Design of a Lantern Conversion Kit: Solar-powered Lighting for Rural Africa

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ABSTRACT

Widespread rural African regions lack affordable mains power and reliable lighting. Kerosene is burnt to provide light in traditional hurricane lanterns, or else, evening darkness makes everyday tasks, like helping children with homework, a challenge. Indoor burning of kerosene poses numerous health and safety risks, from respiratory conditions to fatal house fires. It also represents an economically unsustainable situation. Very poor Malawian families spend a significant percentage of income on kerosene fuel at unit energy costs far surpassing those in Britain. Safe, reliable, affordable and renewable energy is desperately needed. A mixed-discipline, five-person team of undergraduate engineers and product designers, from the University of Leeds, respond to the specific solar lighting needs of Malawian users, under the supervision of charity SolarAid. Primary user and contextual research, testing of existing products and research into photovoltaic options are performed to establish specific design requirements. The final design safely and efficiently converts sunlight into renewable electrical energy to power task and ambient lighting for several hours after dark as well as devices like radios and mobile phones. The robust lamp is designed to be locally serviceable, thus creating local employment, as well as being adaptable, light and compact for transportation, and affordable locally at £5.00 per unit. In testing, the final design performed significantly better than existing options.

Keywords: Solar powered lighting; LED lighting; Rural Africa; product design.

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INTRODUCTION

Once darkness falls in many rural African regions household activities like cooking or helping children with homework become challenging. Reliable, efficient lighting is key to improving quality of life and social sustainability[1]. Malawians, afflicted by poverty and limited local resources, mostly rely on kerosene and disposable batteries for their lighting needs. With no access to grid power this alternative is economically unsustainable. Average Malawian households spend approximately 20% of income on kerosene - around 55 litres annually, at an estimated cost of £80.00[2].

Burning kerosene damages human health and the local environment. According to SolarAid, "burning of kerosene [in typical hurricane lamps] inside houses is a major cause of respiratory illness, fires, burns, eyesight problems and death.[3]"

More expensive and much less efficient than electrical lighting (in $/lumen hour light), kerosene light represents a cost over 300 times that of inefficient incandescent bulbs in Western nations (SolarAid 08)[4]. The World Bank's 2007 statistics place Malawi's per capita earnings at 159th globally[5]. Affordable lighting is, therefore, of crucial importance.

Under SolarAid's guidance, Malawians are taught how to convert hurricane kerosene lanterns into solar LED lamps costing 40,000 kwacha (£5.00). Lamps are guaranteed for three years with batteries designed to provide 1,000 charges. Solar panels and other electronic components are imported from outside Africa. Remaining components are, ideally, sourced locally at low cost. While conversion of recycled hurricanes presents environmental benefits, efficiency of the conversion process and difficulty of local assembly/maintenance of the lamps, calls for a new solution. Solutions must respond to specific requirements of rural Africa, including: capacity to add value and create work and potential to build holistic social sustainability locally. Preferences regarding a new conversion method or an entirely new product remained open and dependent only on a design's ability to meet requirements, such as, suitability for local maintenance, potential for the development of children's education, adaptability to charge other devices and local affordability.

Solar hurricane conversion presents a number of limitations. Conversion is not intuitive and the lamp offers problems, such as limited light dispersion, since product architecture is not designed to accommodate electronics. Identification of local aspirations towards Western incandescent bulb aesthetics, as a sign of wealth, and the need for both ambient and task lighting at once, led to rejection of the conversion idea. It was deemed unlikely to ever fully satisfy the range of target user requirements. Furthermore, evidence that a new product presents the best opportunity comes from competitor products Glowstar[6] and BoGo[7], where success is the result of design, from the outset, specifically for use in rural Africa. There remains significant potential for a new lamp targeting true local lighting needs and local assembly/maintenance, all at a low product cost. To achieve this, the following project aims were set:

- Design safe, affordable and adaptable solar lighting for rural Africa. The product should provide power for other electronic devices too.
- Product accommodates local repair/manufacture.
- Deliver a working design and prototype requiring limited further development for manufacture.

- Design facilitates creation of infrastructure of sales and repair for local entrepreneurs.

METHOD

SolarAid's brief encompasses various demanding specifications regarding; low unit cost, optimisation of electronic components and provision for essential human needs[8]. To successfully meet these requirements a multi disciplinary process was adopted, where integration of designer and engineer knowledge was deemed essential.

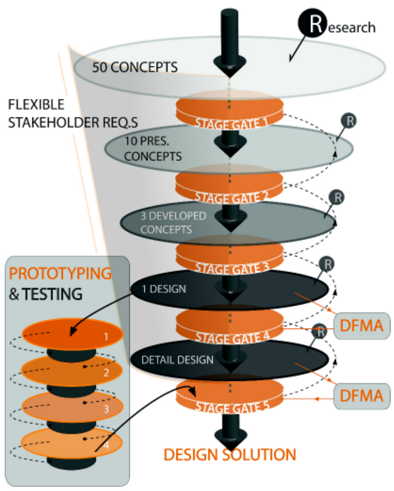

Figure 1. PDP model

Product Development Process (PDP)

The PDP undertaken was based upon the ideal model of Pugh's Total Design: Integrated methods for successful product engineering[9], an iterative approach accompanied by stage gate evaluation, demonstrated in Figure 1. Five iterations were planned from initial concept generation to final design definition, moving from 50 concept ideas to 10 presentation concepts, then three developed concepts and finally, one solution. Complimenting this, a four-stage prototyping and testing cycle was implemented to integrate functionality testing.

Throughout the process ongoing evaluation of design choices against evolving stakeholder requirements (enveloping grey area in Figure 1) was achieved through team meetings at stage gates and meetings with SolarAid representatives and course tutors. Once a single concept had been established for development, Design for Manufacture and Assembly (DFMA) analysis was implemented at each evaluation stage, ensuring low production costs were achieved.

Final Prototyping and Testing

Final production of a visual and functional prototype was assigned to the designers. Manufacturing components were modeled through the utilization of on-site selective laser sintering (SLS) and outsourced stereo lithography (SLA) rapid prototyping. These were designed and produced with regular meetings and input from manufacturing specialists. Similarly, electronic components and circuits were sourced from various companies with input from an electronic circuit design specialist. The engineers undertook final testing of the prototype and at several stages in production.

Tests conducted included light levels and comparison against the LED hurricane, with several component options.

RESEARCH OVERVIEW

Research was conducted through a combination of primary and secondary techniques: Demographic information, local materials and manufacturing techniques, economic data, climate information, existing products, solar technologies, patent information and electronic component information were established through literature sources.

Since primary user and environment research was inaccessible directly, this was collected through interviewing SolarAid employees with area-specific user and product experience and through analysing picture and video resources, provided by SolarAid on our request.

Information into current technologies and manufacturing techniques of solar lanterns, power devices and other solar products, such as phone chargers, was achieved through product tear-downs, and comparisons. Additional technical information was sourced from specialists when required.

Performance information on; SolarAid's current solution, available consumer products, and electronic components and circuits was collected through a range of technical tests conducted by the in team engineers.

Research into users and environmental requirements

Malawi consists of varied ethnic groups with an array of customs[10]. Many languages, including English and Chichewa, are spoken and around 42% of Malawians are illiterate[11]. This suggests the importance of intuitive design whereby interpretation of meaning is probably best understood through culturally-sensitive pictorial representation. Densely populated and predominantly agricultural, Malawi is landlocked[12] and transportation costs are very high[13]. Most imports arrive via Durban, South Africa and goods are subjected to priority tariffs[14].

From photos and literature documenting specific local needs and information from SolarAid's ground staff, specialists in working with the end users, a number of conclusions were drawn. Currently only 7.4% of Malawians have access to mains electricity[15], and many of those avoid using it because of high costs. Houses are small with maximum two rooms, local people aspire to a incandescent lightbulb aesthetic over hurricane-style lanterns as a sign of wealth[16], of crucial importance is the provision of task lighting to benefit children's education after school and the need for ambient lighting generally within homes.

Video analysis suggested electronic devices, such as mobile phones and radios, are common. Our own source in Uganda, reporting on similar conditions to Malawi, explained phone use depends on the ability to charge somewhere with mains power. The body of evidence highlighted local desire for an affordable and reliable means of charging consumer electronics devices through freely available solar energy. Further video stills documented the popularity of radio listening at work, including farming, by drip-charging radios directly from heavy PV panels. Combining this research with studies into the positive effect radio messages can have on the education of HIV/AIDS[17] and empowerment of women helped form conclusions for the need of a compact product that can also power a radio during the day.

A major concern of SolarAid's, that mosquitoes may be attracted to bright LED light, and therefore brought closer to users was also investigated for its potential impact on engineering and design decisions. Dr G. McConkey explained malaria is passaged exclusively by Anopheline mosquitoes that are attracted to other stimuli but not light in any form. Consequently, he suggests LEDs should be ideally suited to lighting situations in Malawi.

FINAL DESIGN

Results are presented and discussed in relation to abbreviated stakeholder requirements, and in comparison to the current lantern conversion design.

- Provide safe lighting for continuation of tasks after sunset for several hours.

The design solution presented in Figure 2 uses a 100mA PV solar panel to convert sunlight into stored renewable electrical energy, which provides enough light to illuminate a regular Malawian home. The lamp offers a safer and healthier alternative to kerosene with a maximum circuit voltage of a limited 6V. Total charge time required to reach battery capacity of 3600mA is 43 hours providing 22.5 hours of use (based on 4 LED's drawing 40mA each), however around 1 hour of use is possible from two hours of charging, meaning from an average 10-hour day approximately 5 hours of use is possible[18].

Figure 2. The SolarAid 'Orb' design

Product versatility comes from the ability to provide ambient lighting and separate task lighting. Family or whole-house tasks can be performed independently from work tasks, such as children's homework, reading & writing or workshop activities. Furthermore, the lamp suits being placed atop a surface, suspended from the ceiling by the handle or used outside for security.

Expandable and adaptable, the lamp is suited to varied users' needs and financial levels. The ambient light can be bought for an entry-level price. The task light may be bought later, as an upgrade, when affordable. Other add-on features could be incorporated into the product range to accompany the task light and mobile phone charging adapter, also costing a little more.

In testing the technical performance of the product far surpassed the converted hurricane lanterns in use[19]. Comparing illuminance distributions in Figure 3 (current conversion) with Figure 4 (solution), a dramatic improvement is noticeable. It can be observed that the solution offers an increased effective spread of light, brighter overall ambient light and eliminates shadow caused by the hurricane's support structure.

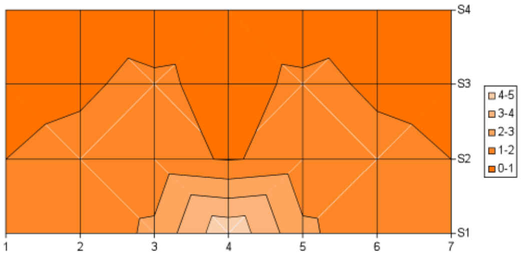

Figure 3 – Luminance levels for current SolarAid solution.

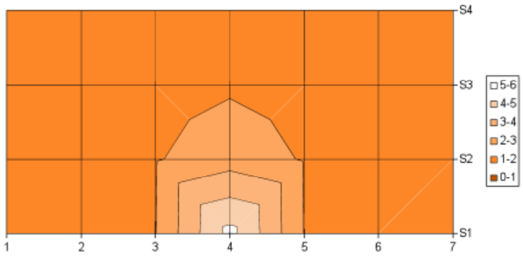

Figure 4 – Luminance levels for produced solution (SolarAid Orb).

- Robust components and structure for long life in harsh conditions and high temperatures.

Main electronic components are contained within the base unit for protection from environmental factors, coloured white for better heat deflection. External exposure of the PV solar panel is essential in daytime use, however, the design protects it when charging is not required through addition of the top unit.

Two factors influencing material choices were heat deflection temperature (HDT) – and price. The cheapest injection-mouldable polymer, high-density polyethylene costs approximately 0.90$/kg[20], however HDT of 42 degrees C would make it unsuitable for Malawi's hot conditions. Suitable materials include high-impact polystyrene and ABS, which was selected. For clear parts polycarbonate was chosen for cost effectiveness, high quality and excellent mechanical properties.

- Have a method for connecting other electrical devices to the power source – particularly mobile phone and radio for daytime use of power.

The internal battery pack, charged from the PV panel, contains three 1.2V 1000mA rechargeable batteries combined with a bundled 1.3mm DC power socket for drip-feeding charge directly from the 6V solar panel to radios and other devices. Taking place alongside charging of the internal battery pack powering the light, charge is not drawn from batteries[21]. Add-on phone charging parts supply the mobile-specific adaptor for drip-charging the same way, at a small additional cost.

- Small size and weight to reduce costs for transport/importation.

Overall product dimensions are specified by the size of the base and bulb with no external components, other than a connector cable for radio/phone charging. This differs greatly from many existing products where the PV solar panel is large and separate to the lamp, requiring connecting whenever charge is needed. Instead the PV panel cleverly friction fits to the top of the base, exposed to the sun during the day, but fully protected within the silver reflector when providing light.

The lamp is shipped containing all components, fit within the base for protection. Electronic components are assembled by local entrepreneurs as a way of turning potential assembly costs into a means of value adding, and therefore; paid work, for local people. No tools are included in the design since main product components fit through friction/snap-fits alone and any fixings require very basic tools. Culturally relevant graphical instruction will be included in shipped products.

- Aim to produce for under £5 and cover own costs.

MAIN LAMP		
Electronics Component	£	Supplier
Batteries (3 pl)	0.79	Hefei Jianjiu Science & Technology Co. Ltd
Battery housing including clip (1 pl)	0.09	Comfortable Electronic Co. Ltd, Taiwan
Diode (Schottky) (1 pl)	0.05	Vishay Int. (vishay.com)
LEDs (4 pl)	0.25	Habei I.T. (Shanghei) Co. Ltd
Radio Socket (1 pl)	0.13	Rapid Electronics (rapidonline.com)
Resistors (4 pl)	0.08	Vishay Int. (vishay.com)
Solar Panel: 6V 100mA (1 pl)	1.32	Ningbo Yongjiang Shenzhou Photovoltaic
Switch (Rocker) (1 pl)	0.07	Yuequing Daeir Electronic Co. Ltd, China
Terminal Block (12 pl)	0.16	Metway (metway.co.uk)
TOTAL	£ 2.94	

Table 1. Component cost breakdown

Table 1 lists final sourced component costs for the main lamp, additional task light and phone adaptor. Unit costs are dependent on a scale of manufacture of 5,000 pieces. A change in number of units or component suppliers may affect unit cost either way, however, it is predicted that investment in production of more units will reduce overall costs further. The result is a product that may be sold at face value (the equivalent to £5) without requiring investment of SolarAid's charitable assets.

These costs leave over £2 per unit for manufacturing and shipping costs or, based on the manufacture of 5,000 units, £10,000. Although attempts to get estimates for component tooling have thus far been unsuccessful due to required financial commitment, a manufacturing specialist has estimated the production requirement is realisable within this budget.

CONCLUSION

Although the design is based upon 'universally' accepted principles of functionality, usability and aesthetics combined with controlled technical testing, a limiting factor of the current solution is the lack of primary user feedback and real environmental testing. A suggested continuation would be to export the prototype to Malawi, to gauge user responses to aesthetics, test reparability and assembly with local entrepreneurs, observe user-product interaction and test technical performance. From this an additional stage or stages of development could be performed to improve the current solution.

Additionally, a final development iteration would be advisable before manufacturing commences. This process should be focused towards the continued improvement of the injection-moulded components for manufacture and assembly, in response to the final DFMA evaluation at Stage Gate 4. As the product stands, input from manufacturing specialists established that further savings in this area would be possible.

ACKNOWLEDGEMENTS

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