photons. Instead for fluorescence and phosphorescence it is the ability to absorb light and subsequently emit light of lower energy, longer wavelength. The real difference between the two phenomena is the time frame in which they are able to emit light. Fluorescence's emission is almost immediate but the source of light photons must be constant, whilst for phosphorescence the material stores some energy to be released later on, ultimately giving it an 'after-glow' response. This effect can survive for a few seconds to a few hours depending on the material and time of irradiation.

Nonetheless, all three effects are related to electronic (electron) excitation, where a molecule-bound electron absorbs the photon's energy and, thus, becomes excited translating the electron from ground state (S0) to an excited state (Sn) nearly spontaneously. Then, the emitted light will be due to the electron falling back down excited states and releasing energy in the form of a depowered photon, which results in a different wavelength and, so, color spectra. [65]

6.4.1. Reason for Interest

The phosphorescence phenomena is a logical solution to night light without electricity. Its delayed luminescence is related to the radiative decay of the molecular-bound electron from excited states.

The use of phosphorescent products, paints, and pigments is starting to have more attention in the market as its applications and physical range have grown. Typically phosphorescent materials include zinc sulfide and strontium illuminate for a yellowish green light and calcium sulfide for a reddish glow whilst metal-earth silicate blue. The range of color, the flexibility of adaptation and the range of possible scopes has led to some advancements in its field. For example the newly and improved 'long persistent green phosphor' is composed of europium-doped strontium aluminate, that is a luminescent compound which can be used in applications where persistent luminous paint, ink or ceramic is required. Its peculiarity also arises by its variety of synthesis methods as sol-gel, hydrothermal synthesis but also traditional solid-state reactions and combustion reactions. Figure 18 shows the most common phosphorescent compounds.

Zinc sulfide (left) and strontium aluminate (right), in visible light, in darkness, and after 4 minutes in the dark.

Calcium sulfide (left) and metal-earth silicate (right) phosphoresce in red and blue respectively.

Figure 18: Most common types of phosphorescent compounds

Matsuzawa, T.; Aoki, Y.; Takeuchi, N.; Murayama, Y. (1996-08-01).

It’s common to see phosphorescent compounds in commercial products and a clear example of its advantages is seen in phosphorescent exit signs that by regulation must be able to provide ‘light’ even when there is no electricity, in case of an emergency. Even on airplanes, and also cinemas, in case of emergency the line strips on the floor are non-electrical, utilizing photoluminescence and phosphorescence.

Examples of this are shown in Figure 19, where signs and paints are used to lead people to safety in case of electricity blackout.

The real opportunity of this material is to provide light after sunset, as a non-toxic, safe, long-lasting glow and great overall luminescence alternative to electricity, solar lamps and panels, kerosene lamps and candles.

Figure 19: Examples of Emergency signs made with phosphorescent plastic

(https://m.made-in-china.com/)

Nonetheless, the cost per kilo of strontium aluminate europium doped glow in the dark powder/pigment ranges between 20 and 50 $ a kilo. It is not yet determined how much of the powder would be required for an optimal night light performance, nevertheless the price could still be an obstacle for a DIY project with locally sourced materials.

6.5. Fresnel Prismatic Lenses & LCD Screens

For this project it is key to mention the important part that lenses play in optics. Since the invention of cameras, lenses have been employed to extrapolate as much light as possible from the surrounding environment to allow a clearer picture to be taken, seen in figure 20.

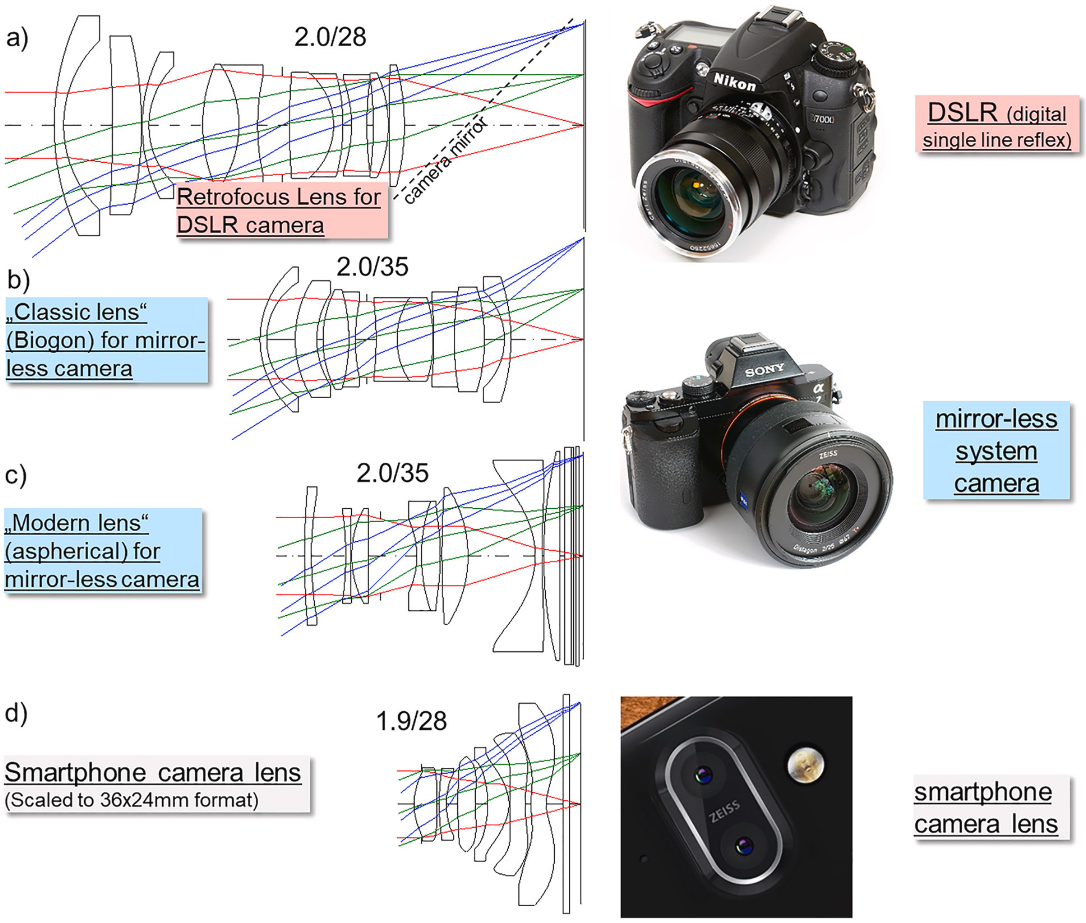


Figure 20: Examples of cameras and thier lenses and how they differ

Blahnik, V. and Schindelbeck, O., 2021. Smartphone imaging technology and its applications. Advanced Optical Technologies, 10(3), pp.145-232.

Through time, a near endless amount of differently shaped lenses and purposes have been created between concave and convex lenses.

The lenses used in cameras are straight forward, they bend light to allow as much of it to enter the pixel sensors inside the focal point.

Fresnel lenses are slightly different from classical lenses as they are made of a series of concentric grooves, engraved into the plastic lens, shown in figure 21. They are commonly utilized in light gathering applications where they are employed as light concentrators, ‘magnifiers’ or in illumination systems.

A simple example would be that OLED screens use Fresnel lenses to direct light perpendicularly to the screen’s surface.

The different grooves present in the lens act as individual refracting ‘lenses’ by bending parallel light rays into a central common spot. Furthermore, relatively thinner than concave glass lenses, shown in figure 21 & 22, and also lighter which offer better advantages by also reducing heat absorption, light wavelength elongation (less scatter) and light focus.

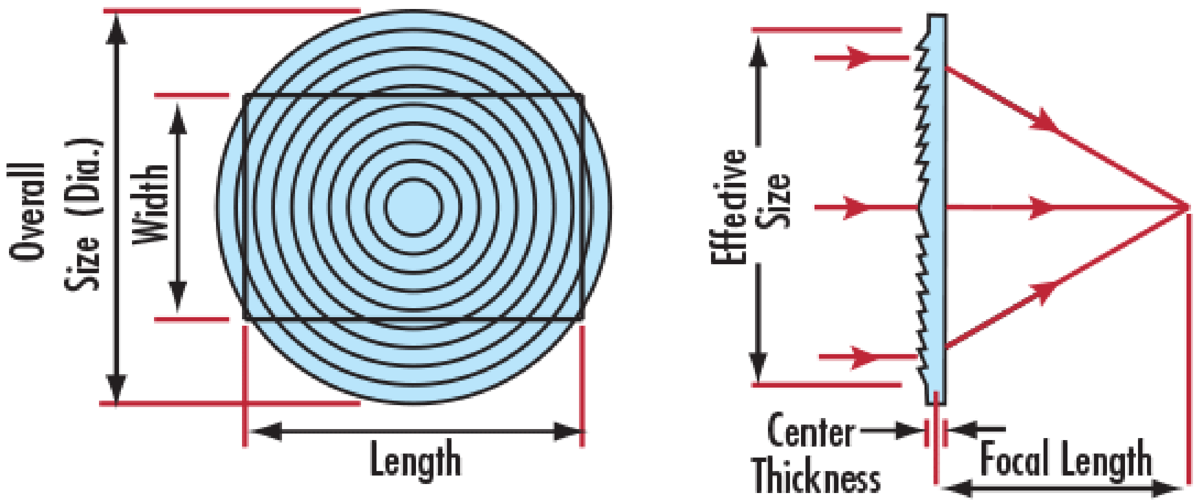


Figure 21: Example profile of a Fresnel Lens

https://www.edmundoptics.eu/knowledge-center/application-notes/optics/advantages-of-fresnel-lenses/

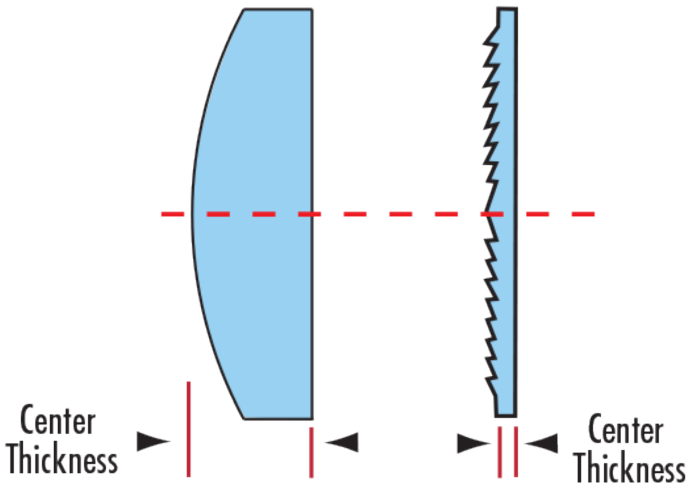


Figure 22: Example profile Convex lense and a Fresnel Lens

https://www.edmundoptics.eu/knowledge-center/application-notes/optics/advantages-of-fresnel-lenses/

Figure 23: Light Collimation of a point source with a Fresnel Lens

https://www.edmundoptics.eu/knowledge-center/application-notes/optics/advantages-of-fresnel-lenses/

As seen in figure 23, Fresnel lenses are of great help on diffusing or focusing the light from/to a single point. This is also the reason why they are researched and starting to be employed in bettering the efficiency of solar panels by collecting and redirecting the sunlight around the solar cell.[66] Furthermore, LCD screens utilize a series of Fresnel lenses to improve the visibility of their emitted light. [67] Thus, acquiring these kinds of lenses is a real possibility, and to employ them as light redirecting tools. LCD screens, instead, contain conductive glass, with a layer of Indium oxide, which can be used to make DIY solar panels. However, the removal of both the lens and conductive glass isn't as simple as it can be.

This goes to show that if you know what to look for, one can find materials by upcycling broken product parts.

6.6. PV Solar Cells & Solar Panels

A real opportunity is presented when realizing that it is possible to create simple DIY solar panels or solar cells from upcycled materials. The first photovoltaic (PV) panel was invented by Ohl in 1946, by creating a thin silicon wafer that transformed phonons energy into electric current. This silicon wafer works by creating an electron current, stimulated by the energy of the light photons, where an electron gained enough energy moves from one layer to another creating an electron hole, thus allowing flow of electrons from a layer to another. PV solar cells can be made of silicon, cadmium-telluride, copper-indium-gallium-selenideand copper-indium-gallium-sulfide. The use of these materials is further categorized by their generation. First generation is the traditional silicon wafer PV cells, the second generation are thin film solar cells and the third generation are nano crystals, polymer based, dye sensitized and concentrated solar cells. As shown in Figure 24, solar cells are theoretically a simple process of electron transfer, however, the right materials must be in play.

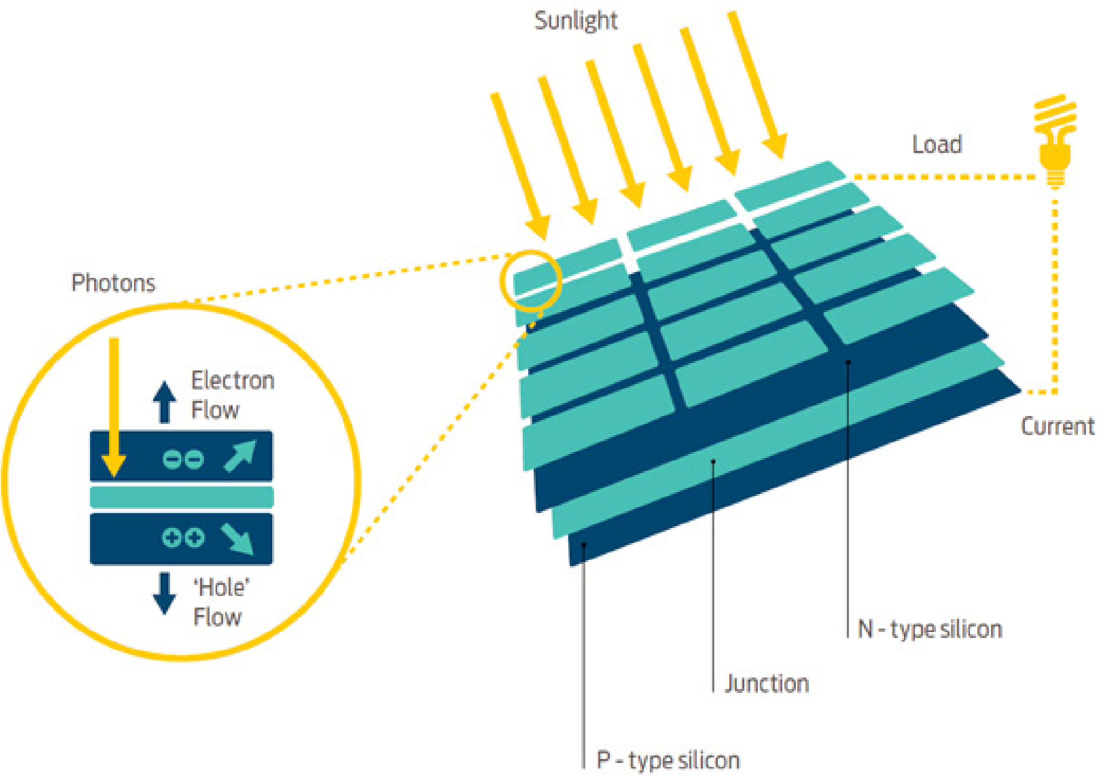


Figure 24: Demonstarates how a solar panel works

https://www.goodenergy.co.uk/how-do-solar-panels-work/

A PV solar cell generates around 0.5 V, thus a solar panel composed of around 18 cells creates a direct current of 9 V. Furthermore, the output DC is perfect for charging smartphones.

The innate ability of silicon, and other materials, to generate current is an outstanding innovation in the field of renewable electricity but it has drawbacks and limitations. Most commercially available solar panels have an output efficiency of around 15-20%, the newest ones are at 46%, and their costs, even though at their lowest, are still a challenge. Furthermore, their reliability and durability are always unknown. [68]

As seen in figure 25, the costs are steadily dropping for solar cells, but as mentioned above, one PV cell is not sufficient to power a cellphone as , at least, 18 V are required. Nonetheless, there are other costs to consider, such as wiring of the cells, positioning and insulation from air. A transformer is needed for big solar panels, as well as installation and transportation costs. The cost is shown in watts, where W = AxV, thus a 0.5Vx8.6Ax0.18$/W cell total cost would be around 0.8 $.

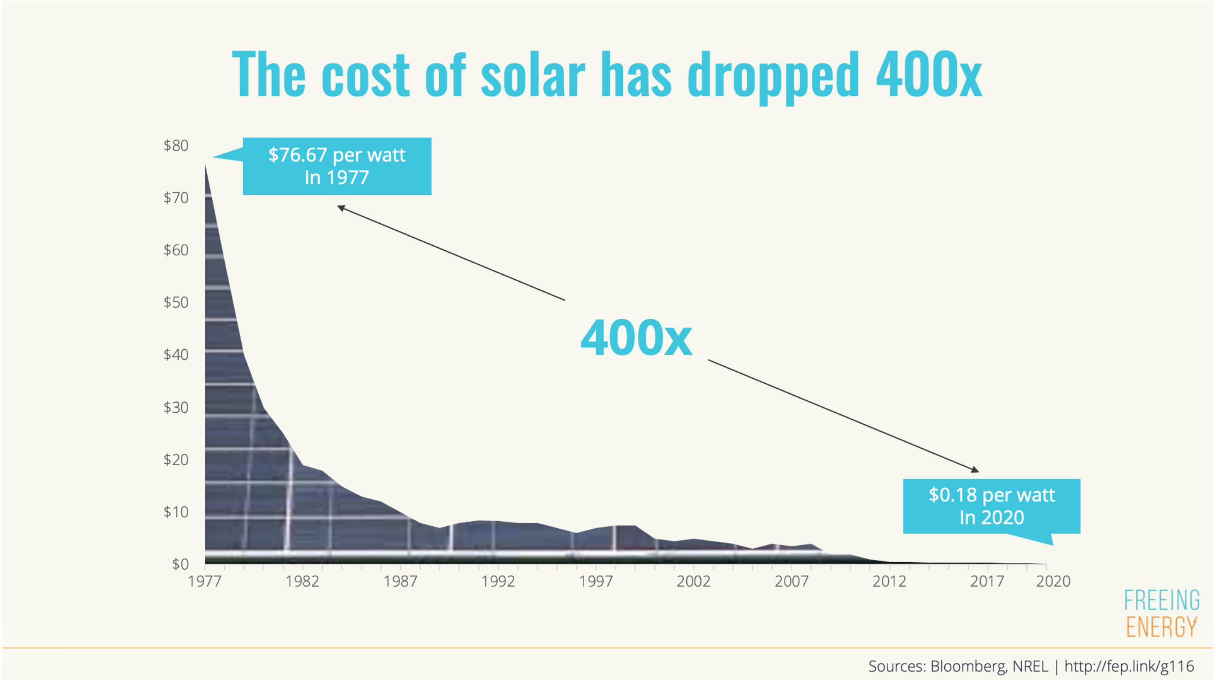


Figure 25: Histogram showing the drop in costs of the PV cell over the years

Bloomberg. NREL

This calculation goes to show that a solar cell starting at around 0.8$, would need to be coupled with another 17, adding up to around 15$, plus tech equipment, inverter, manual work, taxes and other internal costs the true figure of solar panel rises up. [69]

6.6.1 DIY Homemade Solar Cells

After the analysis on the difficulty and challenges of opting light heartedly for the solar panels solution, the question about the possibility of upcycling arises. Would it be possible, by reusing and giving another purpose to household and waste materials, to make solar cells at home? As noted, in developing countries, the availability of brand new and expensive materials is limited to whomever has money or through western sponsorship. For this reason a series of pilot DIY projects have been picked to understand whether the availability of a DIY solar panel can be a real opportunity for this project.

As for the case studies a base format will be used to be able to effectively compare the DIY solar cells project and their real viability, difficulty and replicability. The final outcome will select a few pilot projects to be tested and prototyped to value their functionality and constructibility.

6.6.2 DIY Homemade Solar Cells: Pilot Study Form

DIY Solar Cell & panels

Pilot Study Form

Ideated:

Product Name & Description

Picture of product

Building Process

User

Cost

Replicability & Difficulty

Materials/ components

Technologies

Physical attributes

Advantages

Disadvantages

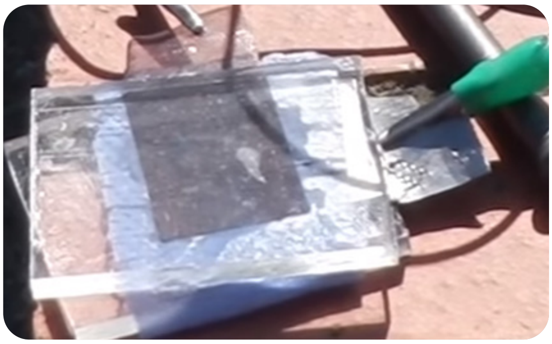
Development Insight

6.6.3. Pilot Study Form>Copper Oxide Mesh Solar Cell (Co-prous Oxide)

DIY Solar Cell & panels

Pilot Project Study

Ideated by: *R. Murrey-Smith - 2020*



Product Name & Description

Copper Mesh Solar cell

Utilising a mesh copper to create a simple copper oxide solar cell, with low voltage. Copper oxide (red) is photoactive as a p-type conductor.

Project for a Copper Oxide solar cell.

Process

1. Obtain meshed copper
2. 'Cook' mesh at 400* x 10 min or 230* for 30 min
3. Red copper to form in nano crystals
4. Cut to desired size, as it affects resulting voltage
5. Obtain Graphoil (flexible graphene) and cut also to required size
6. Place plastic peace, insulator underneath the graphoil
7. Add separator, cloth
8. Add electrolyte, salt water
9. Place treated copper on top of separator creating a sandwitch
10. Place final plastic insulator piece
11. Check voltage, should be very low around 0.2-0.4 V depending on its size.

User: Anyone with an oven of some kind

Cost: Copper mesh: 7 $/m
Grafoil: 1.5 $ roll

Replicability & Difficulty: In itself not complicated, but finding the materials could be hard. Price low enough to buy.

Materials/ components: Meshed copper and graphoil, salt water and plastic insulators

Technologies: N-P type metal oxide solar cell with water acting as an electrolyte.

Physical attributes: A 5x3 cm of oxidised copper mesh and grafoil generated around 0.2 V. to obtain 9 V around 45 of the same size would be required.

Advantages

- Relatively simple to make
- Output voltage is acceptable
- Required handiness medium-low
- Possibility to swap mesh and grafoil to easier to find copper plate and graphene/ graphite

Disadvantages

- Avilability of copper mesh and grafoil uncertain
- Reliability and efficiency of cell is dependent on quality of copper oxide crystals and correct temperauture at which it is cooked at.

Development Insight

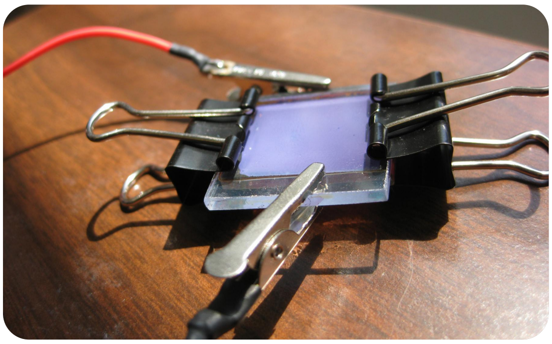
- Real possibility to make simple solar panels using copper oxide
- The uncertainty is the difficulty or ease of finding required materials

6.6.4. Pilot Project Study: Titanium Dioxide Solar Cell

DIY Solar Cell & panels

Pilot Project Study

Ideated by: *M. Grätzel - 1991*



Product Name & Description

Titanium Dioxide solar cell

Home made solar cell composed of titanium dioxide, conductive glass and a few other household items. The solar cell is relatively easy to make but the steps to do so are quite precise.

Process

1. Mix titanium dioxide powder with alcohol and dish soap to form a paste.
2. Apply an even layer of titanium paste onto a square of conductive glass.
3. Heat the glass on a hot plate for 10 to 20 minutes.
4. oak the cooled glass in strong hibiscus tea for 2 to 3 hours.
5. Color the center of a second glass square with a graphite pencil.
6. Cover the sides of the titanium square with tape
7. Add a drop of electrolyte solution to the center of the titanium square
8. Sandwich the 2 glass squares and secure them with binder clips
9. Place the cell in sunlight and check its charge with a multimeter.

User: Anyone with the possibility of access to a supermarket/ store

Cost: Buying the whole materials would cost between 15-30$

Replicability & Difficulty: In itself not complicated, but finding the materials could be hard. Process is longish and somewhat difficult.

Materials/ components: Titianium dioxide powder, soap, alcohol, conductive glass, hibiscus tea and a pencil

Technologies: N-P type dye-sensitized solar cell made with teea to absorb visible light..

Physical attributes: A 5x3 cm of solar cell prooduces around 0.5 V but it isn't constant.

Advantages

- Relatively simple to make
- Output voltage is acceptable
- Required handiness medium
- Possibility to swap some required materials for cheaper substitute

Disadvantages

- Avilability of titanium dioxide and conductive glass uncertain
- Reliability and efficiency of cell is dependent on quality of titanium, of how well process is followed and the overall quality of the materials.

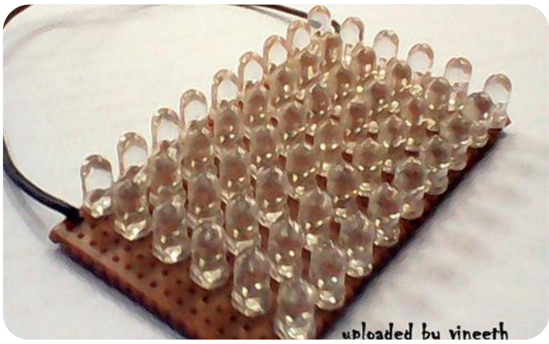
Development Insight

- Long process, even though its not hard but there are a lot of materials involved
- The uncertainty is the difficulty or ease of finding required materials

6.6.5. Pilot Project Study: LEDs Semiconductor Solar Cell

DIY Solar Cell & panels
Pilot Project Study

Ideated by: *M. Grätzel - 1991*



Product Name & Description

LEDs Solar cell
Home made solar cell composed broken LED lights. LEDs are p-type semiconductors that work both ways from emitting light by utilising current, to generating current using light.

Process

1. Aquire a broken set of led lights. E.g. broken torches, led strips ecc
2. Different led lights exist, preferably COB leds or leds where the resistors can be taken out.
3. After disassembling the leds, conncect them in series and measure voltage. The more leds the higher the output power will be.

User: Anyone with a broken led torch, lamps ecc

Cost: LEDs arent expensive new, but preferable to upcycle them.

Replicability & Difficulty: In itself not complicated, but unclear the availability of broken leds.

Materials/ components: LEDs from a non functioning product.

Technologies: P-type junction of a semiconductor that acts both ways in collecting or emitting light.

Physical attributes: Depends on available LEDs and needed output power.

Advantages

- Relatively simple to find broken leds
- Not much is needed to be done except extrating the leds form borken product.
- Voltage output is decent and relatively easy to assemble

Disadvantages

- Current flows only in sunlight
- No precise way to store or transfer power
- Availability and differences in LEDs will affect outcome

Development Insight

- With a simple LED strip one can generate an output power and voltage
- Unclear the amout required for an effective charging station

6.6.6. Pilot Project Study: DIY Solar Cell Summary & Conclusions

There are many advantages in creating a solar panel at home with store bought materials or upcycled parts. The real problem remains in the required skill level, expatriates and willingness of the end user to understand how the PV cells work and how to assemble them. Furthemore, the reliability and functionality of these panels might be outweighed by their effectiveness and power output. Below, table 12, shows a summary of the advantages and disadvantages of making DIY solar cells.

Advantages	Disadvantages
Availability maybe is high while cost of materials is low Does not require high level of expertise Ability to generate 'cheap energy' Real advantages must be recognised to understand upper hand against pv panels	Availability of certain materials unclear Some kind of handiness required to make solar cell Might require some specialized tools

Table 12: Advantages and Disadvantages of DIY solar panels

The making of solar cells isn't in itself complicated but the real obstacle is creating the perception that the work to put in will be worth it. Further real life testing is needed both to fully grasp the level of handiness and work and to find out how easily anyone could do it. Furthermore, some level of understanding of the principles of electronics and electricity would be required to not only lower the hazards and risks but to also end up with a working solar cell that can be used to charge phones and other 'light sources'.

7. Project Proposal

7.1. Brief

The true innovation and possible development lies in perfectly calibrating this project between the modern world technical and scientific advancements against the terrifying reality of the perpetuating poverty cycle that dictates the Third World. This project aims at giving the users all the power necessary to build their own future; starting from light. Nevertheless, even the First World is seeing electricity prices skyrocket, and even more so with the pandemic as there has been a rise in household expenses. The goal of this project is to identify the required materials to make a DIY light solution for the day and possibly at night. The project aims at tackling the energy crisis but also other related factors such as air pollution and water treatment. By replacing kerosene oil lamps and candles the health issues and fire hazards are reduced and the use of natural sunlight will stimulate a healthier lifestyle. Through the use of questionnaires and interviews, it was made possible to clarify the importance of substituting polluting light sources for more renewable ones. Families that depend on these traditional sources of light sacrifice a significant portion of their monthly income to buy kerosene or electricity units, while, instead, with that money they could provide food, goods and education for their family. By creating a product that can be made by anyone,it will truly empower, not only the user, but also the community to both work together, share knowledge and information. This cascade truly underlines the importance of making an easily reproducible product. And as stated by the international NGO Liter of Light, it's more about training and demonstrating to people, which in consequence will be able to train and teach the same technique and process to even more people. This cascades in a semi-independent and growing human infrastructure that slowly spreads the technology and resources necessary to improve conditions for users and their community.

The effectiveness of the impact that the final product has can be thought as mutually connected with the technology present in it and by utilizing cheap and locally sourced materials the manufacture of a 'basic light source' can start right away. Nonetheless, more modern materials and technology can be implemented to improve efficiency, night light and possibly energy storage.

7.2. Projectual Constraints

The real constraints of this project are both of human and financial nature. The project's idea was to be as cheap, or free, as possible by upcycling waste materials present in developing countries. By upcycling waste material it's possible to give it new life and purpose and, hopefully, contributing in lessening the environmental impact and waste cycle that leads to the sea. Nonetheless, some cost must be anticipated such as the price of adhesives or basic nails and screws. Furthermore, the final schematic/illustrations to show the making process of the product will need to be culturally appropriate, and easy to understand if realised.

Moreover, it would be appropriate to 'engineer' the project by understanding the required hanging support for the final product, its real impact in terms of light and energy savings and the development of a delivery/cost transport system that would allow parts and maintenance of the product throughout its lifetime. They are summariesd in Table 13.

Specification	Reasoning
Provides a minimum of 15 lm of light	Better than kerosene lamp or candle
Can be adapted in more than 1 room	Allow houses and bigger families to bring light in different rooms - no need for kerosene lamps
Has Night-time light (min of 2-15 lm)	Can be used at night for 2 h min
Tries to include other functions	Such as Solar cooking or SoDis for wa-ter
Cost of materials should be kept at minimum	To allow nearly anyone to make and make it
End product will be part of a family of products	Allow the initial kit to be sustained by further expenses through a later delivery to maintain, improve and adapt kit to all situations.

Table 13: Key performance specifications for the final proposed solution

8. Preliminary Testing & Project Development

8.1. Existing Project Experimentation & Testing

As a starting point for experimentation and product testing it is necessary to begin from the basis: the Solar bottle bulb. The bottle bulb, the base requirements and working must be understood along with further elements that will bring the innovation needed. As identified in the case studies, different possibilities are available to improve the functionality and efficiency of the final product. Nonetheless, baseline standards must be first understood to start a proper experimental procedure. Table 14 shows the average availability of sunlight in SA, and the power output needed to replicate it.

Measure	Value	Reason for Interest
Average daylight	11.5 h all year round (average), 2500 h total a year (SA) [70]	Quantity of dayligh
Daily Irradiation (average)	3 200 kWh/m^2 per annum 24h average is 220 W/m^2[71]	Understand 'power' of sun during the day

Table 14: Shows the sunlight availability in SA

Furthermore, more detailed needs have been extrapolated to truly have a base for comparison and a goal for each light need. Table 15 shows the ideal specifications compared to acceptable specifications, as a clear result is not ensured. A lot of differences will be encountered throughout the realization of the final product, as culture, society, traditions and economical variety differ from country to country.

Location/Activity	Lighting Goal	Acceptable light level
Traditional Light Sources	-	1-5 lux
General Inside/Closed space	15 lux	5-15 lux
Reading light	25 lux	5-15 lux
Night time	5 lux	2-5 lux

Table 15: Shows the key minimum & maximum performance specifications for the final design

The best procedural method to fully analyze and understand the difficulties and best possible paths to build and ensure a safe, functional, final product is by creating a base idea and breaking it down to each macro component/element and testing the possible solutions and alternatives.

8.2. Experimental Elements & Testing Components

The proposed 'initial' concept, that is derived from previous research and case studies, would be composed of three main components.

Acquiring the light - as the solar bottle

Channeling the light - transport and redirection through mirrors

Further possible uses - SoDis, Night Light, Solar oven

Furthermore, all these elements will be broken down and analyzed to better understand how they can be improved, which configuration would work best, their difficulty to make or reproduce, time and energy consumption, possible alternatives and so on.

To complete such types of experimentation, it is necessary to build a simulated environment with the conditions of interest, see table 10, where it will be possible to measure light with a lux meter. In this manner it is possible to fairly establish comparison between experimental arrangements as they will all be examined in contrast with each other in the simulated solar conditions. Nonetheless, a clear weakness of these experiments is that they are all performed in laboratory conditions, thus ideal, and will most likely not represent the full extent of the true conditions in which the product is set to perform. The experiments are representative of the living conditions and no product can hope to achieve a perfect simulation, however, the experiments are set out to try to improve the final product as much as possible by first understanding the environmental requirements.

The 'box' created to simulate a closed environment is with dimensions 1.5x1.5x2m with the internal walls painted/covered in matte white and the outside in black. It would be important to notice that commonly roofs of informal settlements are made of metal roof panels and sheets, which help reflect more sunlight into the solar bulb bottle. Thus, different measures will be taken to compare a dark/black external roof and a more reflective one, as a metal roof. The testing 'box' is made to be wide so that the light can diffuse and reflect as it would in a house, as a smaller 'box' would highly impact the overall illuminance. A hole in the roof of 10 cm, diameter of a soda 1.5 l bottle, is cut to test out the PET (Polyethylene terephthalate) bottle and possibly understand if there are advantages and disadvantages in their different sizes and shapes. Figure 26 shows the 'box' setup.

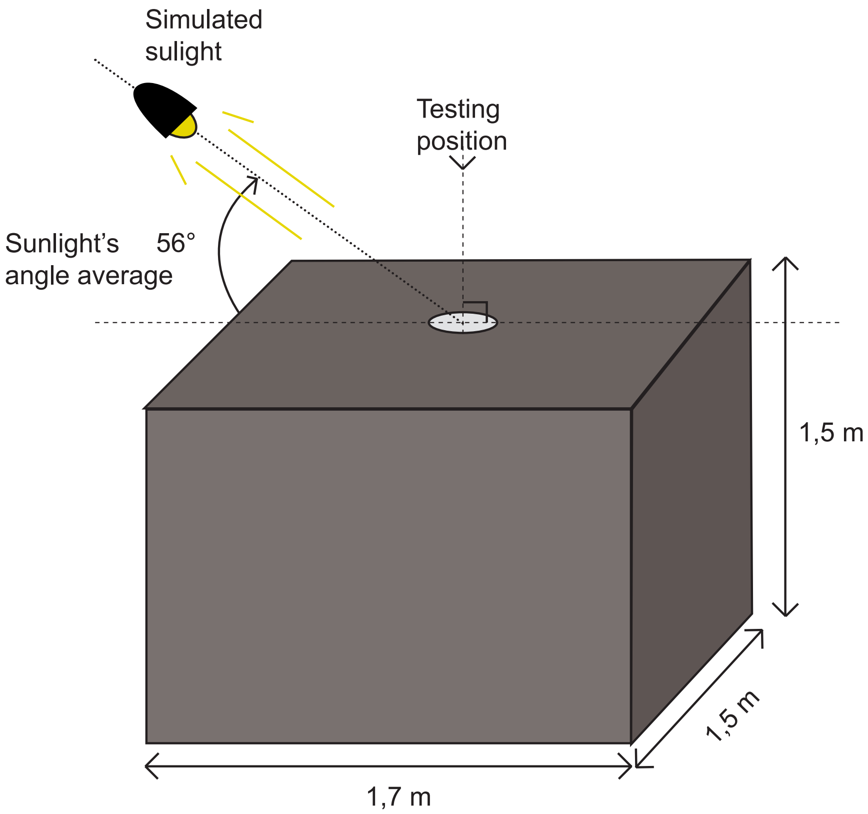


Figure 26: Experimental set up fo 'box' used in the experiments and Solar Bottle Bulb tests

For the simulated sunlight a total of 220 W will be used and different angles of the sun during the day will be incorporated into the study to understand the effects they have on output illuminance. The orientation of the light/lamp, represents the sun's angle during the morning hours, midday and sunset/evening hours. Figure 27 demonstrates the angles and direction of the sunlight, both for winter and summer times.

A point of notice is how solar panels are placed in SA to maximize sunlight, as also seen in figure 27, whereas the sun's angle is studied to understand what position and orientation would maximize the efficiency of the solar panels.

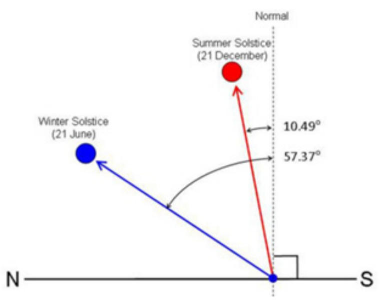


Figure 27: The Sun's angle and location during winter and summer periods in SA.

Conradie, D.C.U. 2010. Maximising the sun. In: Green Building Handbook South Africa: The Essential Guide, Volume 3, pp 146

A categorization of the necessary experiments must be made to better grasp the extent and the interjection between each.

A description of each experiment, its needs and the importance of its results are shown in Table 16 . A similar structure will be done for all and their graphs, discussions and conclusions will be reported right underneath or at the end of the respective testing category.

The luminosity will be tested with a Light meter MT-912 through the 'light box' method, where an imaginary box is created around the light source and all sides of the box will be measured to record their light level. In this way it is possible to better judge the light diffusion and the overall average will be more accurate.

Test	Component	Reasoning	Test .1	Test .2	Test .3
1	**Solar Bottle Bulb**		*Height of bottle*	*Upside Down*	*Shape of Bottle*
		Hypothesis	Placement height of the bottle will affect the final result	The bottle placed upside down will not improve the results	Shape of the bottle will affect the final results
		Argument	The surface area irradiated will affect the final results	Bottom of the bottle generally rounded but uneven features disrupt passage of light	The 'neck' of different bottles will determinate the channeling and focusing of the light
	Reflective Surfaces		*SunFlower'*	*Parabolic Mirror*	*Roof steel sheet*
		Hypothesis	Adding random reflective surfaces will not overall improve outcomes	By focusing the light onto the bottle more light will be able to pass through	The reflective galvanized metal roof sheet will help redirect light into the bottle
		Argument	The effectiveness of reflection works only if pointed towards bottle	By creating a curved mirror it will allow more light to bounce into the bottle	The natural shape of the roof steel sheet will act as a mirror and improve results

			Time to Weight	*Powder Suspension*	*Further Testing*
	Phosphorescence	Hypothesis	The thickness and mass of the powder will affect the outcome	By suspending the powder in e.g glue, will help spread and dilute the powder.	Further tests conducted on the information found in the two previous ones
		Argument	The right amount of incoming and passing through light will show the perfect amount for all of it to be used	It will show if the phosphorescent powder works and how well it can be applied on different surfaces and materials	To validate final theories before starting the final proposed solution

Table 16: Shows the Hypothses and Arguments made for each experiment to be carried out.

8.2.1. Preliminary & Background Testing

To test the illuminance a repetible and fixed set of experimental measures must be taken. All light readings will be recorded in the same positions throughout the experimentation. As previously mentioned the ‘light box’ measuring method will be utilized, meaning that light readings will be taken on the six sides of the imaginary box placed around the source of light, as shown in Figure 28. Each light test is done to be made at around 50 cm from the source and thus creates a 1 m^2 averaged result for the light. It is important to show the direction of the simulated light as it greatly affects each side’s light reading.

It is key to understand the height at which the bottle works best. Liter of Light foundation quotes that the bottle should be 2/3 outside to allow as much surface area as possible to receive light. Thus it must be tested at which height one receives the most light to ensure the viability of the data provided by Liter of Light.

To both test the difference in height and illuminance output, 3 differently shaped bottles were chosen, also to see the difference that the shape can have. Each experiment is repeated 3 times to reduce as much as possible human error and other possible mistakes.

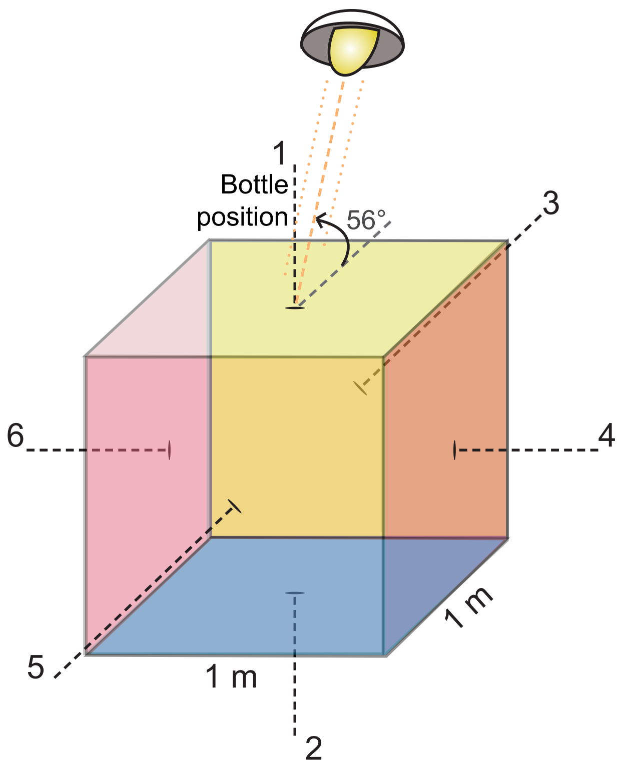


Figure 28: Illustrates the configuration of the lightbox method with respect to the artificial sunlight angle and position.

The first test needed is to verify that the created dark room has 0 light coming from outside with the hole covered. The second test is to record the light reading with only the hole open.

The dark room had a 0 light reading and thus, the hole light emission was measured and is reported below in table 13. Each result is averaged and then the resulting light average is compared with each trial average.

Only Hole	1	2	3	Av.
1	0	0	0	0.0
2	0.6	0.6	0.8	0.7
3	0.3	0.5	0.9	0.6
4	0	0	0.4	0.1
5	48.8	45	49.1	47.6
6	0.6	0.8	0.8	0.7
A	***8.4***	***7.8***	***8.7***	***8.3***

Table 17: Shows the measure light reading for Only the Hole

8.2.2. Test 1: Solar Bottle Bulb

The hypothesis backing the Test 1 (1.1, 1.2 and 1.3) is that different shapes, dimensions and the irradiated surface area will affect the final readings.

The first actual test is to see the differences in bottle height placement and bottle shape.

The 3 bottles chosen are a 1.75 l Coca cola bottle, 1.75 l Pepsi cola bottle and a 1.75 l fizzy water bottle.

Figure 29: Shows the 3 bottles; From the left: Cola bottle, Pepsi bottle and Fizzy water. Also shows them when placed to be tested.

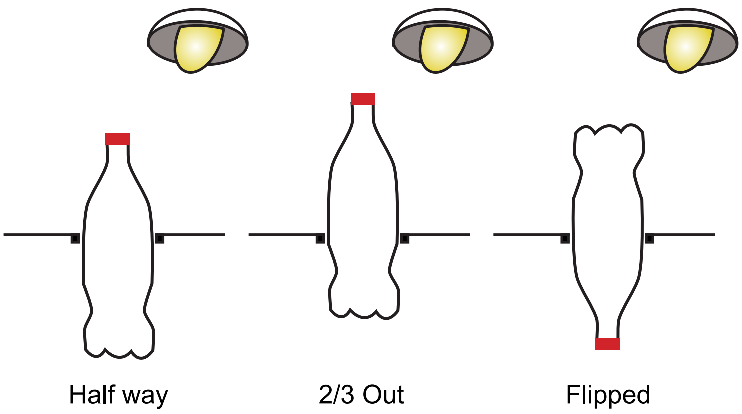


Figure 30: Shows the 3 bottles positions used in the Test 1

The 3 bottles are shown in different light conditions to expose the physical features that will affect the refraction and reflection of light inside them. Each bottle will be tested in 3 different positions to better understand which is the most efficient between: halfway, 2/3 out and flipped halfway.

Test 1.1: Coca Cola Bottle

As seen above, the bottle is placed in 3 positions and each is tested three times.

The bottles total height is 34.5 cm, halfway was measured at 17 cm and 2/3 was measured at around 22 cm.

HalfWay	**1**	**2**	**3**	**Av.**
1	0.9	1.1	1.2	1.1
2	13.2	15.5	15.3	14.7
3	7.3	8.1	7.1	7.5
4	2.5	3	3.2	2.9
5	22.8	21.1	21.4	21.8
6	4.8	5.4	5	5.1
A	***8.6***	***9.0***	***8.9***	***8.8***

Table 18: Shows the measure light reading for Cola Bottle halfway

2/3	**1**	**2**	**3**	**Av.**
1	1	1.2	1.1	1.1
2	10	13.7	10.6	11.4
3	6.1	6.9	6.9	6.6
4	1.7	2.4	2.5	2.2
5	18.8	21.5	22.2	20.8
6	6.2	7.7	8.1	7.3
A	***7.3***	***8.9***	***8.6***	***8.3***

Table 19: Shows the measure light reading for Cola Bottle 2/3 out

Flipped	1	2	3	Av.
1	1.2	1.2	1.2	1.2
2	3.2	3.3	3.2	3.2
3	7.4	7.5	7.3	7.4
4	2.4	2.3	2.5	2.4
5	11.8	11.9	112.2	12.0
6	3.7	3.8	4.2	3.9
A	***5.0***	***5.0***	***5.1***	***5.0***

Table 20: Shows the measure light reading for Cola Bottle flipped

It’s clear that the position of the bottle affects the resulting light output, from the 3 tables it’s obvious that the best performing position is halfway.

Test 1.1: Pepsi Cola Bottle

Like the Cola bottle, the Pepsi bottle was tested 3 times. Its max height was 33 cm, half way at 16.5 cm, 2/3 at 20 cm out and flipped at halfway.

HalfWay	1	2	3	Av.
1	1.3	1.2	1.3	1.3
2	8.2	7.2	8.5	8.0
3	4.9	5	4.8	4.9
4	2.7	2.7	2.7	2.7
5	42.2	42.6	42	41.9
6	5.9	6.1	6.1	6.0
A	***10.9***	***10.6***	***10.9***	***10.8***

Table 21: Shows the measure light reading for Cola Bottle halfway

2/3	1	2	3	Av.
1	1.4	1.3	1.3	1.3
2	7.9	8.6	9.2	8.6
3	4.9	5	4.8	4.9
4	4.1	4	4.5	4.2
5	20.2	20.5	20.2	20.3
6	4.3	4.3	4.2	4.3
A	***7.1***	***7.3***	***7.4***	***7.3***

Table 22: Shows the measure light reading for Pepsi Bottle 2/3 out

Flipped	1	2	3	Av.
1	1.5	1.6	1.6	1.6
2	5.3	5.1	5.4	5.3
3	7.3	7.1	7.2	7.2
4	2.6	2.6	2.7	2.6
5	10.8	10.8	10.8	10.8
6	3.3	3.5	3.3	3.4
A	***5.1***	***5.1***	***5.2***	***5.1***

Table 23: Shows the measure light reading for Pepsi Bottle flipped

As per the Cola bottle, also the Pepsi bottle demonstrates better results when halfway and shows to be more efficient in collecting and reflecting light than the Coca Cola bottle. The Pepsi bottle has 20% improvement over the Cola bottle.

Test 1.1: Fizzy Water Bottle

As per the previous experiments the Fizzy water bottle was tested at 3 different positions. The max height was 32 cm, half way being at 16 cm and 2/3 out at around 22 cm.

HalfWay	1	2	3	Av.
1	0.9	0.8	0.9	0.9
2	8.8	7.6	9.3	8.6
4.8	4.8	4.4	4.5	4.5
4	2.1	2.0	2.1	2.1
5	8.9	8	8.9	8.9
6	3.2	3.2	3.2	3.2
A	***4.8***	***4.5***	***4.8***	***4.7***

Table 24: Shows the measure light reading for Fizzy water Bottle halfway

2/3	1	2	3	Av.
1	0.8	0.9	0.8	0.8
2	9.8	10.7	9.5	10.0
3	4.5	4.5	4.6	4.5
4	2.4	2.4	2.4	2.4
5	7.8	7.9	7.7	7.8
6	3.5	3.5	3.6	3.5
A	***4.8***	***5.0***	***4.8***	***4.9***

Table 25: Shows the measure light reading for Fizzy Water Bottle 2/3 out

Flipped	1	2	3	Av.
1	1.2	1.4	1.2	1.3
2	5.3	6.2	5.9	5.8
5.3	5.6	5.6	5.2	5.4
4	2.5	2.5	2.4	2.5
5	10.7	10.9	11	10.9
6	3.4	3.4	3.3	3.4
A	***4.7***	***5.0***	***4.8***	***4.9***

Table 26: Shows the measure light reading for Fizzy Water Bottle flipped

It is clear that the Fizzy water bottle was the worst performing out of all three tested bottles.

Test 1: Results & Discussion

From the results obtained we can see that the pepsi bottle performed the best compared to the other two. It had a 20% improvement over the Cola and 50% over the Fizzy water bottles. It is safe to deduce that the more rounded shape of the upper part of the bottle allows it to better direct the light at the bottom of the bottle, thus inside the room.

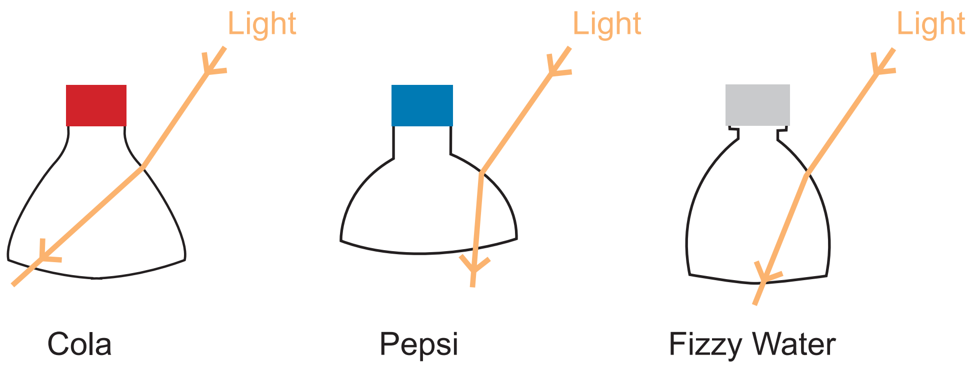


Figure 31: Shows an illustration of the 3 tested bottles and how they refract light due to their shapes

Another interesting point to observe is why the Fizzy bottle performed so terribly compared to the other two. it can be concluded that in comparison to the Coca Cola or Pepsi clear, smooth shape, the Fizzy water bottle has more complex externa features such as wrinkles and multiple points of curvature, as shown in Figure 31.

8.2.3. Test 2: Reflective Surfaces

For the second section of experiments focused on mirror and reflecting surfaces a combination of upcycled waste materials and components were utilized to validate the idea that focusing the light to the bottle will improve the outcomes. Thus, the hypothesis backing Test 2 (2.1, 2.2 and 2.3) is that a reflective surface placed correctly will improve the final light readings.

Through the user analysis it was found that aluminum cans, mostly of alcoholic beverages, were quite common in both urban and suburban environments and even in remote villages.

The first step was to understand how to obtain a reflective surface and then select the best one.

Testing on aluminum cans was done following 3 methods to remove the paint and then comparing the result with the internal pre-reflective surface.

The 3 methods are:

- With a blade
- Sandpaper
- Pressure cooker and acetone

For all three methods the first steps is to cut the aluminum can and separate the top and bottom parts from the center area as seen in figure 32.

Figure 32: Shows where the aluminium can needs to be cut

BLADE

With a blade it's possible to scrape off the paint somewhat easily. Start the process by laying down the sheet of al recovered from the can and start scraping gently. Safety gloves are required to not cut oneself, both from the knife and al can.

Example progress is shown in Figures 33.

The workload required for this process isn't very high but the result is also mediocre.

Figure 33: Shows the progress in scraping off the paint of the aluminum cans with a blade

SANDPAPER

The process for the sandpaper method is very similar to the one for the blade. Start by laying flat the pre-cut al sheet, upcycled from the aluminum can. After laying flat the al foil use the sandpaper, whilst wearing protective gloves, to scrape away the paint. Figures 34 show an example process for reference. Removing paint with sandpaper is not a heavy task, however it is not as reflective as previously thought.

Figure 34: Shows the progress in scraping off the paint of the aluminum cans with a sandpaper

PRESSURE COOKER & ACETONE

This method is more advanced than the others, meaning that it requires a bit more preparation but the overall difficulty is not so much higher compared to the other two methods.

- As for the other two, start by cutting the center piece of an aluminum can.
- Then the following steps are to be followers:
- Obtain a pressure cooker that is able to reach 120°C and a bottle of pure acetone
- Place around 2/3 fingers height of water inside of the pressure cooker
- Place aluminum sheets, from the cans, inside the pressure cooker and close everything
- Let cook for 20-30 mins, depending on quality and ability to keep heat of the cooker
- Open and let cool the al sheet, as they will be hot from the boiling
- Lay the metal sheets flat and, while wearing thick plastic gloves, grab a cotton pad drowse in acetone and wipe with vigor
- The paint, loosened by the heat, should come off very easily. If not, place back in cooker, add more water, and repeat cooking process for longer times 30-40 mins
- The end result should be a clean, mirror-like effect of the external side of the al can.

Figure 35 shows the resulting al sheet by using this experiment. Both the external and internal surfaces are compared to grasp the differences.

Figure 35: Shows the final result of pressure cooker & acetone method, internal vs. external

A study to understand the effectiveness of each process must be done to also understand if the external surface is better than the internal surface, thus validating if the paint removal process is necessary. The testing was performed by shining a light from a fixed distance (30 cm) and recording the reflected light, with the lux meter, also from a fixed position, 30 cm away, for the three aluminum sheets of the three methods. The results are shown in table 27.

	Method 1: Blade		**Method 2: Sandpaper**		**Method 2. Pressure cooker & Acetone**	
	Int.	*Ext.*	*Int.*	*Ext.*	*Int.*	*Ext.*
Try 1	3.8	3.5	3.6	3.4	3.7	4.4
Try 2	3.9	3.2	3.8	3.5	3.8	4.5
Try 3	3.8	3.3	3.9	3.2	3.9	4.4
Average	***3.8***	***3.3***	***3.8***	***3.4***	***3.8***	***4.4***

Table 27: Shows the results between the internal and external surfaces of the cans, developed with 3 different methods

From this simple comparison it is clear that for the first 2 methods the internal and external surfaces are quite similar, with the interior side resulting more reflective whilst, for the 3rd method the external surface was found to be more reflective.

Table 28, shows the intuitive difficulty, time required and result quality for the three proposed methods, to better evaluate their feasibility and if they were realistically reproducible.

	Blade	**Sandpaper**	**Pressure & Acetone**
Difficulty	3/5	2/5	3.5/5
Time taken	3/5	2/5	3.5/5
Final Result quality	2/5	2/5	4.5/5

Table 28: Shows the difficulty, time required and final result quality for the 3 analysed methods

After acquiring a variety of reflective aluminum surfaces through the different methods, it is now possible to start testing the effect and, possibly, improvements that they have on the designated solar bottle bulb experiment.

Test 2.1: ‘SunFlower’ Skirt

To better understand the effect that reflective surfaces have onto the output light, a simple test was created. This ‘sunflower’ test is developed to test how well could the internal side only of aluminum cans reflect more light into the bottle, meaning that it is placed outside of the roof onto the solar bottle bulb, and also for the internal part to test if it can help diffuse more light into the room. The external ‘sunflower’ (facing the artificial sunlight) will, in theory, reflect some of the incoming light rays towards the bottle and increase the light reading recorded inside of the box. Whilst, the internal ‘sunflower’ will ‘push’ downwards the light kind of focusing it to the lower part of the experimental ‘balck box’.

The illustrations and pictures below, Figures 36 & 37, show the steps and results of cutting the aluminum can into a ‘sunflower’ design.

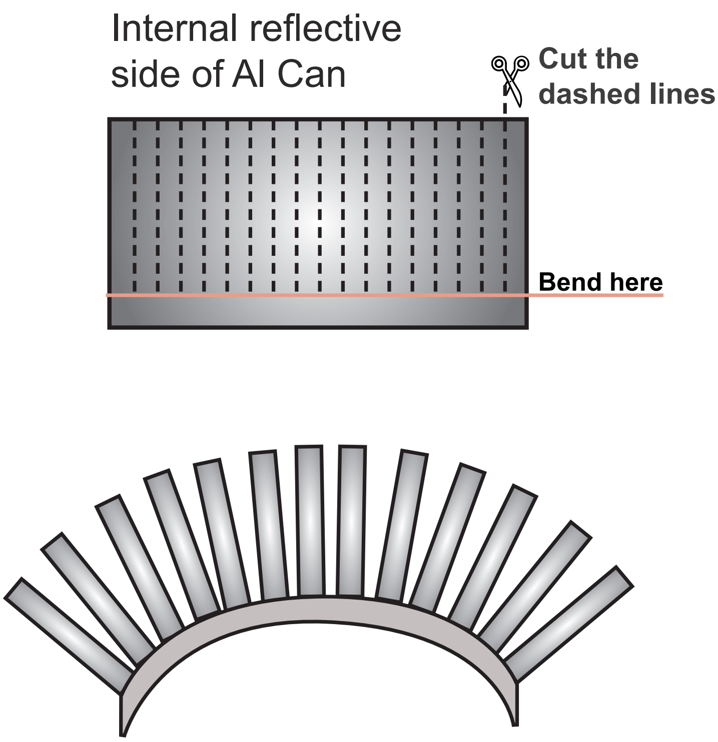


Figure 36: Illustrates the method to create an aluminum ‘Sunflower Skirt’, to be then attached to a bottle

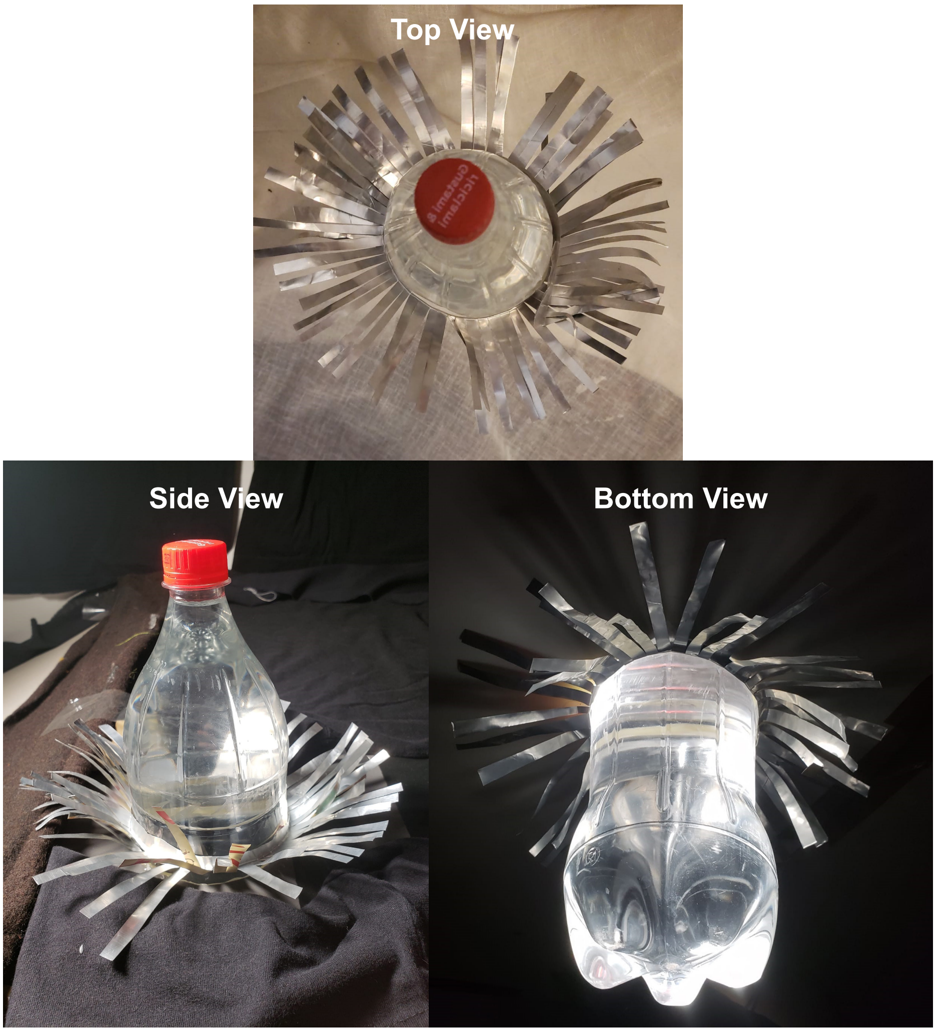


Figure 37: Shows example pictures of the testesd 'Sunflower Skirt' design described, from different angles

The testing was divided into 3 trials where in the first experiment the 'sunflower' skirt is placed BOTH internally and externally on the bottle. The second experiment had the 'sunflower' skirt on the EXTernal side and finally the last one was to compare it to the Cola bottle by itself (NONE), without the skirt. The bottle height was 16 cm, it is important to keep track of this as, we will also see later, it affects the standard only-coca-cola-bottle test results.

Both	1	2	3	Av.
1	1.0	0.9	0.9	0.9
2	18.5	17	17.5	17.7
5.3	4	3.9	4	4.0
4	2.4	2.1	2.3	2.3
5	13.6	13.4	13.6	13.5
6	6.0	5.9	6.0	6.0
A	***7.6***	***7.2***	***7.4***	***7.4***

Table 29: Shows the measured light reading for 'Sunflower Skirt', placed both internally and externally

Ext	1	2	3	Av.
1	1.1	1.0	1.1	1.1
2	15.8	15.6	17.0	16.1
3	4.1	4.3	4.2	4.2
4	2.2	1.9	2.4	2.2
5	15.9	16.5	16.3	16.2
6	6.1	5.9	6.3	6.1
A	***7.5***	***7.5***	***7.9***	***7.7***

Table 30: Shows the measured light reading for 'Sunflower Skirt', placed only externally

None	1	2	3	Av.
1	1.0	1.0	1.0	1.0
2	15.3	14.7	15.6	15.2
3	4.2	4.2	4.2	4.1
4	2.3	2.2	2.2	2.2
5	15.7	16.3	15.9	16.0
6	6.2	6.3	6.2	6.2
A	***7.4***	***7.4***	***7.5***	***7.5***

Table 31: Shows the measured light reading for 'only the Cola bottle, without 'Sunflower Skirt'

By looking at the data it is possible to see that when the 'sunflower' skirt is placed outside and inside the results are lower than when none of them are applied. When only the skirt is placed only outside the results improve. The test for the internal skirt only have not been performed as a sufficient deduction can be made based only on the other two tests, both & ext.

Test 2.1: Sunlight Parabola

By building a parabola around the bottle it would allow for more sunlight to be reflected onto the Cola bottle, and thus improve the overall light levels inside the black box.

The parabola was constructed using the previously cleaned Al sheets derived from aluminum cans and cutting a half circle, which is proportional to the diameter of the bottle. Figure 38 shows an example of the employed method to achieve a parabola shape for the experiment.

Figure 38: Shows the method to create a halfcircle in the aluminum sheet to be then used as material for the parabola

After cutting a half circle in one aluminum sheet, the process must be repeated into another one to obtain a parabola by joining the two rectangles with the semi-circles cut at the center. Then the Coca Cola bottle is placed in the center and the two sheets are joined at the touching corners. Figure 39 shows how the aluminum sheets are placed to be then joined.

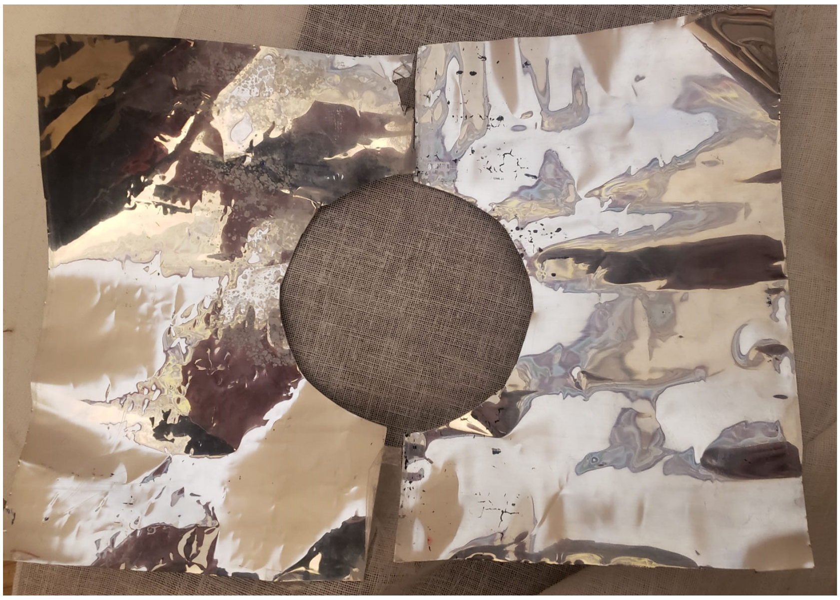


Figure 39: Shows the method to create the parabola by joining the two aluminum sheets, with the cemicircle perviously cut

To create the parabula the aluminum sheets must be placed at around a 30° angle to ensure that light is reflected towards the bottle. Figure 40 shows the final parabola built to fit around a 1.75 l CocaCola bottle.

Figure 40: Shows the side view of the parabola (left) and when it is placed on the bottle for testing

For this experiment the parabola will be placed in two different orientations and compared to without parabola. The orientations are horizontal and vertical, relative to the source of light. Again, for this test, it is important to report the height at which the bottle is placed. In this case it is at 14 cm. Furthermore, for this experiment an extra feature is employed: a small circular mirror is placed in the cap of the bottle to reflect the light from the top to the bottom. The idea comes from thinking that the cap is the only part that cannot reflect and refract light and that some light will not be able to exit the bottle from the bottom and bounce back to the top thus, placing a ‘mirror-cap’ will allow it to bounce back to the bottom with some extra light.

Figure 41 shows the placement of the mirror-cap.

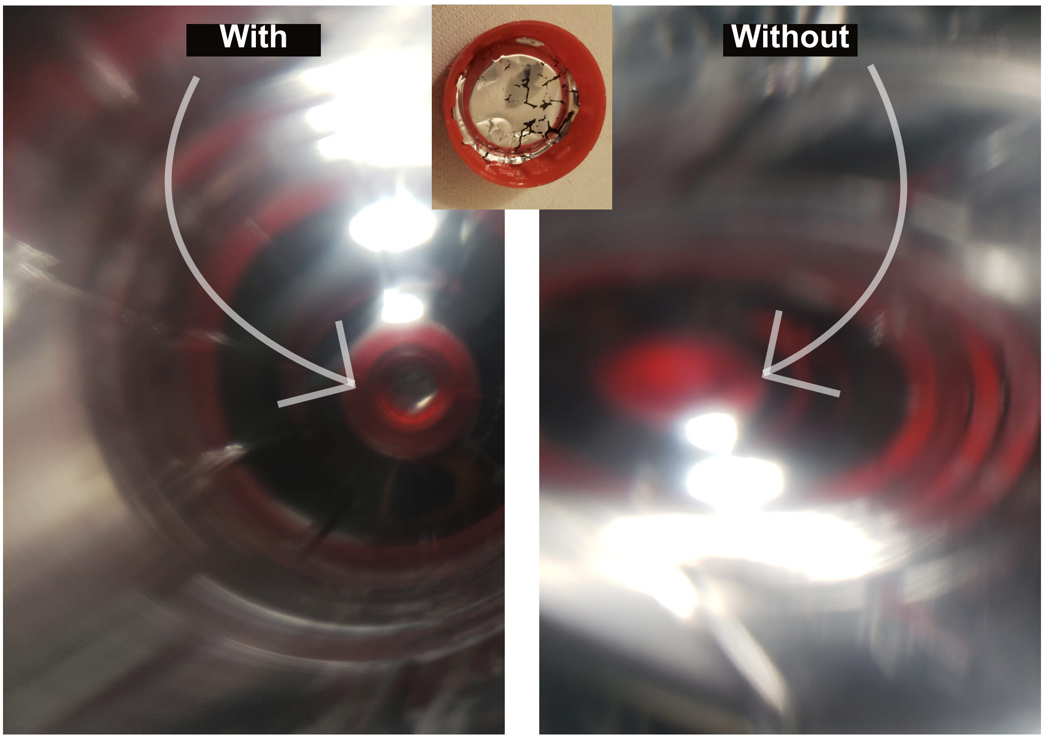


Figure 41: Shows the mirror-cap and the comparison of when it is palced and when it is not

The tests carried out were: Horizontally placed parabola, vertically placed parabola, without parabola but with mirror-cap and only Cola bottle, for comparison with the others.

The resulting data is reported below. To be noted that the parabola is only exterior of the testing black box.

Vertically	**1**	**2**	**3**	**Av.**
1	1.1	1.2	1.1	1.1
2	19.7	18.7	20.8	19.7
3	5.8	5.7	5.8	5.8
4	3.4	3.3	3.4	3.4
5	28.7	28.9	28.8	28.8
6	4.5	4.5	4.5	4.5
A	***10.5***	***10.4***	***10.7***	***10.6***

Table 32: Shows the measured light reading for 'the vertically placed parabola (only external) with the mirror-cap

Horizontally	**1**	**2**	**3**	**Av.**
1	1.2	1.1	1.2	1.2
2	20.4	19.7	20.1	20.1
3	6	5.9	6	6.0
4	3.5	3.5	3.6	3.5
5	29.0	29.3	29.4	29.2
6	4.7	4.6	4.7	4.7
A	***10.8***	***10.7***	***10.8***	***10.8***

Table 33: Shows the measured light reading for 'the horizontally placed parabola (only external) with a mirror-cap

Mirror-cap	**1**	**2**	**3**	**Av.**
1	1.0	1.1	1.1	1.1
2	20.1	19.4	19.7	19.7
3	5.5	5.4	5.5	5.5
4	3.0	2.9	3.0	3.0
5	30	29.7	30.1	29.9
6	3.9	3.9	3.8	3.9
A	***10.6***	***10.4***	***10.5***	***10.5***

Table 34: Shows the light reading for the Cola bottle, w/o the parabola but with mirror-cap

None	1	2	3	Av.
1	1.0	1.1	1.0	1.0
2	15.3	16	15.8	15.7
3	6.0	6.1	6.0	6.0
4	2.9	3	2.9	2.9
5	30.8	30.1	30.5	30.5
6	44.1	4.1	4.2	4.1
A	***10.0***	***10.1***	***10.1***	***10.1***

Table 35: Shows the measured light reading for 'only the Cola bottle, without 'the parabola and without the mirror-cap

The results show a clear improvement in light reading between the parabola and mirror-cap data and the normal Cola bottle readings. The mirror-cap seemed to improve the results and has shown a 4% increase whilst the parabola a 7% improvement. The results are very interesting and show that light reading improves when reflective surfaces are placed.

Test 2.3: Galvanized Steel Roof Sheet

This experiment is carried out to understand the effect that galvanized (mirror-like effect) steel roof sheets have in improving the efficiency and light readings. The NGO foundation Liter of Light advises the use of this type of metal sheet to place safely the Solar bottle bulbs into roofs of informal settlements. The results of this experiment can encourage its user to use a reflective pane around its Solar bottle to improve its lighting performance.

Figure 42: Shows the Galvanized Steel Sheet used for the Solar Bottle Bulb, as roof support

Figure 42 shows an example of referenced galvanized steel roof sheets by Liter of Light, and are taken as an example for the following experimentation. Nonetheless, different types exist, as in Figure 43 is a rounded shape roof metal sheet whilst other have triangular, rectangular or trapezoidal profiles. In this experiment, seen the different options available and the fact that galvanized steel roof sheets are sold in square meter, thus being expensive for the required test, a replica made of cardboard and covered with aluminum tape was utilized to simulate the intended effect. As for the parabola, the test was repeated for both horizontally and vertically placed towards the light and without anything, just the Cola bottle.

Figure 43: Shows the simulated Galvanized steel roof sheet used in Test 2.3

The bottle was placed at 16 cm height, internal, and 18 cm external. The results of this experiment are shown below.

Vertically	**1**	**2**	**3**	**Av.**
1	1.1	1.1	1.1	1.1
2	15.7	14.2	15.7	15.1
3	5.2	5.1	5.2	5.2
4	2.6	2.5	2.6	2.6
5	21.2	21.3	21.2	21.21
6	4.6	4.6	4.6	4.6
A	***8.4***	***8.1***	***8.4***	***8.3***

Table 36: Shows the measured light reading for the simulated metal roof panel placed horizontally (perpendicular to the direction of light source)

Horizontally	1	2	3	Av.
1	1.1	1	1.1	1.1
2	14.3	16.9	14.9	15.4
3	4.6	4.6	4.6	4.6
4	2.4	2.3	2.4	2.4
5	20.2	20.4	20.7	20.4
6	5.5	5.6	5.6	5.6
A	***8.0***	***8.5***	***8.2***	***8.2***

Table 37: Shows the measured light reading for the simulated metal roof panel placed vertically (parallel to direction of light source) .

None	1	2	3	Av.
1	1.0	1.0	1.0	1.0
2	15.3	14.7	15.6	15.2
3	4.1	4.1	4.2	4.1
4	2.3	2.2	2.2	2.2
5	15.7	16.3	15.9	16.0
6	16.2	6.3	6.2	6.2
A	***7.4***	***7.4***	***7.5***	***7.5***

Table 38: Shows the measured light reading for 'only the Cola bottle, without 'the Galvanized steel roof sheet

There are clear improvements in utilizing a highly reflective galvanized steel roof sheet , as seen from the results. The roof sheet improved the light reading by 10%.

Test 2: Results & Discussion

An important point to notice is that after conducting these experiments and the previous ones, the author has noticed that the height placement of the bottle has an impact on light readings. Furthermore, it has to be reported that between the experiments the light was moved, by accident, and its position shifted lightly, however, losing the idea that it was a constant throughout all experiments and thus affecting the ability to compare all experiment between each other, effectively, as the certainty that all the dependent variables are controlled. Nonetheless, all the experiments are true to themselves and it is also the reason why all tests are concluded with only a Coca-Cola-Bottle test, to understand the standard level.

In this set of experiments, conducted to understand the effects that reflective mirror-like surfaces can have in the light readings, it was found that overall increments in light readings are possible by placing reflective surfaces externally around the bottle. The first experiment, 'sunflower' skirt showed that a small improvement with randomly placed reflective strips is possible but at the same time it can be deduced, by having a lower light reading when the skirt was placed both internally and externally, that it can also negatively affect the results. The skirt is not able to focus and reflect enough light towards the bottle, and sometimes blocking its path too, as seen in the 'both' trial. Compared to when there was only the bottle the improvement recorded was only around 3%. The other two experiments yielded better results, the parabola has shown an 8% improvement and the galvanized steel roof sheet an outstanding 10% increase.

The improvement in light readings are probably due to the focusing of more light onto the bottle and effectively translating this increase in focus into higher readings of light output.

8.3. Strontium Aluminate

Strontium aluminate doped with europium and dysprosium is the compound that has the effect of phosphorescence or glow-in-the-dark, as it is called in the market. It was selected as an electricity-free solution for the night time light issue. Nonetheless, a lot of parameters need to be understood to clearly comprehend the mechanisms behind phosphorescence, not the science but the timings, duration and how to efficiently use them.

This set of tests are made to pinpoint the best way to employ this compound and achieve the best results as a night light solution. In these experiments a bag of 100g of Strontium aluminate was acquired and experimented on to understand both its viability as a night-time light solution and overall to be effectively used, as in not too much of it is required to obtain a decent lighting level. The experiments will evaluate the mass per area needed to have enough light penetrate and irradiate the whole phosphorescent powder. The time required to have the longest light emission and further testing .

It must be noted that a set of standard specimens will be created to be then used in all experiments to have a basis for comparison and evaluation.

3.3.1 Test 3: Afterglow Duration

The first experiment is set up to understand at which thickness, over a fixed area, allows light to go through and irradiate the whole phosphorescent powder. This is done to understand how well light penetrates the powder to reach its furthest points form the light.

The powder chosen for these experiments is a yellow-green glow-in-the-dark powder. Figure 39 shows the phosphorescent effect of the powder after being placed in artificial light for a few minutes.

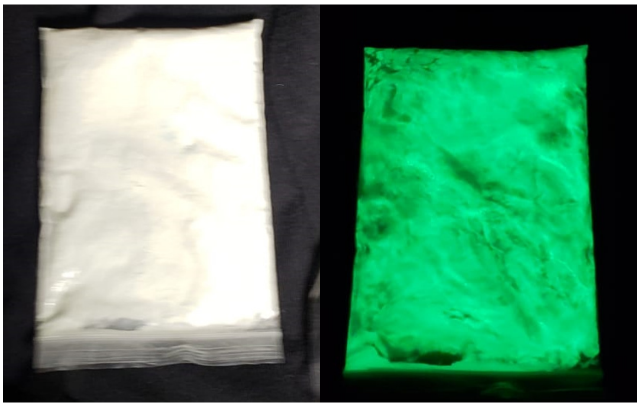


Figure 44. Shows the Strontium Aluminated powder, before and after being irradiated (5 min)

Different samples were made to evaluate the previously mentioned hypothesis. They are shown in Figure 45. The tested specimens named and marked are placed in a glass enclosure to be able to see if the light emitted from the A side is similar or comparable to the B side. This will show how well light penetrates the specimen to reach its B side and understand the ideal thickness so that all the Strontium aluminate powder is both irradiated and then glowing. Figure 46, shows the differences between the Front (a) and Back (B) sides and how thicker spots of powder struggle to emit light and are seen as dark spots.

All the specimens will be tested for different times of irradiation and, thus, how long they glow compared to it. Furthermore, the water bottle with the powder inside, not soluble, is studied to evaluate if a similar phenomenon as for the solar bottle bulb, snell's law and total internal reflection, happens and how well it can be employed to possibly reproduce a similar result.

Test 3.1: Time-Density Irradiance

All the above specimens will also be referenced to the bag containing only Strontium Aluminate powder, seen in Figure 44. The tests will be carried out with a 2h increase each time and then recording how long they emit light. A standard smartphone (iPhone 7) will be used to record the video proof but it is to be mentioned that different smartphones cameras and IA systems react differently to low-light environments, meaning that when it seems to not 'see' anymore glowing, the reality is that the specimens and powder will be still emitting very low light but is not able to pick it up. This leads to implementing a further test, performed by the author, on checking if the final light, that is not able to be seen from the iPhone, is enough to read small writing of a book.

The videos are all recorded from a fixed position and for a fixed length of time. All the results will be compared through pictorial and visual analysis, as the lux meter hardly picks up the emitted wavelength due to not having enough energy.

All pictures shown in table 43 have a +20% brightness to clearly show the drop in luminosity and allow the reader to see the phosphorescent powder glow.

Figure 46 demonstrates how the thickness of the powder will affect the absorption of light from the side not facing it. After understanding the weight-thickness illuminance ratio, the thicker bags are not able to let enough light pass for the back side to be irradiated too. This shows that the density and tightly packed phosphorescent powder has limitations on how well it can absorb and release light.

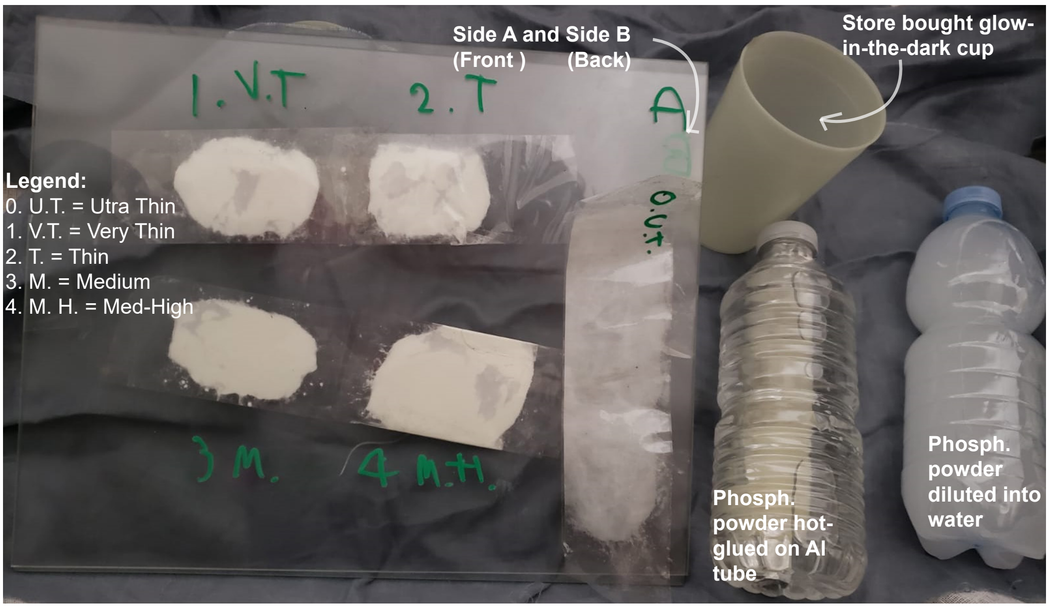


Figure 45. Shows the specimens to be tested for light irradiance and overall resulting luminescence

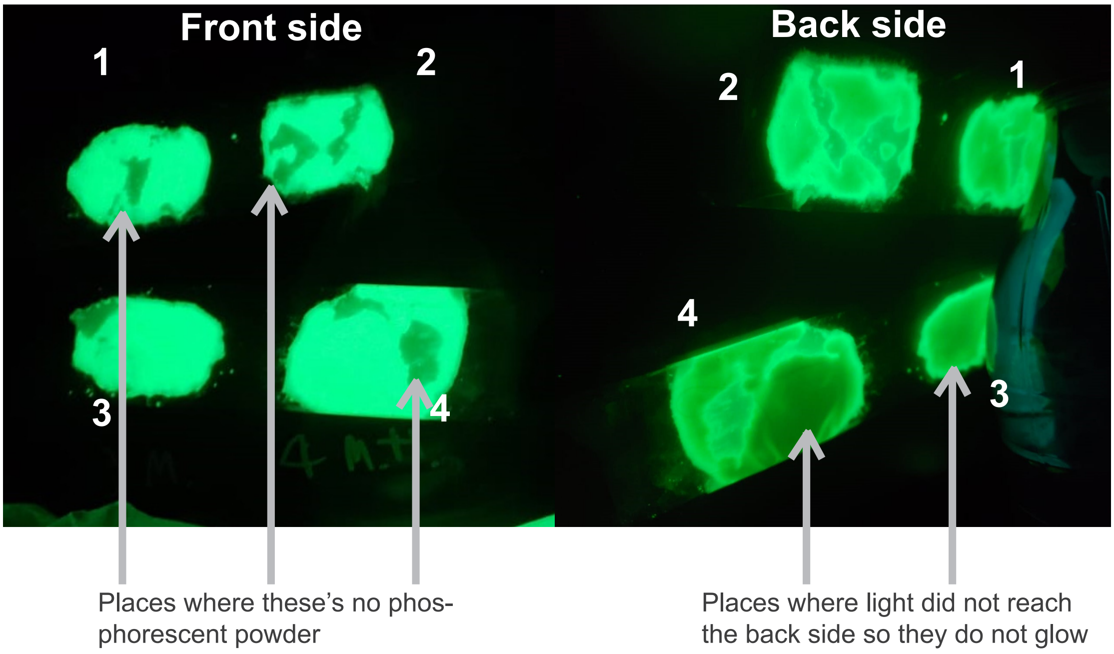


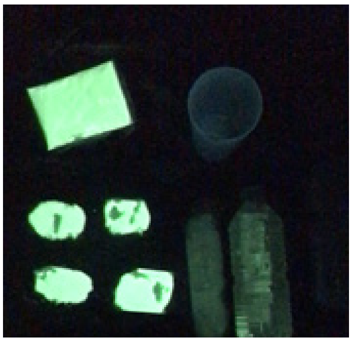
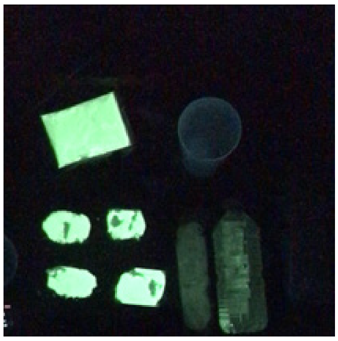
Figure 46. Shows the back and front side of the tested specimens, to highlight how the thickness affects the absorption of light and thus its emission

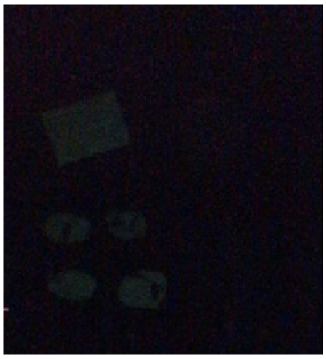
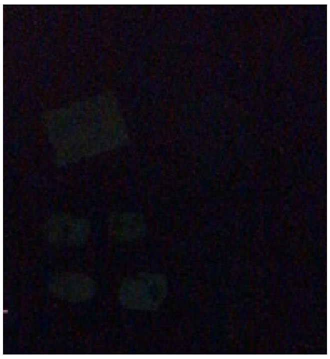
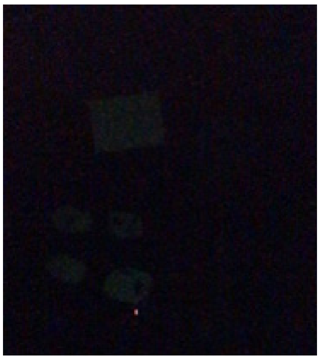
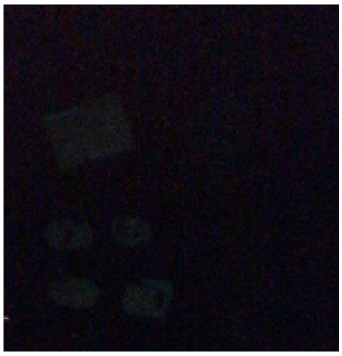
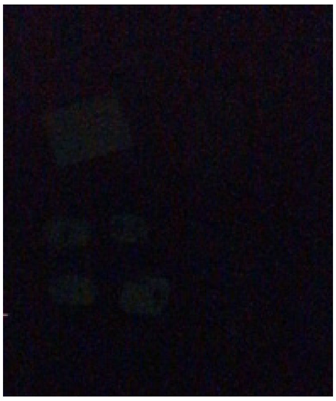
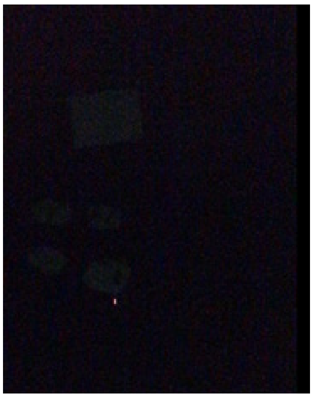
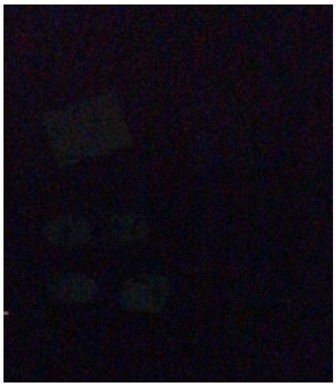
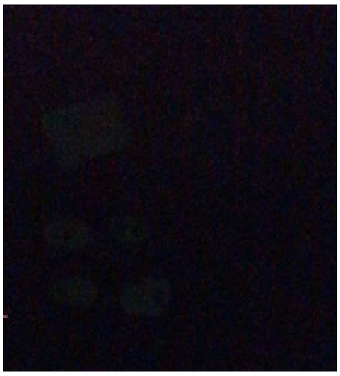
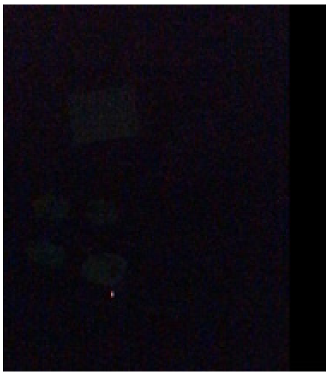
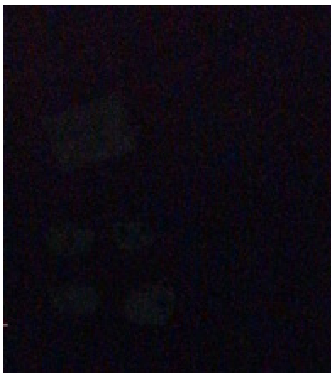
The above studied specimens are then tested to evaluate if the specimens 3 and 4, that have been found to create dark spots due to being too thick, release afterglow for longer compared to the others. As mentioned before, in the experiment a few additions were added to be able to compare different phenomena in a single experiment. Thus, a water bottle filled with water and around 3 g of powder, a bottle with a rolled up aluminum can with hot glue dipped in powder and a store bought phosphorescent plastic glass were added, as seen in figure 45.

Name	Weight & Composition
0. U.T.	0.9 g phosph. powder
1.V.T.	2.0 g phosph. powder
2.T.	2.5 g phosph. powder
3.M	3.5 g phosph. powder
4.Med-High	5.0 g phosph. powder
Water Bottle	3 g dissolved in water

Table 39: Shows the specimens and their contents of phosphorescent powder

An interesting 'incident' happened, whilst using hot glue the author noticed that when the moten hot glue touched the Strontium Aluminate powder it started to glow, giving space to the thought that as light gave energy to the electrons to rise and fall from electron orbits so did thermal energy, however only for a short instance. This could lead to further experimentation to see if light could be exchanged for thermal energy in some way, or integrated to speed or improve the process.

Start	2h of Light	4h of Ligth	6h of Light
0 min			
5 min			
15 min			
30 min			

45 min			
1 h			
1 h 15 min			
1 h 30 min			

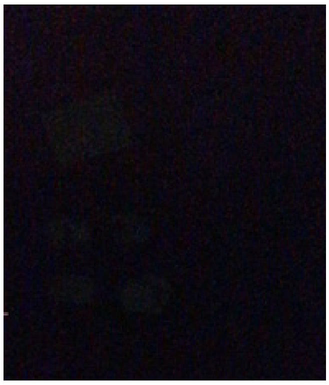
1 h 45 min			
2 h			

Table 43: Shows the pictures taken of the different specimens irradiated for different times, after set intervals of time

This experimentation with a 2h increase, seen in Table 43 using the weights specified in Table 42, seems to bear no fruits however, in all 3 tests the store bought cups performed terribly. The assumption could be that they:

- Have low content of phosphorescent pigment
- Are old and therefore emit less afterglow
- Have not been placed in the position that would allow it to absorb as much as possible

Nonetheless, the results of the store bought cup are similar to the water bottles experiments where similar assumptions can be made. For the water bottle with the al tube and powder covered hot glue, the best guess to be made for its poor results is that there is not enough powder to decently absorb and release energy and that the aluminum tube is not aiding in the predicted way. It was placed to help reflect the incoming light, from outside the bottle, that passes through the powder then the glue and back towards the powder.

The bottle containing only water and powder had disappointing results. The idea was that as the Solar bottle bulb the light would be ‘trapped’ by the water and redirected towards the powder.

The poor results can be assumed to be due to the sideways inclination of the bottle that would affect the 'ability to trap' the light as the distance between the point of entry and the powder was not enough. The round shape distorted the light aways from the powder thus decreasing its afterglow. Figure 42 shows an early test where both the store bought glass and water bottle containing phosphorescent powder.

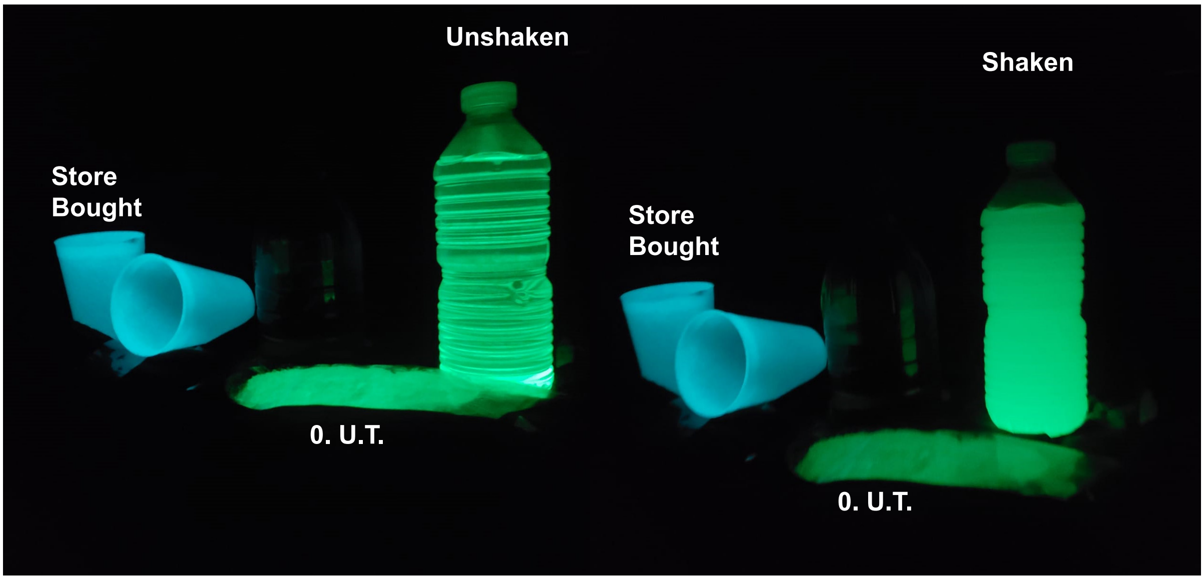


Figure 47. Shows the water bottle containing the phosp. powder and the store bought glasses in an early test. Left is the water bottle not shaken, right is the water bottle shaken

The interesting point to be taken from Figure 47 is that position and light angle and orientation can greatly affect the results and perception of them. The time of irradiance was not recorded for such an early experiment, however further testing on how effectively can water disperse and in a way focus the light, can be done. The interest is because by looking at figure 47 the unshaken bottle seems to better disperse light so that even its bottle cap can be seen.

Nonetheless, overall all the specimens recorded a sharp decrease of afterglow in the first 15 minutes with a then apparent slower decrease in afterglow. The phosphorescent powder bag appeared to be brighter due to its increased surface area, thus proving that a larger surface area, even with a small thickness, can effectively make a difference.

Test 3.2: Strontium Aluminate Suspention

In this experiment, the Strontium Aluminate powder will be mixed with glue to be able to better utilize the powder and spread its effects on a wider surface. The previous experiment, Test 3.1, showed that there is a maximum thickness so that all the powder is irradiated and then glows, but the more powder does not mean that it lasts longer. So for this experiment the hypothesis is that when the powder is suspended it will help to 'spread' the pigment and to shape it by mixing it with glue. This will allow for an understanding and control of the amount of powder vs. glue, how the white glue affects the resulting afterglow and the resulting dried glue powder mix. The specimens used for this experiment are shown in Figure 48, where it is shown that the different powder weights are mixed with different quantities of glue. Furthermore, a plastic bottle cut in half will be used as a representation of how well the glue-powder mix can stick to other surfaces and thus how effective it is to cover a surface. Overall the specimens' afterglow will last longer when irradiated more, however it will reach a point where more light will not increase the afterglow duration.

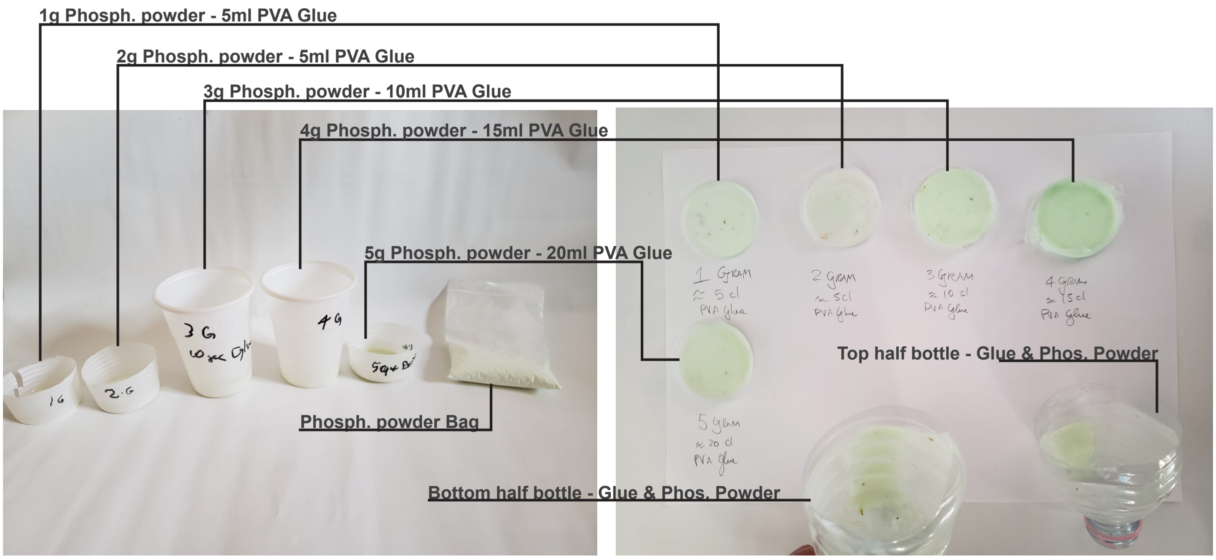


Figure 48. Shows the created specimens for the second set of experimentation of the Strontium Aluminate powder

Figure 48 shows the final experimental set up where the new specimens are tested and compared with the specimens utilized in test 3.1. This is done to see if any apparent differences are seen and possible contrasts between them.

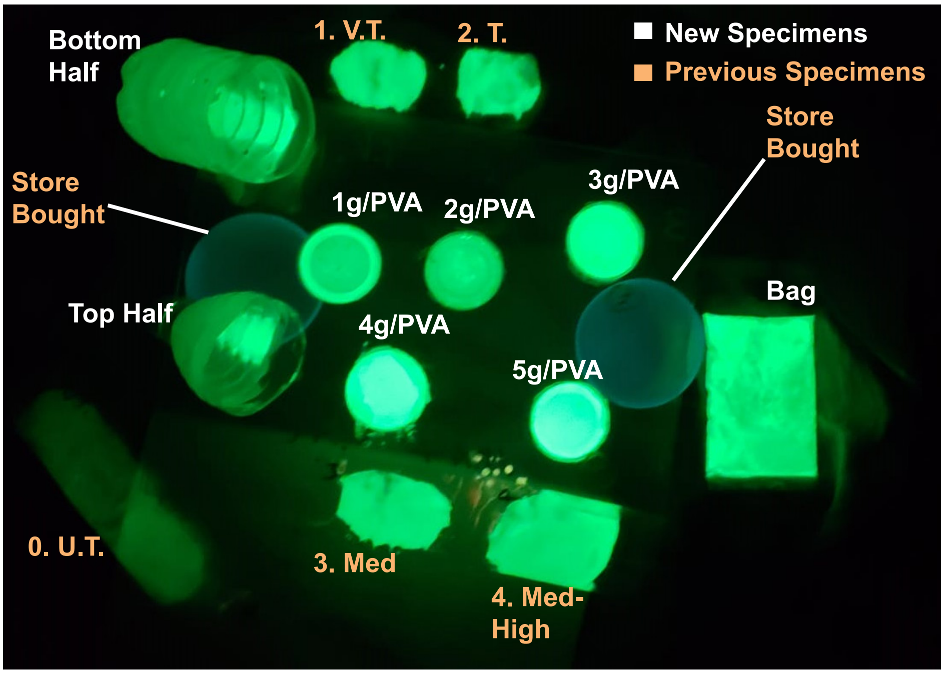


Figure 49. Shows all the specimens utilized to test the Strontium Aluminate powder mixed with white PVA glue and compared to the specimens of Test 3.1.

Already from Figure 49, there's an obvious difference between the specimens. As it can be seen the 4g and 5g with PVA glue are brighter or somewhat whiter. This could be an effect due to the camera or due to the glue being white, thus the light emitted would appear white.

In the previous experiment, test 3.1, the tests where repeated every 2 h, meaning that light was shone over the specimens for 2 h then recorded the afterglow for 2h, then shone for 4 h and recorded for 2 h and lastly shone for 6 h and recorded for 2 h again. In this experiment light was shone over the specimens for 5 min, 10 min, 15 min, 30 min, 45 min and 1 h and the afterglows for each different time length of shining light over the specimens was recorded for 1 h. These timing and recording length were decided after the tests conducted in Test 3.1 as it was seen that very little difference was found over the 2h intervals thus, it was decided to shorten them to also understand the minimal values to have a decent afterglow and its duration.

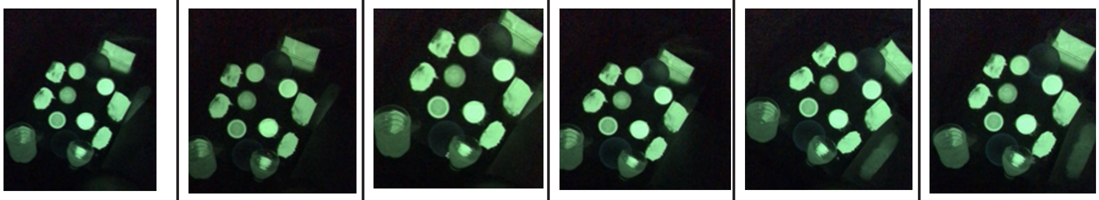
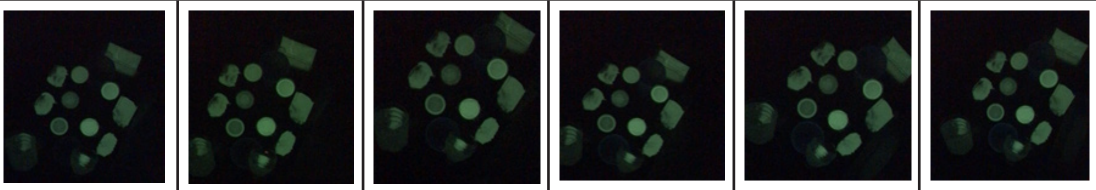
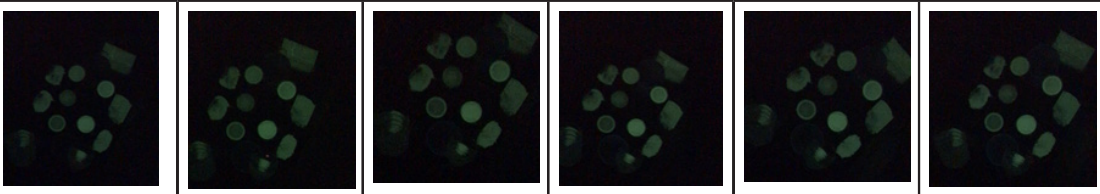
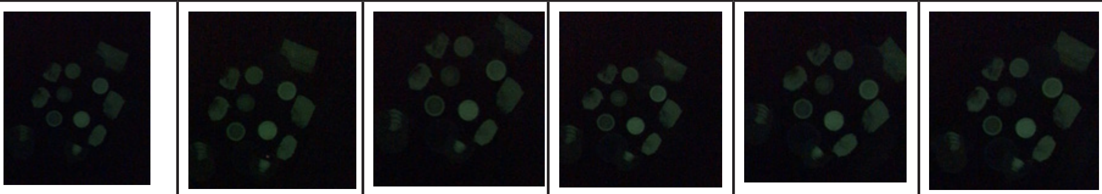
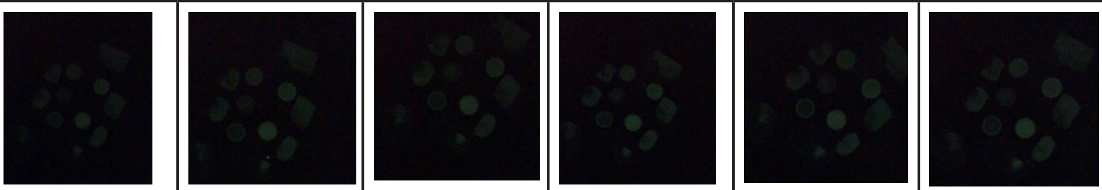
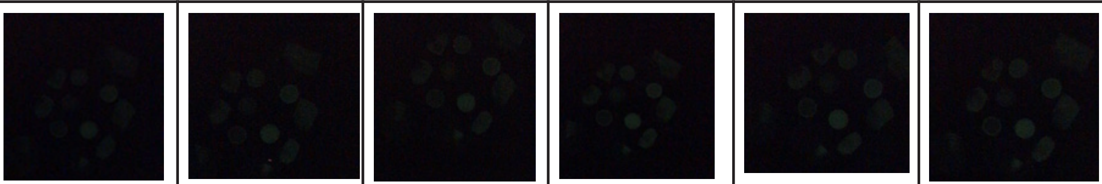
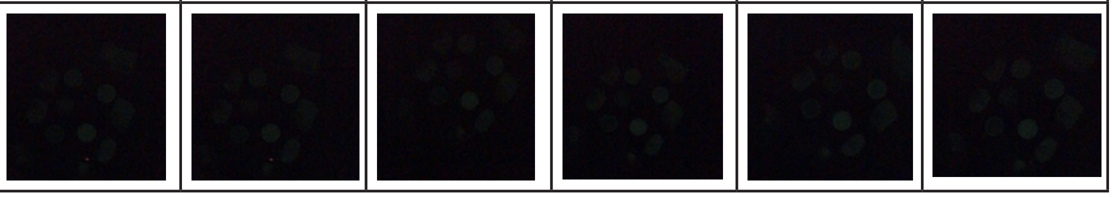
Start	5 min of Light	10 min of Light	15 min of Light	30 min of Light	45 min of Light	1 h of Light
0 min						
5 min						
10 min						
15 min						
30 min						
45 min						
1 h						

Table 40: Compares the pictures taken at different set time intervals between different times of light irradiation for all specimens made, tests 3.1 & 3.2

The table 40 shows that effectively there is a difference from a 5 min of light against 1 h of light, nonetheless in between these times the effective visual difference is low. From the 15 min mark of the recorded video it starts to be clear how the time of irradiance affects the duration of afterglow. Furthermore, the specimens which seem to be brightest and last the longest are specimens 4g/PVA and 5g/PVA, even compared to the previous specimens, of test 3.1, and the bag containing only Strontium Aluminate.

Test 3.3: Further Testing & Findings

Before proposing a final design, a few more elements must be investigated. This is to be able to propose the best solution possible. The next investigations will be conducted on:

Can thermal energy activate the Strontium Aluminate afterglow? If yes, how well and can it be effectively used as a substitute for sunlight?

When the Strontium Aluminate is placed in a bottle of water, but is not mixed in it, does it diffuse light effectively?

Very simple tests will be performed to clear the doubts of the two aforementioned points. The two small experiments will be tested to identify if it is a valid addition to the proposed solution or if further points could be investigated.

1. Thermal Energy

The point of discovery of this interesting phenomena was whilst working and experimenting with hot glue and phosphorescent powder. Hot glue is reported to melt at around 100°C, and when it came into contact with the phosphorescent powder, without being previously irradiated, it started to glow. Thus, a very simple experimentation will be done to ensure that:

The Hot glue-powder discovery was not a causal coincidence

If it is possible by placing the powder in a similar 100°C environment to replicate the observed effect.

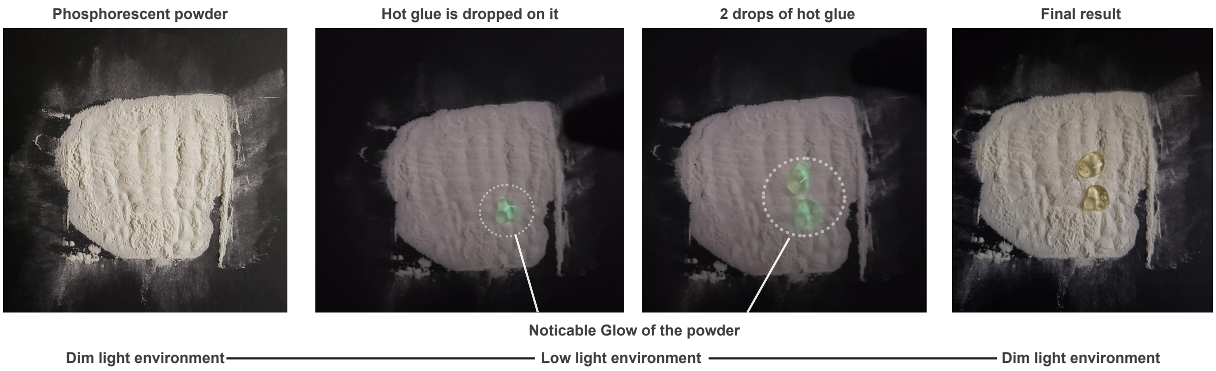


Figure 50. Shows the process of discovery, and, thus, the proof, that thermal energy creates the afterglow without being exposed to light

As it can be seen in Figure 50, the hot glue does cause the phosphorescent powder to glow thus proving that there are other possible methods to 'recharge' the afterglow effect after it has gone out. Further experimentation will show how effectively it can be used and if this effect can be a substitution to shining light over the specimens.

The second stage of these tests will be performed by utilizing a previous specimen, from tests 3.2, to be submerged in hot/boiling water and looking at the results.

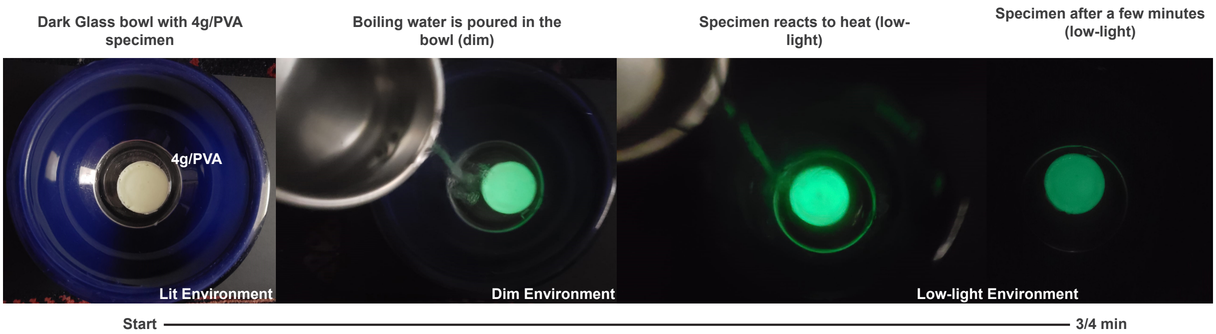


Figure 51: Shows the specimen 4g/PVA being tested in a glass bowl where boiling water is poured in, over time

Figure 51 shows how the boiling water activates the glowing of the specimen 4g/PVA, which lasts for as long as the water is hot. Further testing could be done to see if the glowing dissipation speed is similar to, better or worse than for the standard light irradiation. From test 3.2 it is known that after the 30 min mark the afterglow gets very dim, thus it would be reasonable to do a few pilot experiments and see the difference in afterglow duration between a boiling bath and a 10 min of light irradiation, meant as a preliminary test. For this pilot test, the 5g/PVA specimen is divided in two, to ensure an equal analysis between the boiling water test and the light test.

From the previous pilot test it was found that after removing specimen 4g/PVA that it had semi-dissolved into the water. This is probably due to the PVA being heat sensitive and releasing back into the water some of the phosphorescent powder.

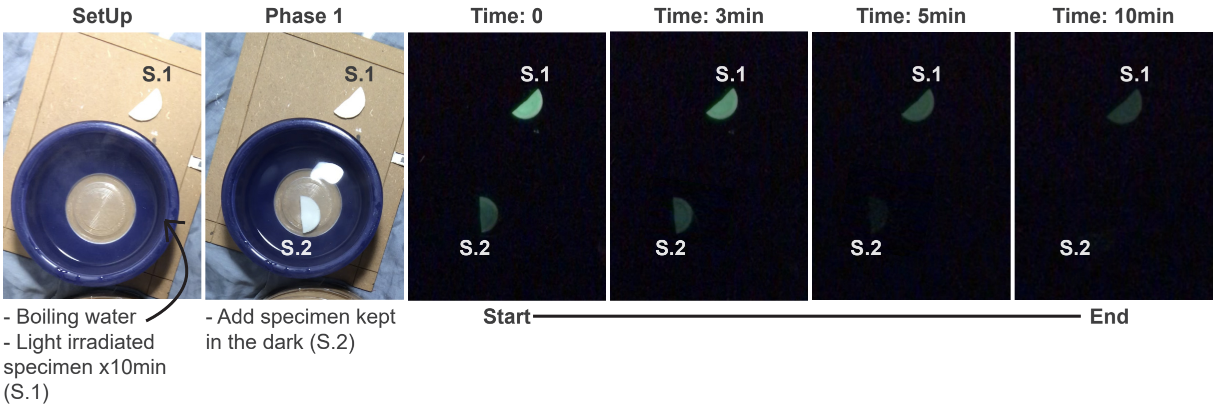


Figure 52. Shows the specimen 5g/PVA broken in half and put to test. Half (S.1) is irradiated for 10 min vs. the other half (S.2) which has been kept in the dark but placed in boiling hot water. Tested for 10 min total

Figure 52 shows the results for the second pilot test to evaluate thermal energy as a substitute energy source. It's possible to see that the effect persists, however the comparison shows strong differences between them. The two specimens emit light but dissipate the afterglow at different durations. Specimen 1 (S.1) lasts for the whole duration of the 10 minutes that has been recorded in a video, whilst Specimen 2 (S.2) after the initial 5 min mark starts to fade quickly. To note also is that the temperature of the water dropped rather quickly, due to the wide surface area of the bowl, and could transfer heat at a much lower efficiency than before.

Other points to be noted after this pilot test:

Specimen S.2 did not suffer a similar fate to 4g/PVA, which lost some of its mass to the heat, but stayed perfectly intact (only lost a tiny bit of excess glue)

S.2 after being in the hot water turned whitish/white (probably the glue vulcanizing) but after it dried it turned back to its previous color

The two specimens while tested were not showing the same side but one (S.2) was flipped. This could have affected the results but is not clear.

FURTHER TESTING

Possibilities of further tests to better understand the relationship of heat exchange and alternative hybrid solutions arise after these pilot experiments.

Such possibilities include, but are not limited to:

Would irradiating and heating a specimen make the afterglow last longer?

If a better container is used, which would reduce the heat loss, could it improve the duration of the afterglow?

If higher temperatures are reached, would the afterglow last longer or shine brighter?

Each of these paths would lead to further testing and experimentation to fully grasp the opportunities created by this phenomena, however it is outside of the project's scope.

Solid phosphorescent specimen in a bottle with water

This simple pilot test is designed to show the validity of the principle brought by the Solar bottle bulb. Two differently shaped specimens will be compared and tested in the same bottle to understand if there is a shape improvement factor to be accounted for and understand what possibilities can be taken advantage of.

Also for this project there are a lot of variables that could be changed and have an effect on the outcome and further improve how effectively the phosphorescent powder and PVA glue mix, such as the powder glue mix balance, the shape and its durability in water over time.

The first specimen was created to be circular and somewhat flat using a mix of 7g of powder and 4 g of PVA glue, whilst the second is meant to be conically shaped but hollow made with 5g of powder and 5 g of glue. The differences between the two are to test if plausible differences are noticeable when there is more or less glue/powder and if the shape influenced the maximum light penetration in the specimen, the afterglow duration and the overall apparent brightness of the specimen. The process of placing the specimens inside the bottle and the results are shown in figure 53.

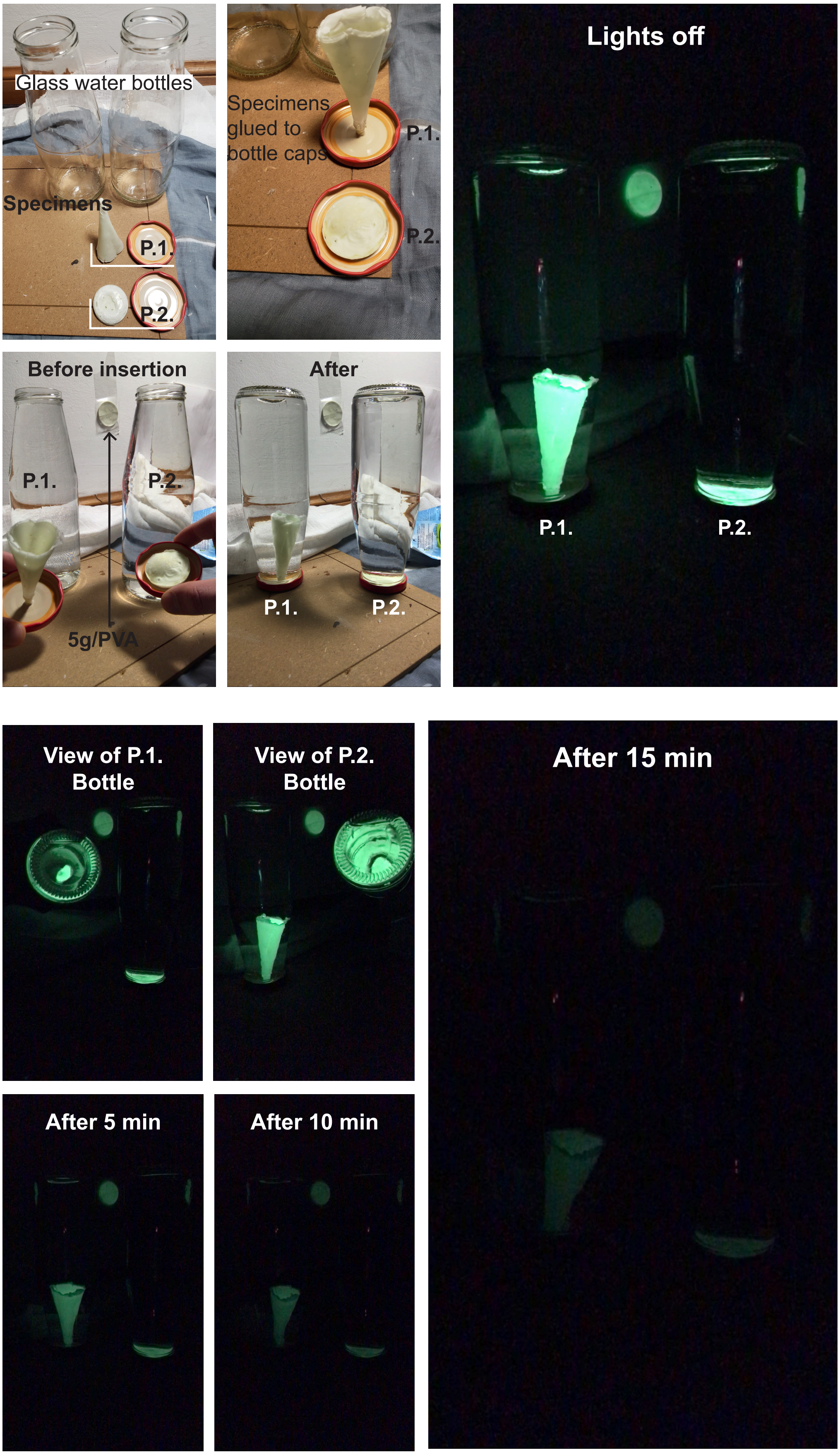


Figure 53. Shows the process and results of the test 3.3 part 2

For this test the specimens created, P.1. and P.2 , were glued to the caps of two glass bottles. These types of glass bottles were used as they have a larger aperture which would easily fit the specimens, in contrast to normal water or soda plastic bottles. In this experiment the total internal reflection effect was studied to understand how well the phosphorescent specimens acted as a source of light, compared to the Solar bottle bulb.

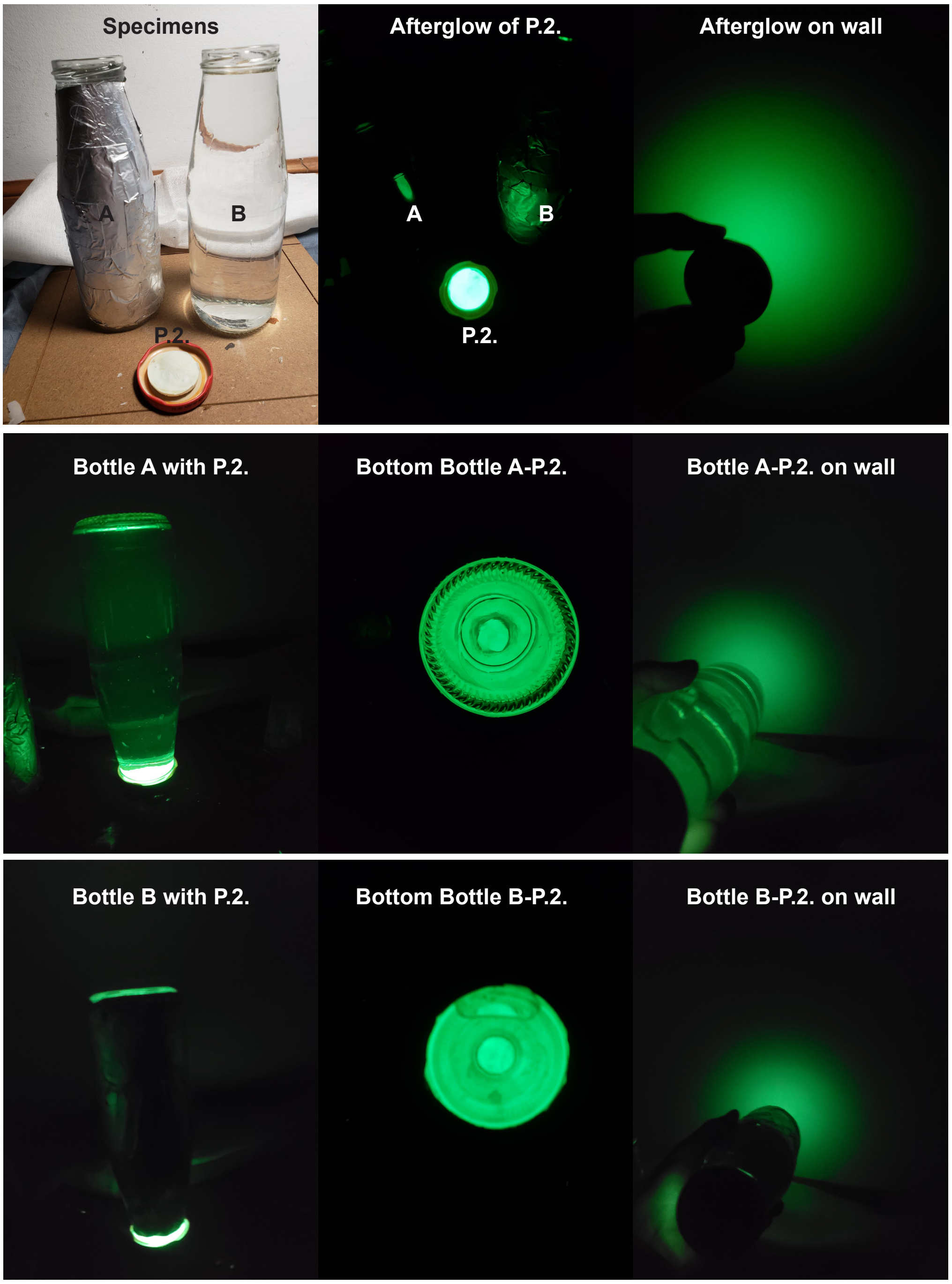


Figure 54. Shows the process and results of the test 3.3 part 2

From Figure 53 it is possible to see how, from the side, not much is happening differently. However, when the bottles are inclined the light from the specimens is more visible and channeled. The bottle from specimen P.1. seems to emanate relatively less light than the bottle of specimen P.2. The assumption that can be made in this case is that even though P.1. has relatively more surface area, as it is a cone, than P.2., but it delivers it less effectively, as more is lost inside the cone. Thus, the deduction is that a wider area of afterglow irradiance would be preferable to draw out as much light as possible. The pictures showing the duration and fading of the afterglow, also show that P.1. deteriorates and crumbles due to the effect of the water onto the thin specimen. P.2. instead does not follow the fate of P.1. and remains nearly perfectly intact after being in contact with water for more than 1h.

A possible next step presents itself whilst thinking that as most of the light is redirected towards the top of the bottle also the light emitted to the side could do the same. Therefore, if mirror-like material would be placed around the bottle without covering the top one could create a sort of flash light that only emanates light from one hole. `

Figure 54sa, shows the tests with specimen P.2. with two different glass bottles. One bottle with nothing, whilst the second one with reflective mirror-like aluminum foil wrapped around it. Both bottles are compared to only the specimens afterglow.

The results do not show a major improvement between the bottles and only the specimen. One main difference that can be seen is that the specimen P.2. gives off a more disperse and diffuse light whilst the bottles seem to focus it and channel it better. What can be drawn from this test is that a greater surface area allows for more afterglow and thus, provides more light.

Further testing could be done to ensure the stability of the specimens in water and how long they would last before dissolving or breaking. Different bottles could be tested to evaluate how the flat surfaces or wrinkled features affect the overall light dispersion/ focusing abilities of the bottle.

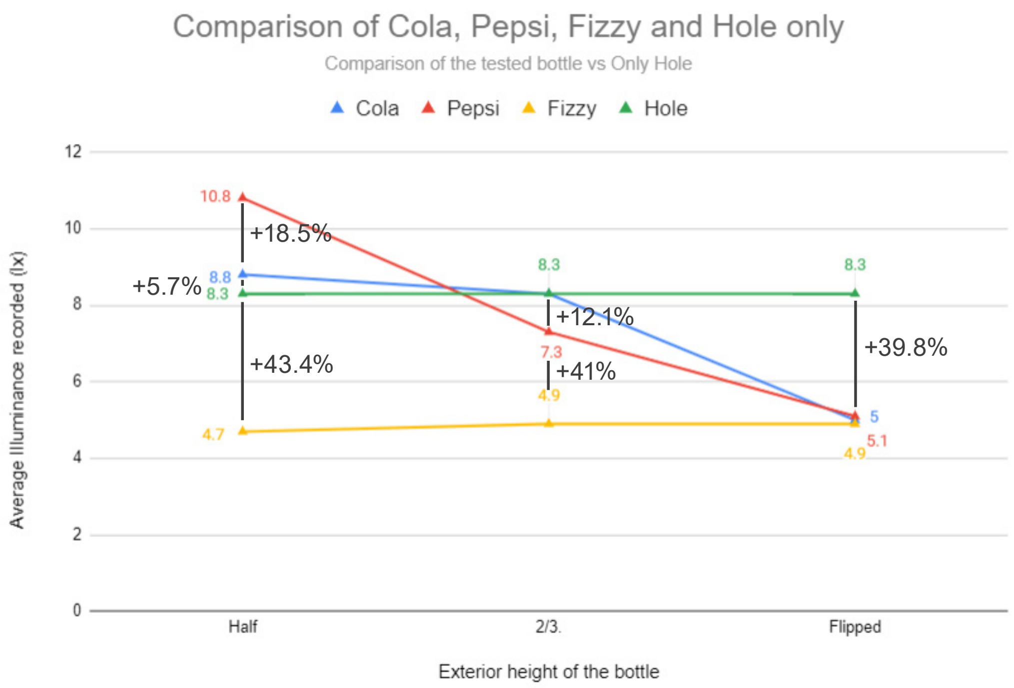
8.4: Results & Discussion of all Tests

All these experiments are constructed and theoreticized to better grasp and effectively employ the Solar bottle bulb and to study a proposed solution to the night light dilemma. The first two sets of tests, Test 1 and Test 2, are made to build research and baseline standards for future works on the Solar Bottle bulb, and to prove its validity as a project. The Solar bottle bulb is the core of an international NGO called Liter of Light, however they go through great lengths and effort to bring these innovative and naive solutions to poverty-stricken places around the world without knowing how to maximize their efforts and projects.

These studies are meant to be a guideline on how to better the results and understanding of the project, through methodological studies and experimentation the author aims to set a path in the direction of sustainability and waste recycling built on scientific experimentation.

Test 1: Solar Bottle Bulb

Test 1, studied and evaluated the shape and surface area exposed to the light to better grasp how to improve the resulting channeled light.



Graph 1. Shows the comparison of the recorded illuminance results for the 3 bottles tested. Shown is the percentage improvement for each test.

Graph 1, shows the comparison of the results obtained by testing the 3 different bottles for their external height and position, halfway outside, 2/3 outside and flipped upside down against the test for only the hole recorded illuminance. From the graph it is possible to see how a change in bottle shape and external height can have an impact on the recorded results. Both the Pepsi and Cola bottle performed very well at half height showing a near 25% improvement of registered lumens inside the experimental black box. The graph also shows how the Fizzy water bottle performed terribly and it is a good baseline of comparison to the others and a chance to understand why it has performed so badly. Both the Pepsi and Cola bottles have a smooth surface, without wrinkles or surface features, thus allowing a clean and clear channeling of the light inside the bottle. The surface features of the Fizy water disperse the light inside the bottle and augment the reflection and refraction but in all directions therefore being counter productive. To better understand also how the light is affected by the shape and features of the bottle one needs to take a closer look at each of them. This will also theorize why, when the height is changed, the exterior height affects so much the resulting illuminance.

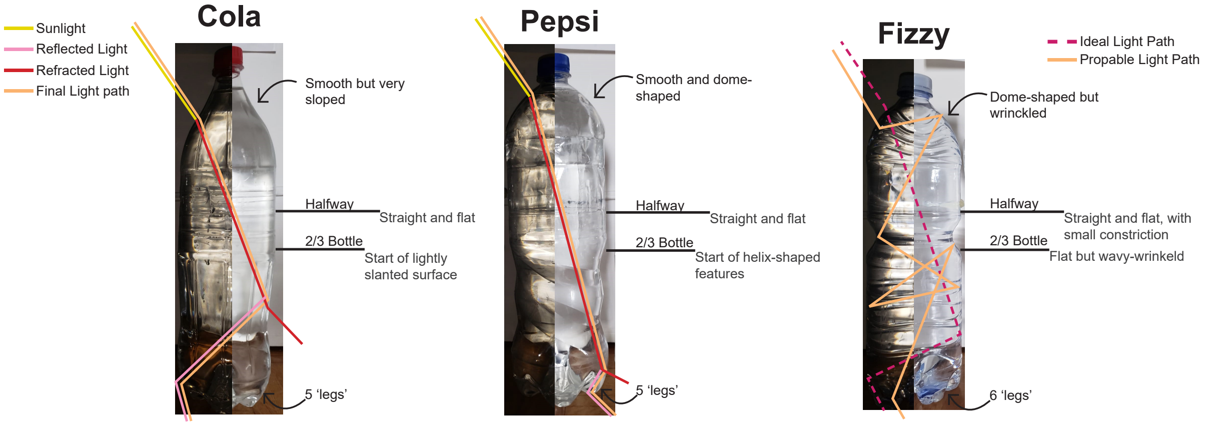


Figure 55. Shows comparison and study of the 3 studied bottles employed for Test 1

As shown and detailed in Figure 55, the 3 bottles act differently and present different results due to their shape, features and placement height. In all three bottles an example of light ray passing through it is shown to better understand how the sunlight is refracted and reflected inside the bottle onto the outside environment.

The CocaCola bottle has the overall best results at all heights and, thus, in reflecting and refracting light. This is both seen in Graph 1 and Figure 55, as it has the least surface features and overall it is smooth and semi-flat or slightly slanted. At the positions of Half way and 2/3 it is still flat, thus easier to install, and the simple surface allows for a clear and clean delivery of light. It has only 5 'standing legs' which help, or affect, how the light is propagated at the bottom of the bottle.

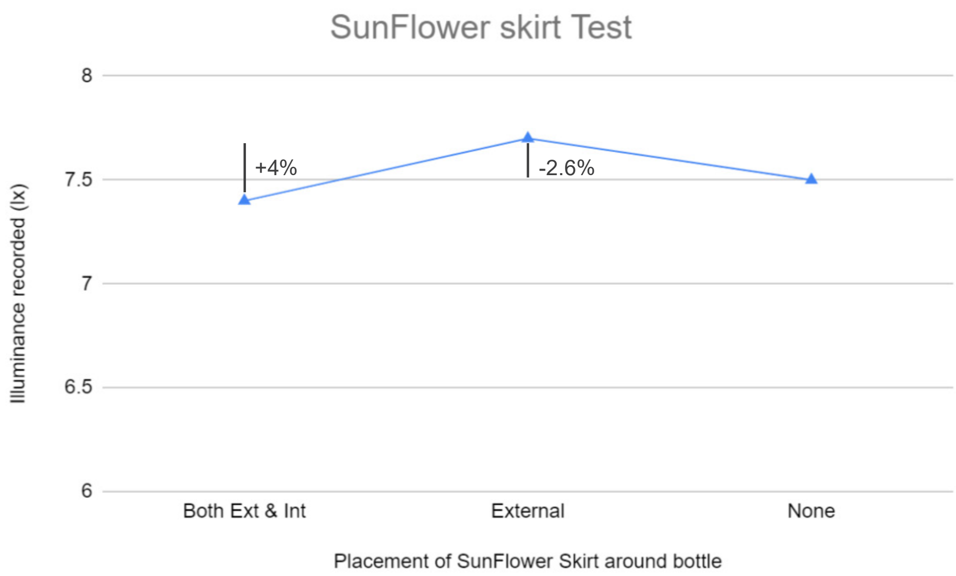
The Pepsi Bottle presents the best results at half way, and it can be deduced that it is due the dome shaped top of the bottle. This helps send the light rays further down the bottle and, thus, 'losing' less light. The bottom of the bottle has helix-shaped features that disrupt the channeling of light when the bottle is 2/3 out because they reflect the light towards the top of the bottle instead of the bottom. This bottle has also five 'legs'

The Fizzy Water Bottle has the worst results of all, even the hole. This is because of the surface wrinkles on the bottle that cause light to refract and reflect in nearly all directions. As shown in Figure 48, an example of an ideal light ray is shown compared to a more probable one that bounces off in various directions due to the wrinkles and constriction of the bottle. Furthermore, when placed 2/3 out, the constricted part is in the sunlight, which worsens the situation as even more light cannot pass through the constriction. Moreover, the more the light is reflected and refracted internally the more it drops in illuminance as it gets split multiple times.

This test was useful to understand that the shape and height placement of the bottle are key to achieving the maximum result and efficacy of the Solar Bottle Bulb.

Test 2: Reflective Surfaces

Test 2 undertook the tasks to comprehend the value that mirrors and other reflective surfaces could have in improving the effectiveness of the Solar Bottle bulb, but also as a medium to reflect and concentrate sunlight. The starting point of analysis for these tests was the case forms studies performed in Chapter 6, where the mirrors' versatility and use was put to comparison. A lot of commercial products employ mirrors for simple and articulate tasks, but here they were studied for the ability to nearly perfectly reflect sunlight. Simpler and more intricate tests were performed to first understand if any reflective surface could help, if the galvanized steel sheet used by Liter of Light improves the light reflection and if a man-made recycle material parabola could boost further the performance of the Solar Bottle Bulb.



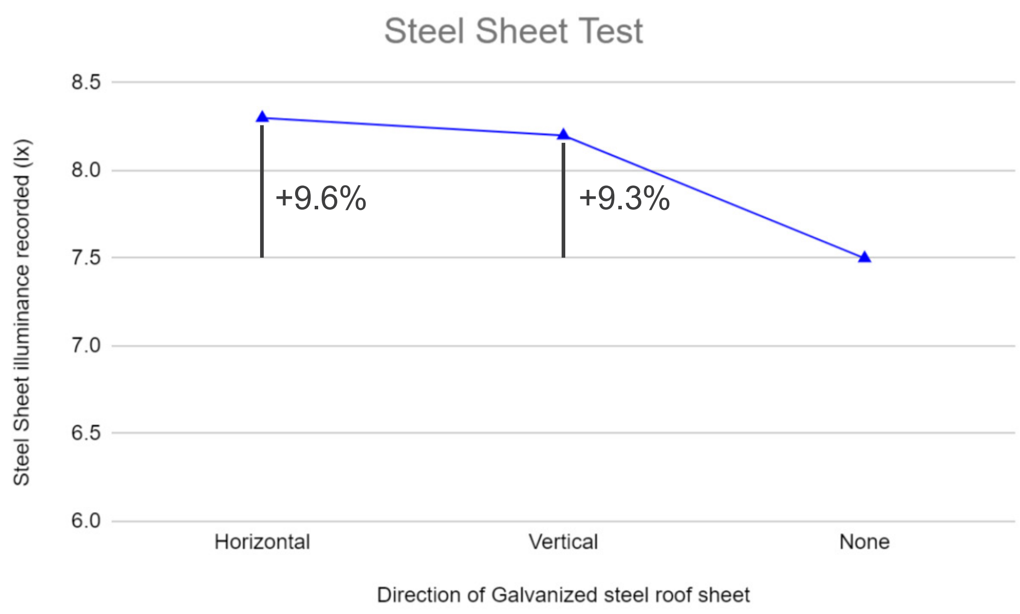
Graph 2. Shows the recorded illuminance between when the 'SunFlower' skirt was inside and outside the box, when it was only external and when there was only the Cola bottle.

Graph 2 shows the results recorded for Test 1.1, where a ‘SunFlower’ skirt was made out of small beer cans cut to create reflective petals. The hypothesis behind this test was to certify if any reflective surface around the bottle could help propagate and diffuse more light, thus improving the light readings.

By looking at graph 2 it can be assumed that when the SunFlower skirts are placed both inside and outside the results drop. This can be due to the fact that the skirt actually blocks and diverts the light instead of helping focus it on the bottle. This is useful as it can be interpreted that even a bit of leaves or dirt can block the entrance of the sunlight and reduce the efficacy of the solar bottle. When the skirt was placed only outside the results slightly improved, the reflective surfaces on the petals helped reflecting some light towards the bottle but they weren’t very conclusive.

This experiment shows that reflective surfaces can be of help but need to be placed correctly to truly improve the performance of the bottle. Nonetheless, it also showed that it takes only a bit of dirt to disrupt the refraction of light.

The next test, showed if the galvanized steel roof sheet that are utilized by Liter of Light, and they advise to use them too, actually bring overall improvement or not. And thus, if they are truly required as they are expensive.



Graph 3. Shows the results for the Test 2.2, where a simulated galvanized steel roof sheet is applied around the bottle. Performed horizontally and vertically with respect to the light

Graph 3, shows the results of the test 2.2, where a simulated galvanized steel roof sheet (simulated because they are expensive and come in various shapes) was placed around the bottle. The tests were divided into: horizontally placed in respect to the direction of the light, vertically in respect to the light and without the simulated roof sheet. This test was performed to understand the true value of placing a highly reflective roof sheet and the actual numerical advantages compared to placing none or a rusty-non-reflective one. The horizontally placed one showed the best results but the vertically placed one performed just 0.3% less better. Overall it proved that a near 10% improvement in light delivery and focus on the bottle was real. Figure 56, represents the behavior of the light in the two different scenarios and demonstrates why the horizontal placement of the sheet provides better results.

Horizontally the light bounces back to the bottle from the features behind it and the front ones help too, whilst the vertical position allows only for the side features to bounce the light towards the bottle. Exactly because the two act similarly the results are very close to each other. Nonetheless an important fact remains, that steel roof sheets are made with these types of designs to allow rainwater to flow thus, they will have to be put vertically to prevent cloggings around the bottle and reduce the risks of leakage.

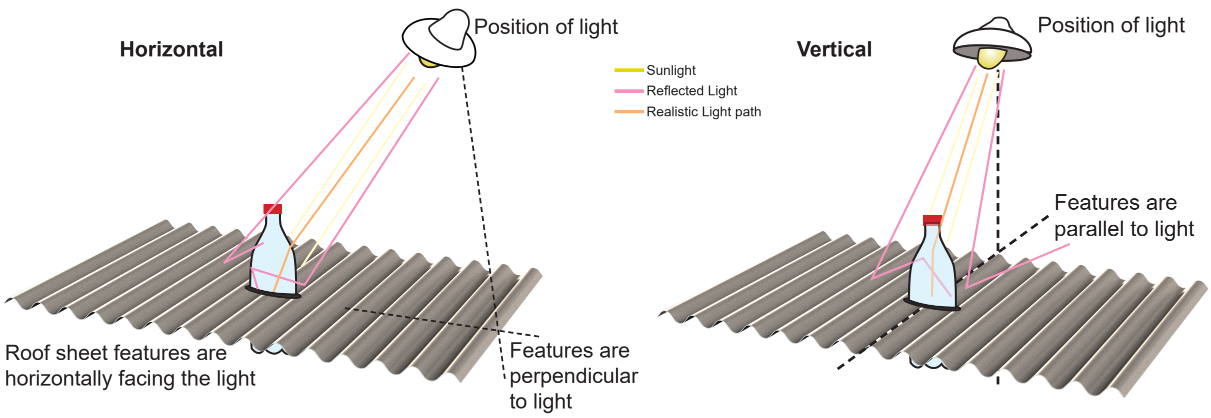


Figure 56. Shows how the direction of impact of the light onto the simulated galvanized steel roof sheet affected the results

This experiment showed how much of an improvement such small details can make and the importance of simple reflective surfaces have on the resulting illuminance of the bottle, internally.

To further understand the relevance that a mirrored surface could have upon the bottle and thus the resulting internal illuminance and test was created. By employing one of the most common waste product, as reported in the user questionnaire, the aluminum can, a parabola-like mirror was created.

The hypothesis to be tested was that by adding such parabola a higher quantity of light would be focused onto the bottle thus resulting in a higher internal illuminance. Furthermore, by conducting the previous experiments, the author noticed that a visible light dark spot was always present at the bottom of the bottle due to the bottle cap. The idea is also validated by the fact that most of the light is reflected and refracted outside the bottle, however, some will bounce back to the top due to the total internal reflection effect, and therefore be 'lost', seen in Figure 57.

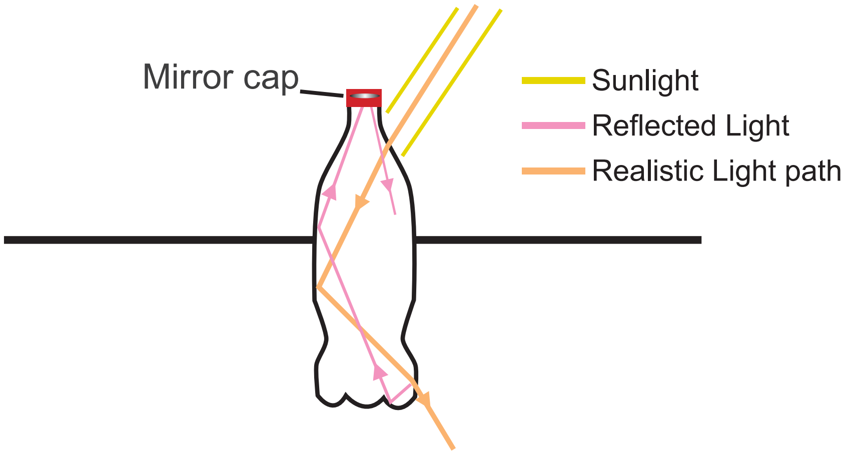
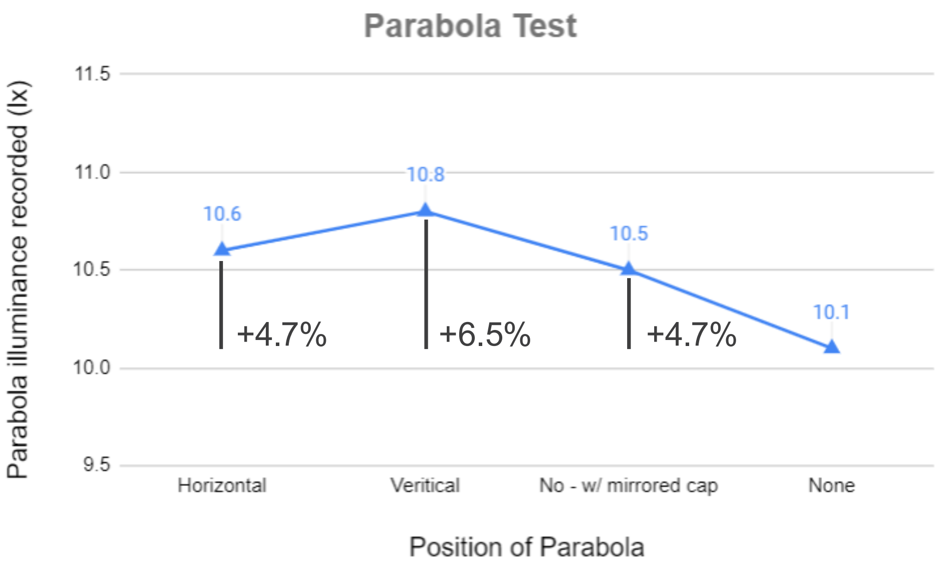


Figure 57. Shows the reasoning and placement of the Mirror cap

Therefore a mirror cap was placed to test its effectiveness and the possibility of its future placement in Solar Bottle Bulbs. The results are presented in graph 4.



Graph 4. Shows the results of the Parabola experiment and mirror cap tested in different positions

Graph 4 shows the performance of the Parabola, made with aluminum cans. The parabola performed better when it was placed vertically and enabling the refracted light to bounce back towards the bottle. When placed horizontally, the lateral flaps still concentrated more light than without, but relatively less.

The mirrored cap placed at the top of the bottle cap, seemed to have a good result proving to improve by nearly 5% the light reading, however, that would mean that the parabola only added a 2% improvement to the overall light reading. A few explanations can be guess by analyzing the results:

- The parabola improved but simultaneously reduced the access of some of the bottom portion of light, seen in Figure 58
- The curvature and inclination of the parabola play a bigger effect than expected
- The surface of the handmade aluminum parabola was neither perfectly clean nor perfectly flat. The curvature was adjusted by hand and its curved results are questionable
- There was human error involved during the experimentation, possibly before too. The heat inside the testing black box was rising quickly due to the light and human body temperature which in consequence raised the temperature of the LuxMeter. This is not a direct correlation of error but the temperature recorded by the luxmeter at the end of the last experiment was around 25°, whilst for all other tests the max temperature recorded was 23°C. Nonetheless another issue could be the cause, during the placement of the parabola the simulated sunlight lamp was moved which could have had an effect on the reading.

The parabola experiments, in spite of the above, showed that an improvement is made by both placing a curved mirrored parabola and a mirror cap inside the bottle. More in depth tests and research must be done to ensure the full validity of the results and to have a clear understanding of the effect of a mirror cap.

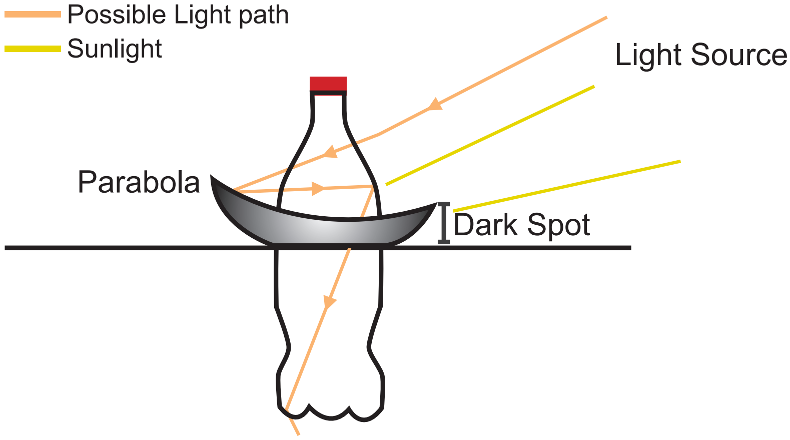


Figure 58. Shows how the parabola contributed but also reduced the light readings

Table 41, shows and compares the obtained improvement percentages of each experiment. Furthermore, it provides a total maximum improvement, calculated by adding the Pepsi bottle improvement percentage (as it is an improvement over the standard Cola bottle), the galvanized steel roof sheet and the parabola's improvement %. This goes to show how a few details and features can make a big difference in increasing the luminance output.

<table>
<tr><th>Test N°</th><th>Finding</th><th>Tests</th><th>Improvement %</th></tr>
<tr><td rowspan="3">Test 1</td><td rowspan="3">Shape and height do affect illuminance</td><td>Cola vs. Hole</td><td>+5.7%</td></tr>
<tr><td>Pepsi vs. Hole</td><td>+24.2%</td></tr>
<tr><td>Cola vs Pepsi</td><td>+18.5%</td></tr>
<tr><td rowspan="3">Test 2</td><td rowspan="3">Mirrors, if employed correctly, improve the overall illuminance</td><td>'SunFlower' Skirt</td><td>+2.6%</td></tr>
<tr><td>Galvanized steel roof sheet</td><td>+9.6%</td></tr>
<tr><td>Parabola and mirror cap</td><td>+6.5%</td></tr>
<tr><td colspan="3">Total Best of Improvement %</td><td>+34.6%</td></tr>
</table>

Table 41: Shows and compares the percentage improvement findings for each experiment. A final theoretical maximum percentage improvement is shown

Test 2: Reflective Surfaces

The experimentation undertaken to better understand how to maximize the afterglow of Strontium Aluminate was done to analyze and evaluate phosphorescence as a nightlight solution. The study and, consequent, understanding of how to best utilize the phosphorescent powder allowed for the development of a solution. The first experiments evaluated if there was a maximum thickness, which would not allow light to pass through all of it so that even the specimen side not facing the light would be irradiated.

The specimens tested in Test 3.1 were described in Table 42 and their estimated densities calculated. This was done to try to grasp at what density, thus powder concentration light did not pass through it.

This is because to maximize light absorption, thus energy absorption, the right amount of powder must be used so that all of it can glow in the dark.

The same specimens were tested also for afterglow duration, starting from 2 h with two h added each trial.

Name	Weight & Composition	Dimensions	Final estimated Density
0. U.T.	0.9 g phosph. powder	160x50x0.2 mm	5.625E-4 g/mm^3
1.V.T.	2.0 g phosph. powder	60x45x1 mm	0.00074 gmm^3
2.T.	2.5 g phosph. powder	60x45x1 mm	0.00093 gmm^3
3.M	3.5 g phosph. powder	60x50x1 mm	0.00116 gmm^3
4.Med-High	5.0 g phosph. powder	60x50x1 mm	0.001 gmm^3

Table 42: Shows the final calculated densities for the tested specimens of Test 3.1

It was found that after 2 h of light irradiance the specimen afterglow duration did not appear to last longer or shorter, proving that there is a maximum of energy absorption, entrapment and release. Although the afterglow emitted light is of a lower spectrum of the incoming light, and therefore cannot be picked up effectively by the Luxmeter, it still provides qualitative data that can be built upon. The second phase of the phosphorescent tests was to evaluate how the powder performed when suspended in an additive. Such descision was conducted to evaluate how the powder could be

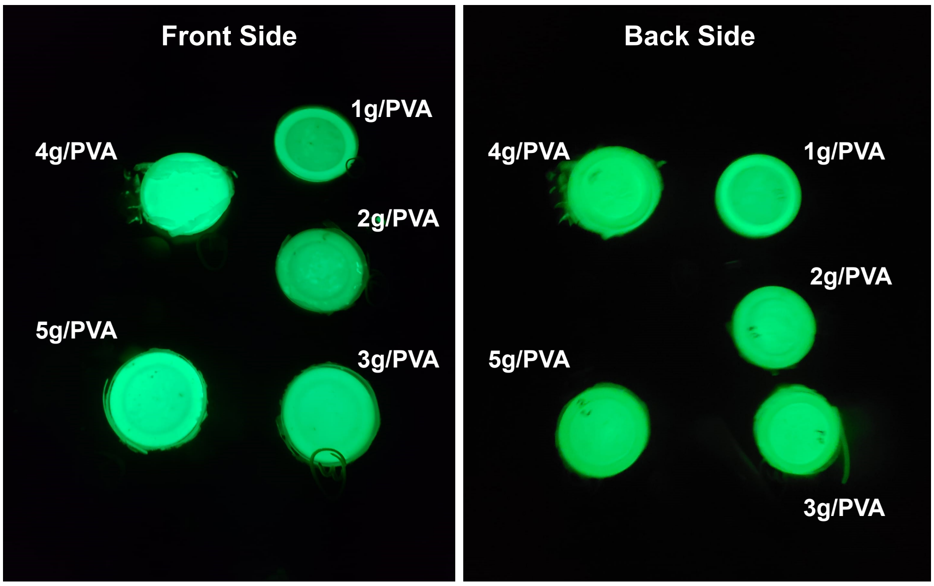


Figure 59. Shows the front and back side of the specimens of test 3.2

shaped and purposed in different situations.

This was achieved by mixing Strontium aluminate powder with white PVA glue, at different quantities of both glue and powder. By differentiating the specimens and their composition, also application on different surfaces, it was possible to establish a background for the final proposed solution.

Figure 59, shows the front and back of the specimens of Test 3.2, and how they irradiate from both sides. This goes to show how with some glue the light is able to pass through without problems. Below, in table 40 another mass density calculation is made to understand and compare them to Table 39 and evaluate the effect of the presence of the glue.

Name	Weight & Composition	Dimensions	Final estimated Density
1g/PVA	1 g phosph. powder	Diameter - 45mmx Height - 1mm	6.3E-4 g/mm^3
2g/PVA	2 g phosph. powder	D-45mmxH-1.5mm	8.4E-4 gmm^3
3g/PVA	3 g phosph. powder	D-45mmxH-1.5mm	0.0013 gmm^3
4g/PVA	4 g phosph. powder	D-45mmxH-2mm	0.0017 gmm^3
5g/PVA	5 g phosph. powder	D-45mmxH-2mm	0.0021 gmm^3

Table 43: Shows the estimated powder densities of the specimen of test 3.2

In the estimation presented in Table 43, the glue was not taken into consideration as its quantity is extremely low and after it dried it reduced even more. Nonetheless, by comparing table 42 and table 43 it is possible to see that the densities are similar. What is to be drawn from comparing the different specimen densities is the fact that for specimens of test 3.1 there was a ‘limit’ of thickness which after that not all phosphorescent powder would be irradiated, however for the specimens of test 3.2, all of them were able to absorb and release afterglow . The assumed reasoning is that by suspending the powder molecules into the glue they were more distanced between each other and the light would reach all of them more easily. Furthermore, it can also be assumed that the light would somewhat bounce internally, due to the glue drying as a semi transparent solid, thus improving the irradiation of the powder.

Thermoluminescent tests have been performed after the accidental discovery that Strontium Aluminate powder is not only phosphorescent but also thermoluminescent created the possibility to study this effect in a few experiments to evaluate its possibility of being a substitute to a light source. It was found that thermal energy does work but only at a fraction of the efficacy of light energy. Another opportunity to test the thermoluminescence would be by placing the specimen in hot air and evaluating how it would react. This would be interesting in an environment where fire is used for cooking and the smoke could be used to charge the Strontium Aluminate powder and/or bottle.

Nonetheless, after some research, articles backing the thermoluminescence of Strontium Aluminate have been found describing how due to the doping of Strontium Aluminate with Dysprosium, allows for the thermal release of electron holes. [73] Thermoluminescence proves that the opportunities available with Strontium Aluminate are near endless, also it has the phenomena of mechanoluminescence, and that it can be employed in different situations and with different results.

To test the effect of phosphorescent powder inside the bottle, and replicate a night solar bottle bulb, two specimens were glued to bottle caps and their effects studied and compared.

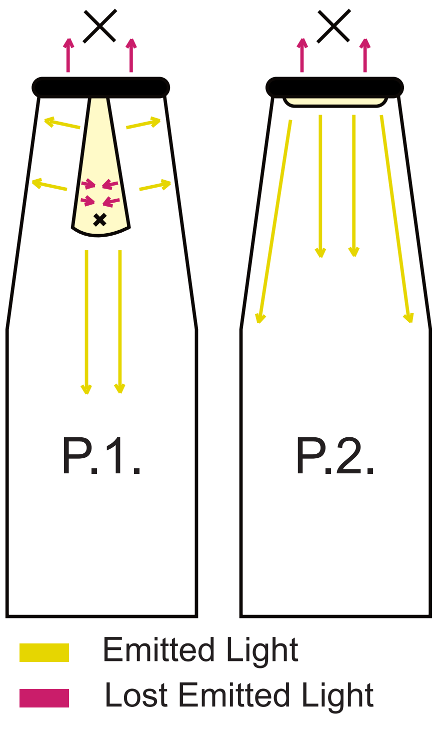


Figure 60. Illustrates the specimens P.1. & P.2. and how the emitted light acted inside the glass water bottles

Figure 60 illustrates the predicted behavior of the light emitted from the specimens inside the bottle. From the pictorial study of the two specimens, it was deducted that more surface area is key but it must be utilized appropriately. Overall P.2. seemed to perform better as it was able to deliver more light towards the end of the bottle, whilst

P.1. lost some of its light to itself and some was redirected outwards.

This experiment goes to show how crucial the surface area range and delivery of the light are to maximize the performance of the phosphorescent powder.

Another point that can be understood from this study is that the afterglow from the Strontium Aluminate powder must be employed close to what needs to be seen. The light emitted is relatively dim but has potential when it is close to the target. *It would be ideal to employ it as a table lamp or flash light as it can be moved around and carried by hand by the user.*

8.5. Proposed DIY Night Light Solution

The proposed solution is aimed at tackling the night light issue, as the Solar bottle bulb tackles the day light issue, by developing it on the basis of the previous studies and tests performed.

The information and knowledge on the phosphorescence and thermoluminescence of Strontium Aluminate acquired from the tests and research is presented table 44.

The proposed solution is an agglomeration of the lessons learned whilst experimenting with Strontium Aluminate powder, also when mixed with PVA glue, shown in Table 43.

The proposed solution will be hand carried so that the user can adapt it to its needs and environments. Previously two different shapes were tested and it was understood that a wide surface area is ideal but it must allow the light to reach all of it. Nonetheless, a higher quantity of phosphorescent powder will not, certainly, improve the emitted afterglow therefore, a substantial but limited, to not increase costs uselessly, amount of powder/glue mix must be employed. For the final proposed solution two different types of PVA glue will be tested to evaluate improvements or any changes that appear. The two proposed prototypes and solution will also test if any difference is perceived when two differently shaped bottles are used.

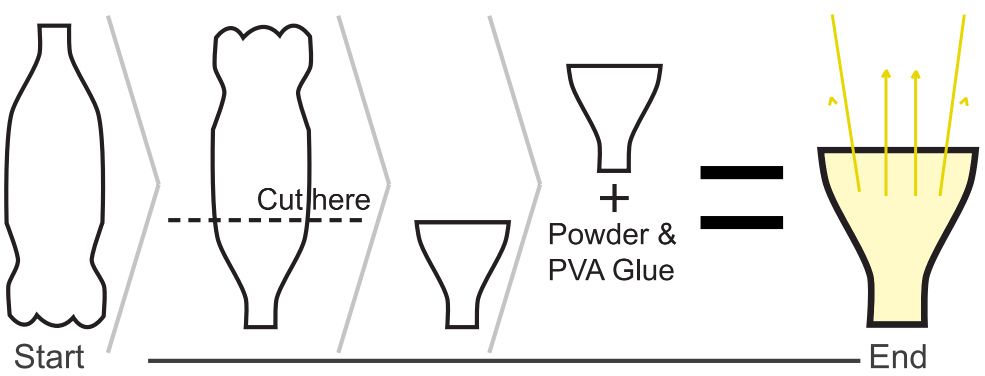


Figure 61. Illustrates the process to build the final proposed solution for the night light

N°	Information	Reason for Interest
1	After 2 h of irradiance the resulting afterglow will not last longer or shine brighter	The duration and brightness of the powder has a limit of absorption and release of light
2	There is a relative maximum density for the powder only, not mixed	When only the powder is irradiated, there is a risk that not all of it is able to absorb light
3	Strontium powder is not water soluble	Cannot be mixed directly in water
4	By adding glue, and thus suspending the powder, it is possible to better shape it	The glue allows for a wider range of solutions and shaping possibilities
5	The glue/powder mix seems to improve the max density to full irradiance range	The glue seems to allow reflection of light internally the specimen, therefore all powder is irradiated
6	Higher surface area will be more effective over a higher quantity of powder	It appeared that the more the powder is spread the more effectively the afterglow is delivered
7	When heated Strontium Aluminate glows	Alternative energy source for the powder
8	The powder/glue mix is good but can fail after long use in water	To keep in mind that a better suspension media can be employed whilst keeping in mind the limitations of the PVA glue.
9	Effective range of illuminance of the powder is relatively short	The powder must be close to what needs to be lit up.

Table 44: Shows the knowledge gained from the experimentation carried on Strontium Aluminate powder

Figure 61 shows the simplified graphical representation of the creation process for the final proposed solution. As mentioned above, the idea behind this design is that the final result must be easy to carry and can be easily left outdoors to be charged by the sun.

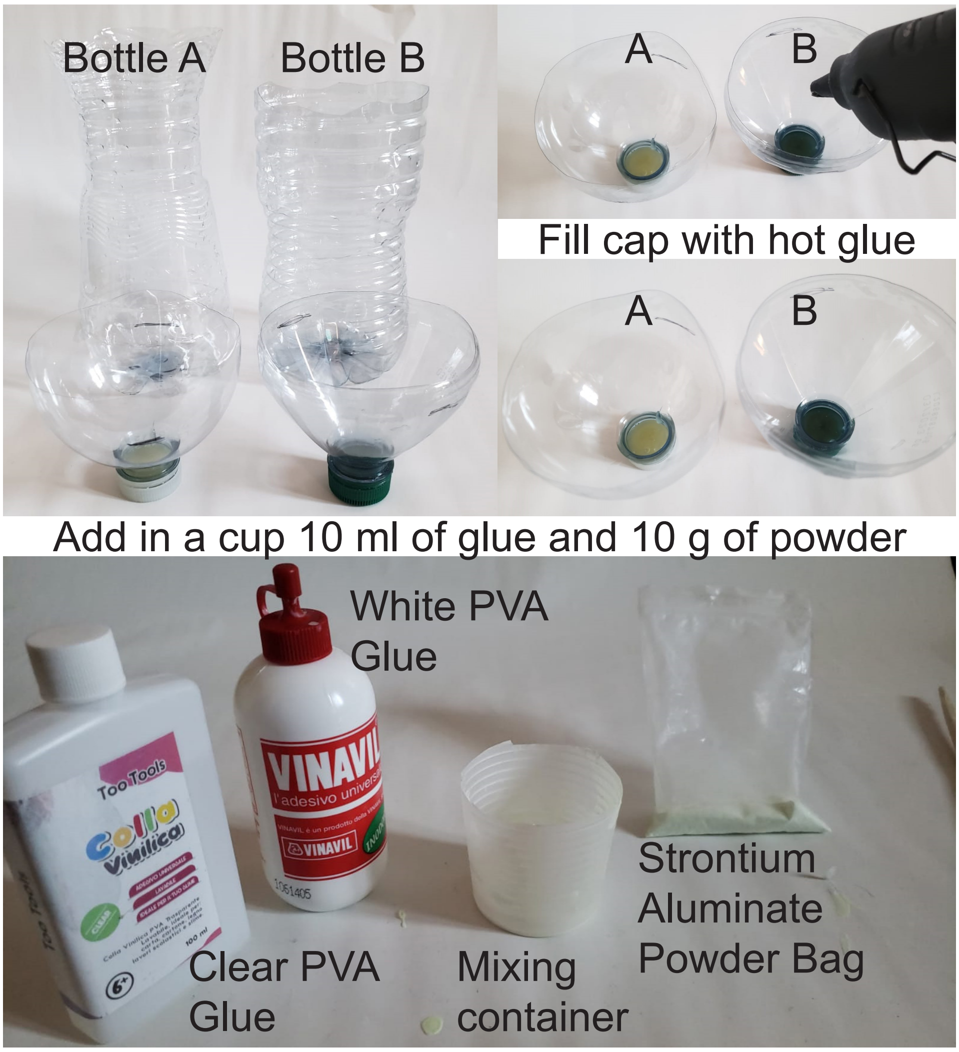


Figure 62:. Shows the process and materials required to make the proposed solution

The process to build the final solution is not complicated nor long or exhausting, shown in figure 62. This is exactly what would be an ideal DIY project for a simple solution to an intricate problem. The acquisition of such materials should not be of issue, however, the availability of Strontium Aluminate powder is key for this solution.

After mixing the powder inside a small container, practical to pour contents inside the small bottle opening, the glue/powder mix must be spread as equally as possible on the walls of the bottle head. The results are shown in Figure 63.

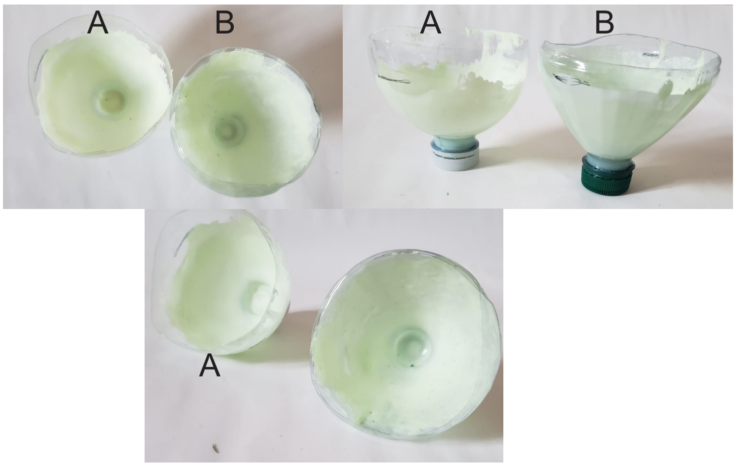


Figure 63. Shows the proposed solution from different perspective

The specimen A was made with 10 g of powder and 10 g of white PVA glue, whilst the specimen B was made with 10 g of powder and 10 g of clear PVA glue.

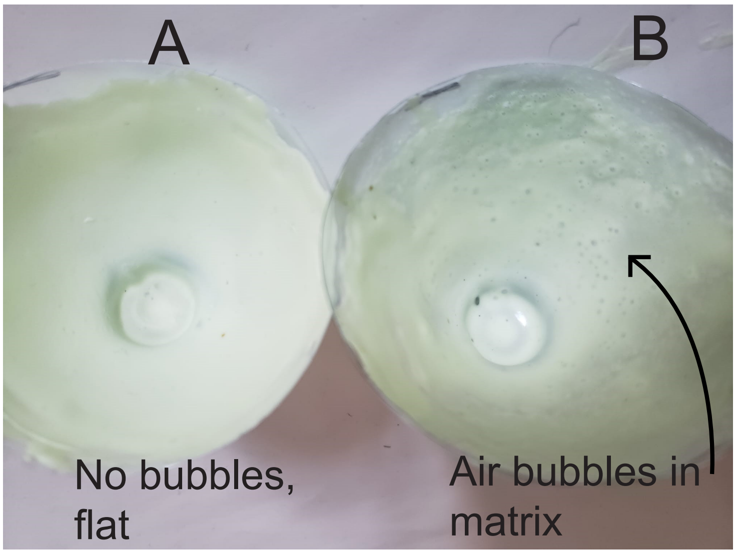


Figure 64. Shows the proposed solution from different perspective

As Figure 63 & 64 shows, the two specimens present differences due to the glue used. Specimen A, shows no signs of bubbles or any kind of defaults, whilst specimen B shows bubbles and signs of uneven spreading of the mixture. This is due to the clear PVA glue utilized which showed signs of early agglomeration and slimy texture. Nonetheless, the two specimens have the required and specified features expected and will be tested to see if the hypothesis, of requiring a wider surface area, is met and if the results improve the tests of 3.3.

The next step is to test the resulting illuminance of Specimen A & B, both with the lux meter and then to be used as a reading light. The bottles will be placed right at the lux meter, as mentioned the wavelength of Strontium Aluminate are weaker and are harder to be picked up by the lux meter, and a reading will be taken at different times after the start.

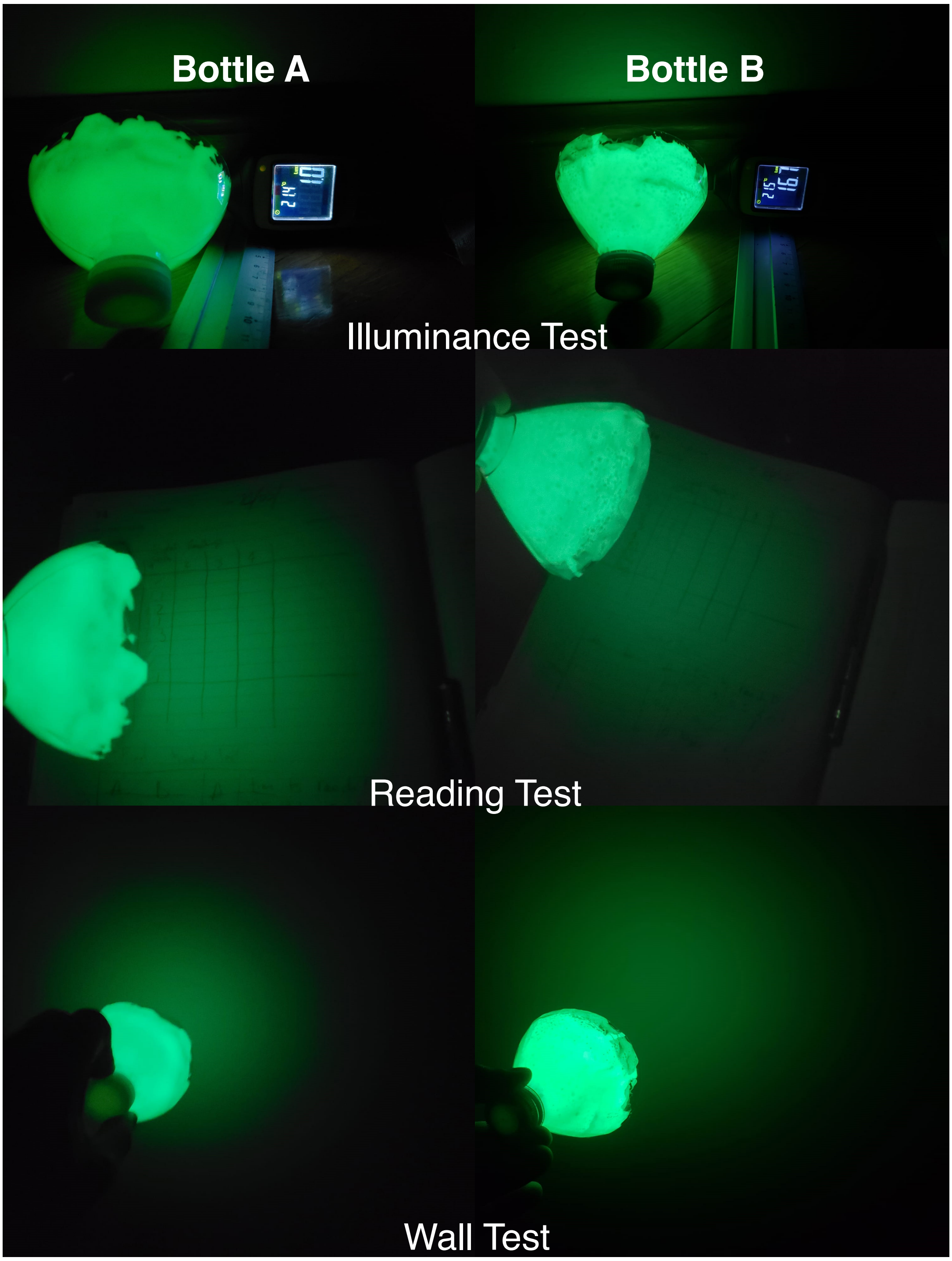


Figure 65. Shows the test, the reading trial and how it looks against a wall

Figure 65 shows the two specimen tested, Bottle A & Bottle B. The figure shows three steps:

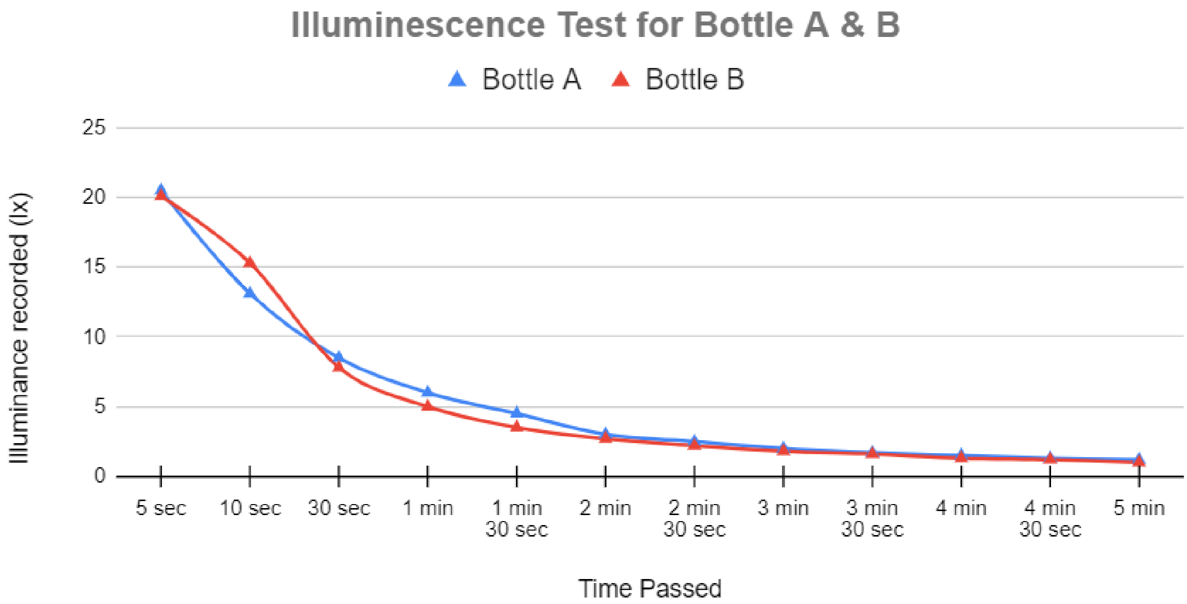
1. Illuminance test - done with the lux meter for both bottles
2. Reading Test - Both bottles tested to validate thier ability to be used as a night light
3. Wall Test - To evaluate if the bottles worked as flash lights

In all three tests the specimens performed well. Thier ability to absorb light evenly and release it unifromly, allows them to create a nice circular light spot on the wall and book.

Recorded Time	Bottle A	Bottle B
0 sec	20.5	20.1
5 sec	13.1	15.3
30 sec	8.5	7.8
1 min	6.0	5.0
1 min 30 sec	4.5	3.5
2 min	3.0	2.7
2 min 3 sec	2.5	2.2
3 min	2	1.8
3 min 30 sec	1.7	1.6
4 min	1.5	1.3
4 min 30 sec	1.3	1.2
5 min	1,2	1.0

Table 45: Shows the data collected for the illuminance tested for Bottle A and B

Table 45 shows the recorded results for the two specimens. Both had a sharp drop in luminescence right after the start. This is logical, as right at the beginінng is when the Strontium Aluminate is at its most excited state but after the 2 minute mark it stabilises and emits at a steadier pacce. The data is plotted and shown in Graph 5.



Graph 5. Shows the plotted data , of the recorded illuminance, for the Bottle A & B

Graph 5 shows the exponenttial curve for the data collected on bottles A & B. Both results are similar and comparable, neither present differences that can be associated to the use of a different PVA glue.

The interesting point is the negative exponential distribution of the data points. This can be associated with the results reported from the Tests 3, where the drop in luminosity are clear in both Test 3.1 and 3.2.

Next to evaluate the adapatability of the propsed solution, the specimens will be tested in different condtions. The ability to be employed in various situations and needs is the key behind this design. The solution is studied to understand how to best expolit the afterglow effect and to maximise the Stronitum Aluminate's irradiance. The first trial is to test the specimens with water bottles, to assess their validity as a fixed table lamp, where more people can use the light.

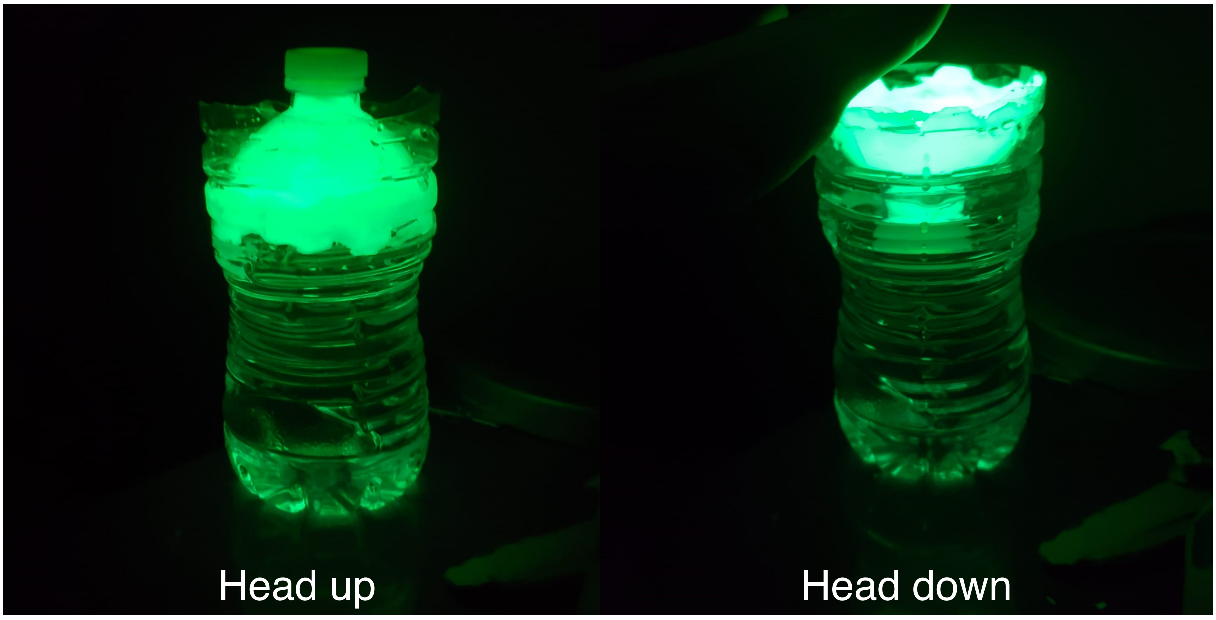


Figure 66. Shows specimen A head up & down in half a bottle of water

Figure 66 shows specimen A inside half a water bottle, head up & down. In both cases the water is irradiating diffuse light as intended, however, the stregth of the afterglow is greater in the inside of specimen A (as it is where it has been irradiated by light). In the 'Head Up' the light is brighter inside the bottle, whilst in 'Head Down' the majority of the afterglow is direced outwards.

Figure 67. Shows specimen A, head down, in light and dark conditions

Figure 67, shows specimen A inserted into a Coca Cocla bottle to evaluate how it would perform as a table lamp. The results are satisfying and the reading test is passed.

A further test is performed by adding a cone hat, similar to a rice hat, made with the aluminum sheets created for experiments 2.1 and 2.2. Figure 68 shows the results observed, to compare them to the previous test.

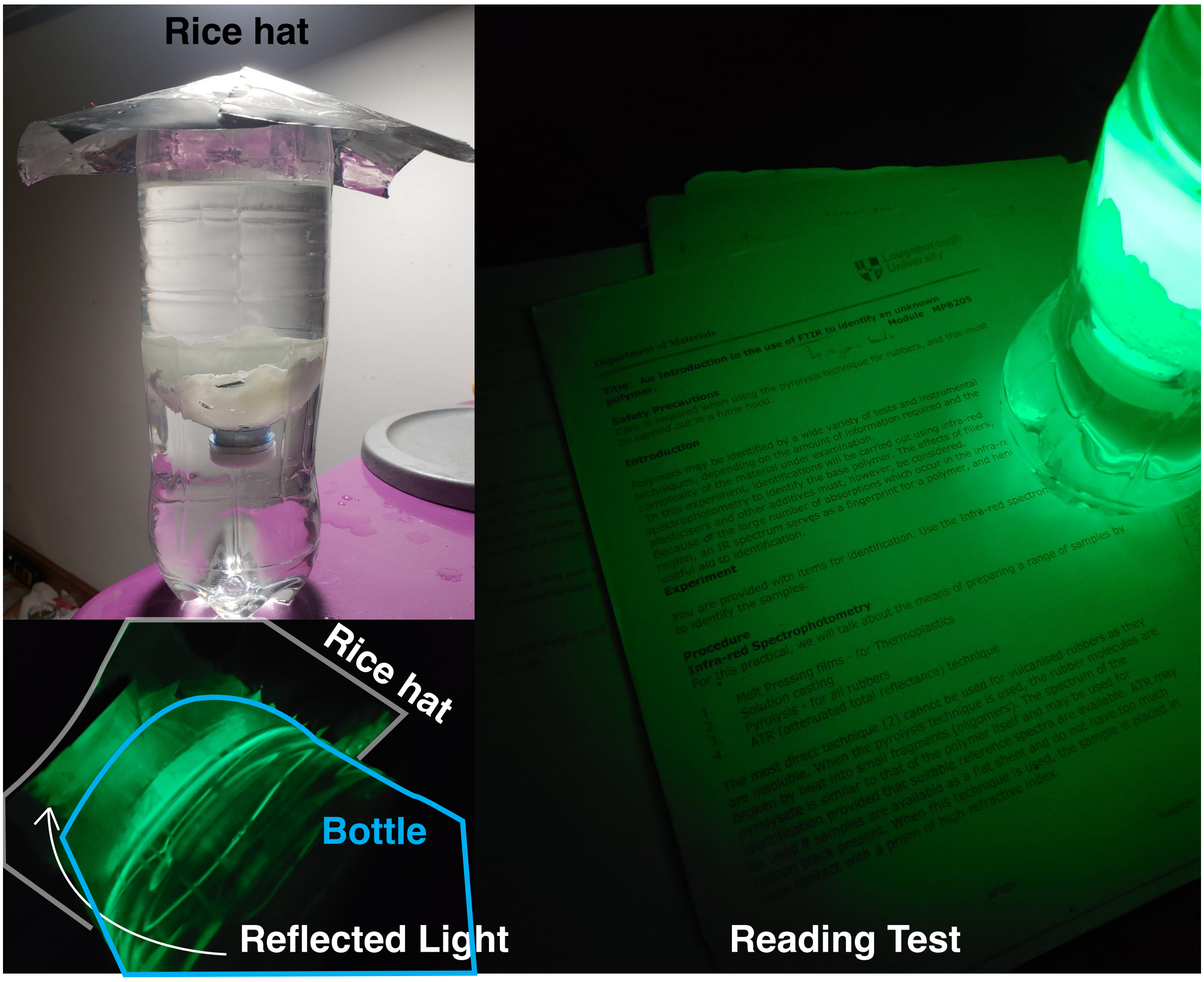


Figure 68. Shows specimen A, head down, in light and dark conditions. A reading test is also shown together with proof of functionality of Rice Hat

To judge the validity of the design, further testsing conditions must be undertaken. The night light solution tackles a range of activities such as reading and cooking. This understand how mobile and easily adaptable the prototypes are. Furthermore, they are necessary to weigh in the stregths and weaknesses of the projects to be able delineate possible future steps.

Figure 69. Shows specimen B, attached with a rope to fixed support, shining over some vegetables

Figure 69 shows how the prototypes can be attached with a rope to a nail on the wall, ora hanged from a fixed support. The test shows simulated cooking conditions to asses both the colour of the light and how it affects the visibility of the vegtables. The afterglow duration slowly degrades, however, as it decreases the specimen can be brought closer to the area to be lit.

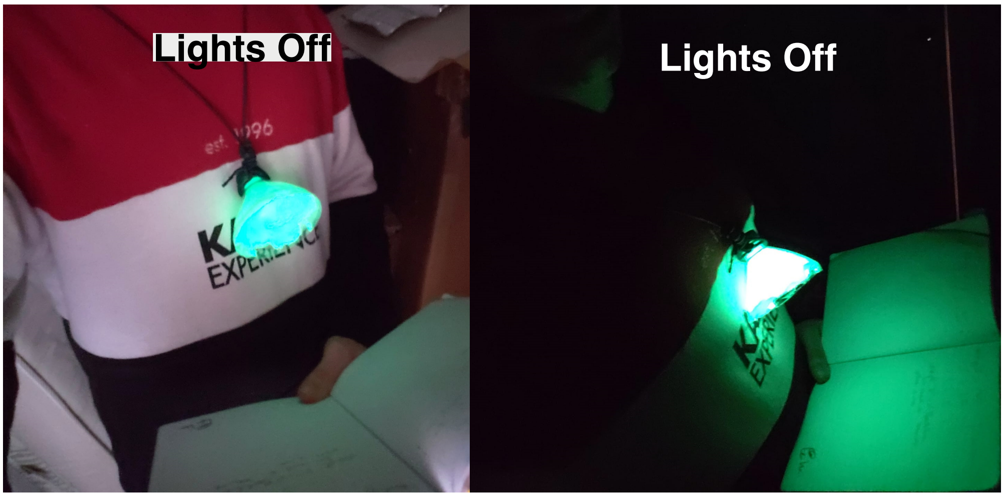


Figure 70. Shows specimen B, attached as a necklace, illuminating a hand-held book

Lastly, Figure 70 shows the pictures demonstrating how the design can also be attached to the neck as a necklace or a protable light. Having the possibility of carrying the light hands free, allows the user the opportunity to read, as if they were in bed, or to do other manual activities in completely safety.

Proposed Night Light Solution: Summary

The proposed solution for a night light has been successful to further the studies on alternative light sources. The project has elaborated and detailed the ground basis for further research on this topic and on phosphorescence.

The suggested design was tested in different environment and morhped into creative approaches to solve the key issue of bringing light after dark. Plentiful of data, both qualitative and quantitative, has been collected which demonstrates the validity of the proposal and of Storntium Aluminate as a easy to use, handle and work with DIY approach to tackle the energy, electricity and humanitarian crisis of Sub-Saharan Africa. Furthermore, it was built upon the research and study, confirming the ideology of simplicity, replicability and passing the knowledge by word of mouth and physical demonstration. By testing, reporting and analyising each step taken to figure out the most effective and appropiate way to create and deliver the final prototype, future studies can pick up where it has been left off. These investigations open doors to future experimentation, expoloration of other materials, adhesives, phosphorescent powders and many more details that make up the bueaty of Liter of Light's simplicity and effectiveness. The backbone of this solution is that with a near zero cost, low work and nearly no previous required knowledge, anyone could build the night light model and directly impact thier lives and futures. The design presened is only a first step into the study and understanding on how to best employ Stornium Aluminate powder, how to draw out its brightest afterglow and how to exploit its natural thermoluminescence and mechanoluminescence. Nonetheless,the summary of the key findings and observations are reported below:

1. Strontium Aluminate powder can be shaped and mixed well into an addithive, and possible other suspending solutions, to created a defined and well measured mixture.
2. The comparison between white PVA glue and clear PVA glue did not result in any significant different in afterglow measurement.
3. Afterglow was found to have a negative exponential curve of light fading over time.
4. The proposed design is adaptable to different needs and requirements, which span from alone reading, cooking and as a table lamp, that have been all tested.
5. The surface area, on which the phosphorescent powder & glue mix has been applied, will affect the maximum light output percieved. Meaning that as the light dims in time, the higher the surface are the more it will be percieved the afterglow lasts.
6. The color of the afterglow affects the visibility of some small prints, some colors especially shades of green, as they mix, and shades of red as they are canceled by the green hue.

Conclusion

The presented research paper set itsel the goal to analyse and understand a large number of convoluted factors related to the energy crisis in Sub-Saharan Africa. The study has highlighted the issues at the core of this thematic by brining to the surface the shortcomings of Eskom, the countries' government approaches, the difficutlties in integrating the new infrasturcture and the reasons behind the frightening high number of communities without electricity. Furthermore, through a semiotical perspective, a gasp of how mislead and misjudged projects ripple in worsening the realities of the end users compared to the thier expected outcomes. Understanding the key factors behind so many failing or mistargeted projects, has permitted this paper to scrutinize products, research and DIY projects, to partake with great opportunities for further development. The realisation that oftentimes the most advanced technological solutions are not the appropiate answers to tackle a humanitarian emergency, which sprouts directly from the users and their community, has brought into play the evaluation of simplicity and pragmatism that other project employ as their foundation. The final user, its needs and expectations have been challnged by placing in their hands the choice to improve their lifestyle, opportunities and the choice to actively contrast the slow rate of electrification. Through the empowerment of the user to make their own and be their own 'Hero', shows how through willpower, determination and a few materials and tools oneself can make a difference. As denoted by the great Chinese philosofer Confucius: '*Tell me and I will forget, show me and I may remember; involve me and I will understand*', where he explains how true understanding, and therefore aquired knowledge, comes from how involvment in activities will be more beneficial than just sitting idly by the problem.

Exactly through the involvment of users, communities and real people, projects like Liter of Light, thrive in the passage of knowledge from people to people, from a community to another both by word of mouth but mostly by developing a simple and replicable product. The NGO foundation Liter of Light has very similar core values and has been established exactly as: '*an open-source, DIY programme that could easily be replicated by anyone around the world using readily available materials and basic carpentry/electronics skills. Rather than relying on large-scale, imported or patented technologies, the project sought to create a grassroots green lighting movement starting from the principle that anyone can and should become a solar engineer.'*

The ideology of Liter of Light truly shines in a context where the value is palced in the hands of simplicity, replicability, upcycling materials, avoiding foreign technologies. As accurately stated by Liter of Light, anyone should become involved in spreading the underlying principles of Do It Yourself that presents itself in a multitude of occasions.

Through the online questionnaire and interviews, it was found how the crisis affects the majority of the inhabitants, how often balckouts and load shedding occur. The truth being that all are affeccted but only a few have the means to counteract it financially. The availability of 'free' and 'endless' sunlight creates opportunities for solar powerd alternatives, but as very often reported, that often fail misaerably after a few years of use and abuse. Interviewees expressed thier discontent and disdain towards the way the electricity and energy crisis situation was handled by thier government and electricity provider, Eskom, pointing out the stagnating situation. All to lead back to comparing solar powerd products that do more with less, such as the Solar Bottle Bulb.

Moreover, in depth studies to understand the real parameters that encircles the Solar Bottle Bulb have been performed to create a ground basis for further projects that aim to investigate further how to improve this project. Through the use of in-house laboratory tests and wide-eyed assumptions, some guidelines have been drawn. The experiments concluded have been over 20 to appraise various dependent and indipendent variables that affect the experimental results. To approach and tackle the night light dilemma pictorial testimonies and short experiments were carried out and reported to legitimize Stornitum Aluminate doped Europium and Dysprosium as a possible solution. Thus, the thesis's objectives of tackling and having a direct impact on the issue has been achieved. The experiments cover the technical details on how the Solar Bottle bulb can be improved, what bottles are best and how to maximise the sunlight entry into the house. An analysis on the impact of reflective and mirror-like surfaces, and how to obtain them, has been completed to show the importance and possible future uses, how their shapes and position affect the quantity of light reflected. Furthermore a preliminary investication of the use of phosphorescence has been presented as an alternative to LED lights and solar panels for night time use.

Conventional Light Bulb	Consumption	Cost
50 W 18.75 lx	50Wx14h day= *0.7 kWh/ day* **255.5 kWh/year**	Average electricity price= **2 R x kWh**
0.77 kg of CO_2 per kWh	255.5 x 0.77 kg= **196.7 kg CO_2 per year**	Saved up: 255.5x2=***511R/year***

Table 46: Shows the costs and CO_2 consumption of a conventional 50 W light bulb

Solar Bottle Bulb		
Comparable to: 60W 22.5 lx		
Bottle placement & shape improvement %		
Coca Cola Bottle (used as reference bottle)	/	***60 W 22.5lx***
Pepsi Bottle	*+ 18.5 %*	***70.8 W 26.55 lx***
Reflective Surfaces		
Sunlight Parabola	*+ 6.5%*	*Tot%=* ***+16.1%*** ***69.7W 26.1 lx***
Galvanized Steel roof sheet	*+ 9.6%*	
Total Max imporvement	*+ 34.6%*	***80.8 W 30.3 lx***

Table 47: Shows the numerical and percentage improvements to the Solar bottle Bulb

Table 46 shows the calculated costs and pollution due to utilisation of a 50 W conventional light bulb. This is to show the costs that go with it for a whole year's worth of usage. It is also written the amount of CO_2 emitted, associated with the use of conventional lighting bulbs. The values reported are estimates based on average South Afican electricity costs and average CO_2 relased for each kWh. Table 47 shows a improvement of light output of maximum 35%, allowing the theoretical brightness to reach 80W. A lightbulb consuming 80W would have a much higher cost and would pollute a lot more.

Nonetheless these figures show how much a rural family could save by not using electricity, and it is also relatable to not employing kerosene lamps, and thus buying kerosene, and candles. The saving in costs is key but also by reducing the amount of required kerosene and candles for lighting, implies a reduction in black carbon pollutants and a reduction in fire hazards, indoor pollution and, possibly, the need for illegal connection to the power grid, also a dangerous electrocution hazard.

Night Light	Traditional Solution
Irradiates Up to 2 h - 1-25 lx Free sunlight recharge Storntium powder = 0.05-0.2 $/g No Hazards or Dangers	Kerosene Lamp consumes 3l/month (4 h a day) - 2-45 lx Kerosene = 17.725 R/l Fire Hazards & Pollution
Strontium Powder: 10gx0.2= 2$ PVA Glue= 1.5$ Total Starting Cost: 3.5$	Lamp Cost: 5-35$ Kerosene cost: 8 $ Total Starting Cost: 13-43$

Table 48: Shows the comparison between the proposed night light against the traditional night light solution of a kerosene lamp

Table 48 shows the comparison of the proposed night light against the traditional night light solution of a kerosene lamp, which is somewhat more common than a candle. The table describes the health and cost advantages of the two compared designs, underlining their differences. The proposed night light is nor perfect nor the ideal solution but definetly imacts the unwaving position of the kerosene lamp.

N°	Objective	Passed	Reasoning	Further steps
1	Provides 15 lux	Partially	Provides 15 lux but dims over time	Evaluate how to improve afterglow duration
2	Reading light - 5-15 lux	Partially	Provides 1-20 lux for different duration	The afterglow dims but is sufficient to read
3	Night time light - 2-5 lux	Partially/ passed	Passed but for a limited time	Evaluate options to last longer
4	Discover best bottle shape and postion	Passed	The experimentation showed clear improvement results	Further test possibilities to integrate more functions
5	Mirrors improved performance of the Solar Bottle Bulb	Passed	The results showed higher light reading	Research mirrors as a light transport system even when the roof cannot be accessed
6	Costs of materials kept at a minium	Passed	Mostly upcycled materials with cheap PVA glue and Phosph. powder	Find if some materials can be sobstituted for cheaper versions

Table 49: Shows the objectives of the thesis, thier success and possible future improvements

Table 49 shows the summary of the objectives imposed in the thesis and how they have been undertaken. The reality of developing a night light, through testing and understanding how to best boost the effectiveness of Strontium Aluminate, has been a challenge worth taking up. There are plenty more information, details and studies to be completed to even try to full grasp the possibilities created by the phosphorescent powder, its complexity and other types of luminescence have allowed this compound to be of great interest to tackle the electricity crisis issue.

Nonetheless, farther research and experimentation must be done to further advance the ground level knowledge on the Solar Bottle bulb and on the possible uses of Strontium Aluminate, to create solidguide lines for whom ever would want to reacreate the project and proposed solution. Here below are some starting points for additional research:

- Test hybrid systems of the Solar Bottle Bulb and mirrors
- Test for simplified installation of the Solar Bottle Bulb
- Evaluate placement of similar designs of Solar Bottle Bulbs placed in sun-facing walls
- Understand if light trasnport through mirrors, preferably through tubes, is feasible and if:
- It can be employed light more rooms though a single hole in the roof
- It can be collected in a single spot to be used as a Solar Oven
- It can be used for the SoDis process whilst lighting the room
- The phosphorescent effect must be studied in more details to evaluate how:
- A very wide surface area will, dim in time, but be enough to light a whole room
- Through thermoluminescence the phosphorescent powder can be recharged or kept at a decent level of luminosity for longer, for example by placing a Stonrium aluminte coated slow heat release material into a heat vent (as for a indoor fire place)
- By implementing technologies, such as batteries, LEDs and solar panels, could the effect of phosphorescence be improved or hybridized the two together.

All the mentioned in depth research would truly allow this project to take off into a realm of bestowing the power to the people to help themselves, to teach and help others and highlighting how sometimes less is more.

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Figure's Index

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Glossary

Electricity Access

- Electricity access refers to the percentage of people in a given area that have relatively simple, stable access to electricity.

Electrification Rate

- Electrification Rates serves as a good proxy for other indicators of wealth and opportunity in a country.

SSA

- Sub-Saharan Africa

Black Carbon (soot)

- part of fine particulate air pollution (PM2.5) and contributes to climate change. Black carbon is formed by the incomplete combustion of fossil fuels, wood and other fuels

DIY

- Do It Yourself: meaning that the project is meant to be done by the viewer, thus being simple and easy to make.

Refractive Index

- In optics, the refractive index of a material is a dimensionless number that describes how fast light travels through the material, characterized by the formula n=cv, where 'n' is the refractive index, 'c' is the speed of light in a vacuum and 'v' is the velocity of light through the material.

Critical Angle

- In optics, the greatest angle at which a ray of light, traveling in one transparent medium, can strike the boundary between that medium and a second of lower refractive index without being totally reflected within the first medium.

Total Internal Reflection

- (TIR) is the optical phenomenon in which waves arriving at the interface (boundary) from one medium to another (e.g., from water to air) are not refracted into the second ("external") medium, but completely reflected back into the first ("internal") medium.

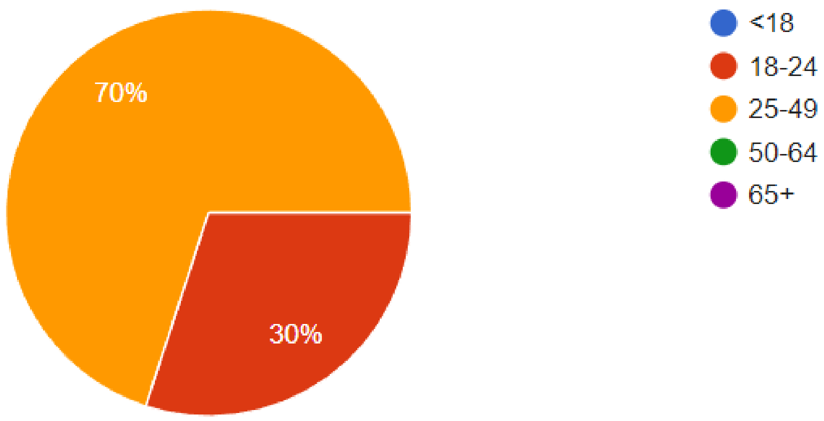
Load Shedding

- To reduce the load on the electrical infrastructure by planning the interruption of electricity supply to avoid excessive load on the generating plant.

Appendix A - Online Questionnaire

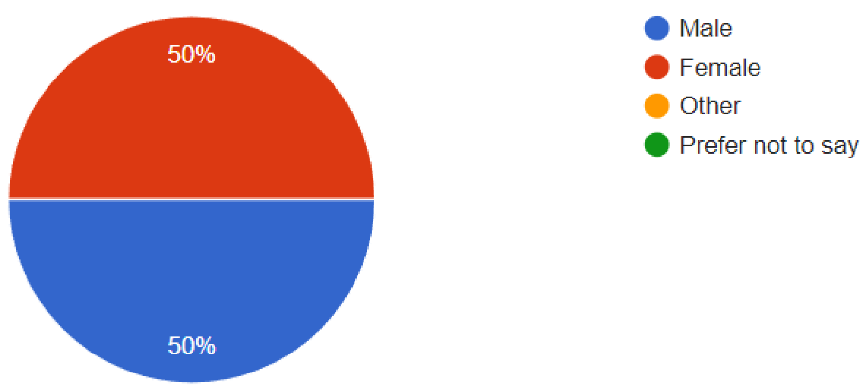
How old are you (age group)?

10 responses



What is your gender?

10 responses



Nationality & Hometown (where you live at the moment)

10 responses

South African, I'm in Somerset West

Zambian, Choma

Nigerian Abuja

Durban, sa

South African, Pretoria

Zambian. Lusaka

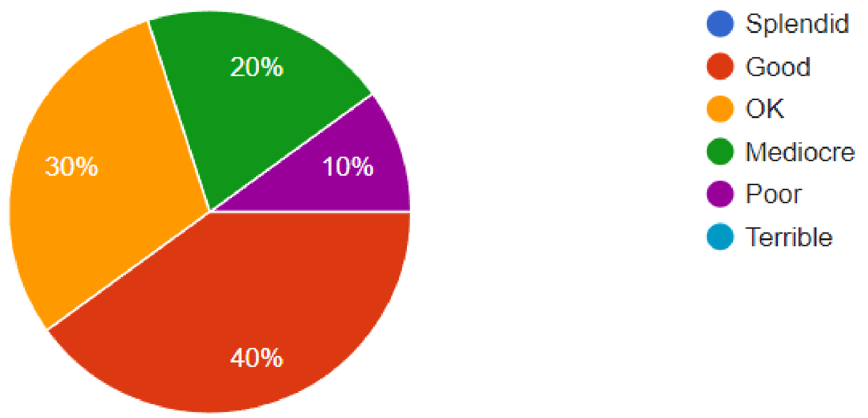
Dakar

Zimbabwean, Harare

SA, cape town

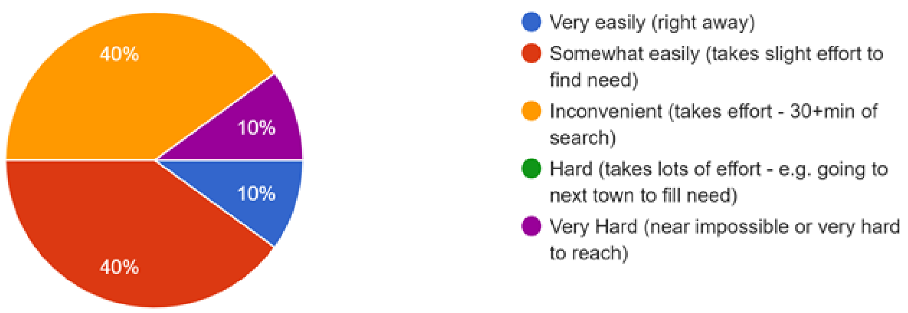
How would you define the living conditions in your area?

10 responses



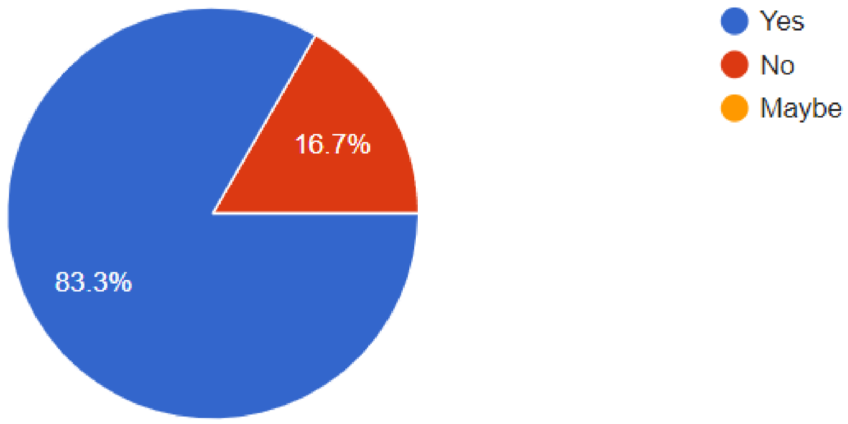
How easily can habitants in your hometown get access to basic services such as healthcare, education, electricity, public transport, etc?

10 responses



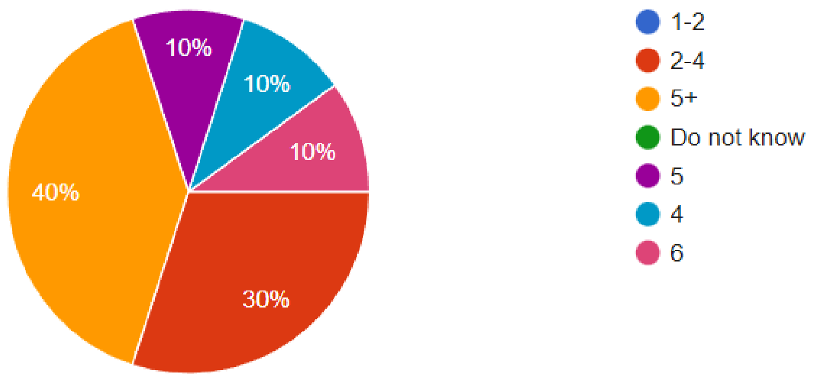
Have you ever been or lived in a "rural community" or Sub-Urban area?

6 responses



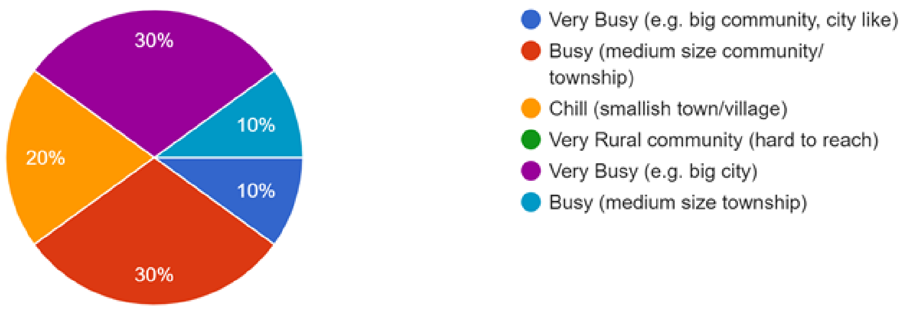
How many people live, in average, in a household in the area/community, that you know of?

10 responses



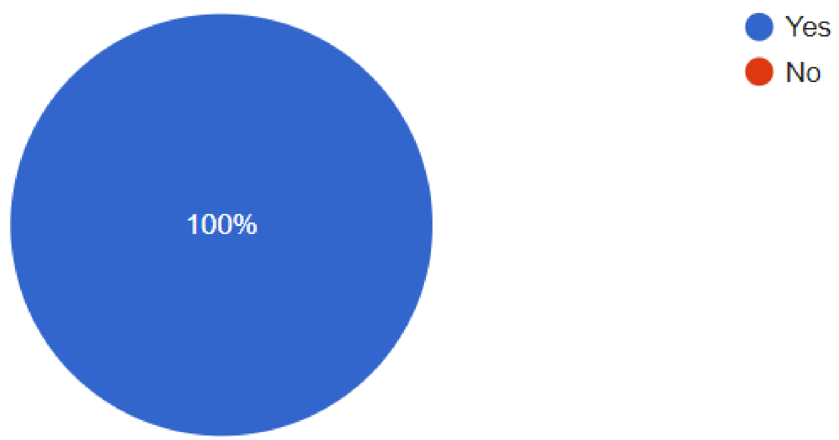
If Yes, is or was this community/area...

10 responses



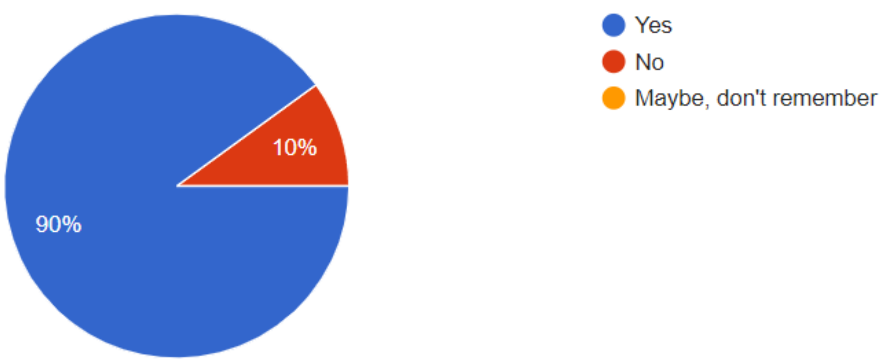
Are there existing infrastructures supporting power lines and grids?

10 responses



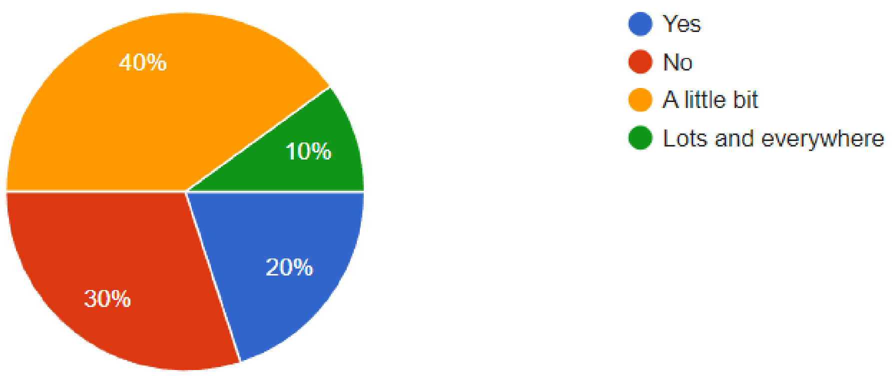
Have you ever come in contact or used a kerosene lamp, oil lamp or candles, whilst in an electricity poor community/area? (as a source of light, for cooking or heating)

10 responses



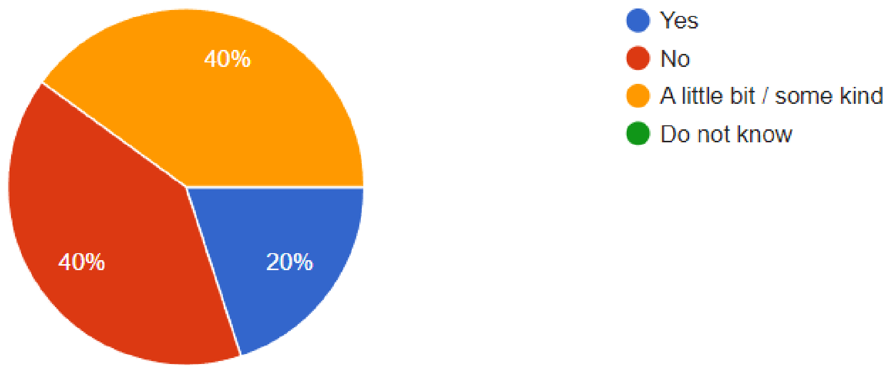
Is there a lot of waste/rubbish in that community/area?

10 responses



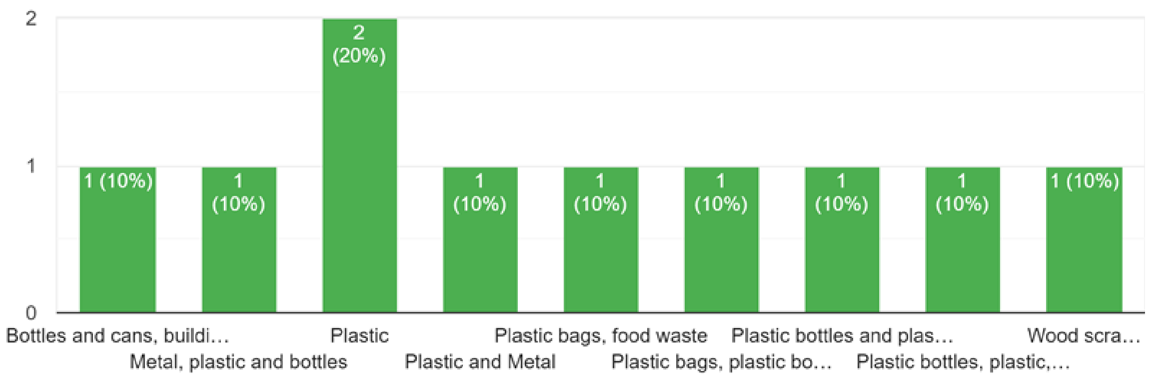
Is there a recycling and waste management in the community, that you know of?

10 responses



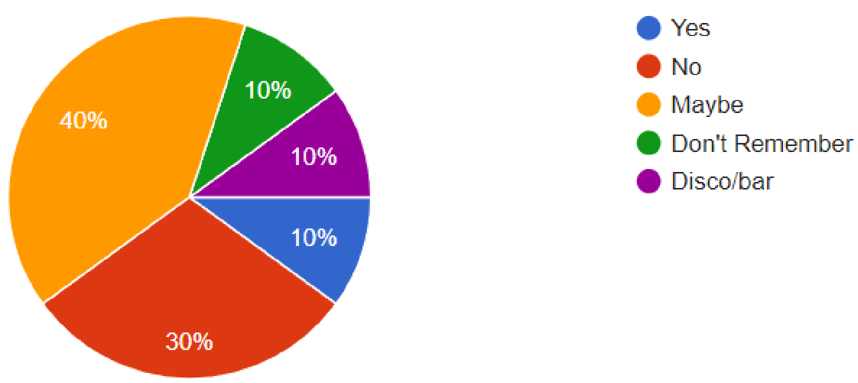
What are the most common waste 'objects' or materials that can be found easily/anywhere? As in wood, plastic bottles or bags, metal scrap and so on...

10 responses



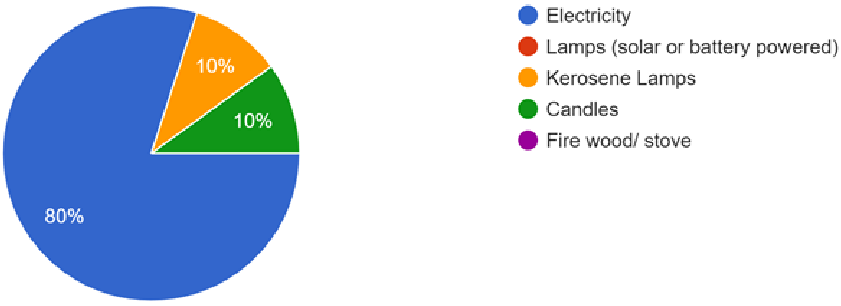
When you were back home have you ever encountered phosphorescent products, such as bottles, plastics or paint? (image below Ex. of Glow-in-the-dark stars (phosphorescent plastic))

10 responses



During the day and night what source of light do you employ the most?

10 responses



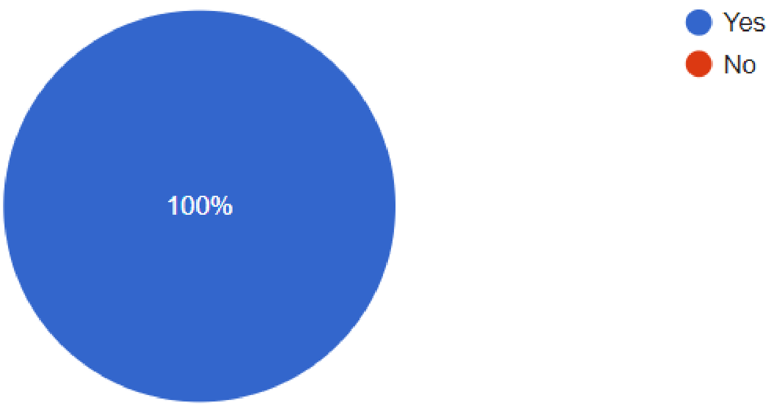
For how much time do you use a light source (of any kind) during the day and night? (e.g 10 h during the day and 4 h during the evening/night)

10 responses

6h during the day and 5h during the evening
At night, 12hrs
2h during the day and 6h at night
2 H during the day and 5h during the nights
None throughout the day because of natural sunlight, 6 hours throughout the night.
4/5hrs at night
Night 3h
2-2h
2-3/4h

Do electricity black outs occur in your area? Or some similar phenomenon?

10 responses



If, yes, how often (e.g. how many in a week/month) and for how long (h) are you left without electricity and/or light?

10 responses

2 - 3 times a week. 4 h at a time

Once a week. An average of 3hrs

2x per day, each lasting about an hour

Often for a week for around 2-4 hrs a day

Once a week

In rural communities , light is available daily for maybe 5hrs

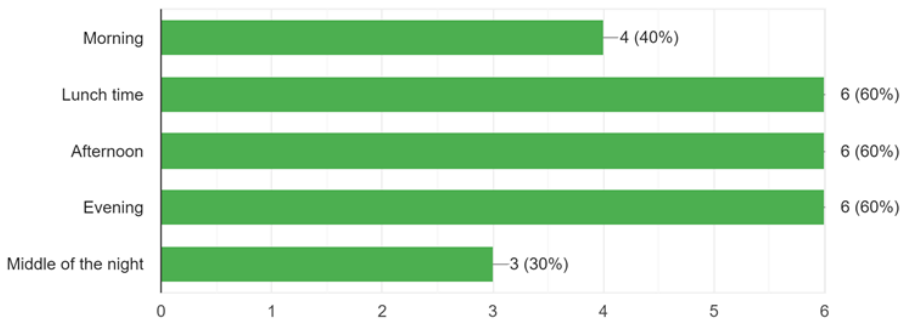
Nearly none

2 h a few times a week, de0enda on period of year

A few h a week

Generally, when during the day do the black out occur?

10 responses



Do you know what are your or your family's total costs for light (as is costs of electricity or any other source of light as lamps and candles) in a month/week?

9 responses

K700 /month

600

A month commonly around R500-R850

R500

In rural communities it is less than 10dollars a month

.

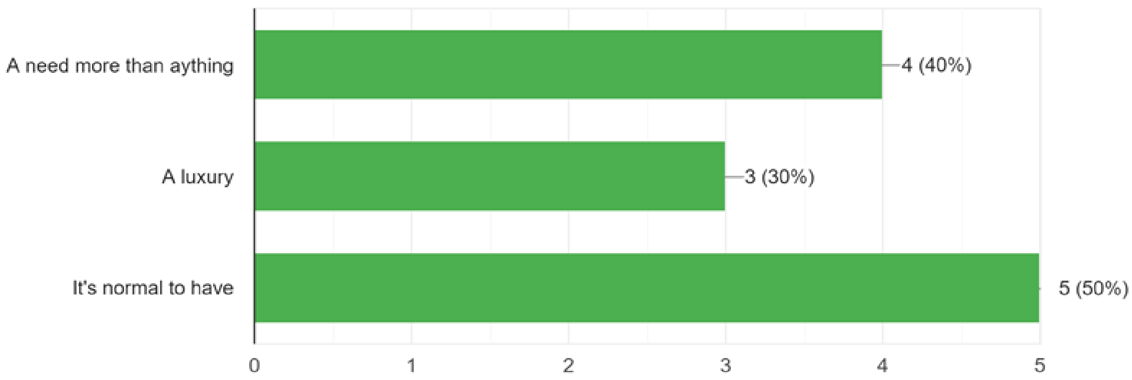
700-888 rand

No

600 rand

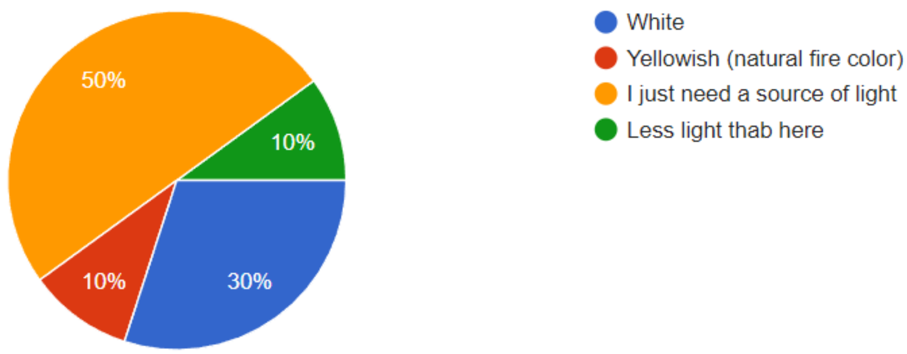
How would you say light is perceived in your community/culture?

10 responses



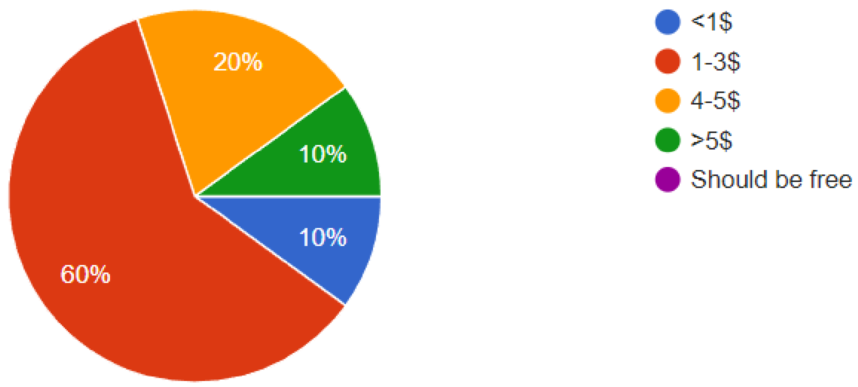
What is your preference of the colour of the light? Or is it important to just have light?

10 responses



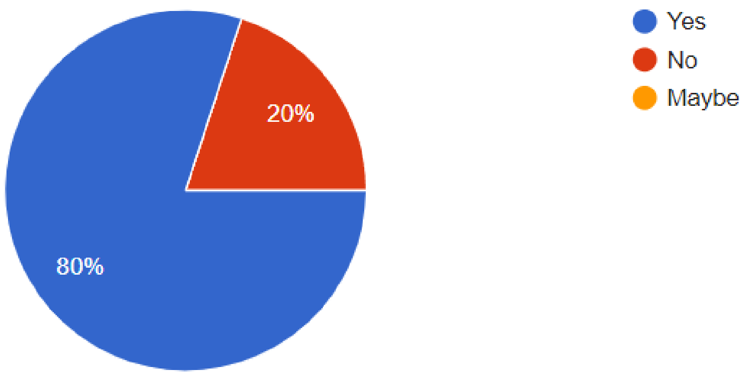
How much would you be willing to pay for a simple DIY natural light product?

10 responses



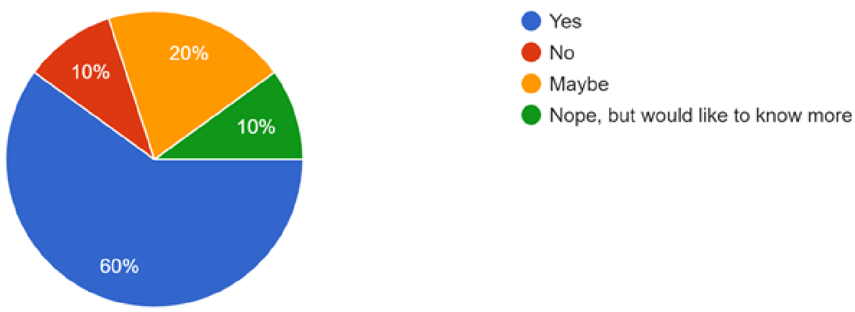
Have you ever taken up other DIY project's and, thus, could say you have a decent level of 'handiness' with tools and materials?

10 responses



Do you have any knowledge of electrical wiring, solar panels and solar powered lamps?

10 responses



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