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Evaluation of the Sunlabob Battery Lantern from the Perspective of Users in Rural Lao PDR

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Abstract

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Tomas Bergsten

Access to electricity is fundamental in modern everyday life and throughout the developing world; NGOs and development agencies are, in different ways, providing electricity to remote areas in order to increase quality of life. Electric light can eliminate the need to use polluting kerosene lamps and allow villagers to conduct income generating activities and children to study during the dark hours after sunset.

The objective of this thesis was to evaluate the features of a battery lantern designed to provide electric light to rural villagers at a cost competing with using the traditional kerosene lamp. This is done through a business model where the lanterns are funded by an NGO or public donor and the solar charging station is funded by the manufacturer and/or private investors.

The evaluation was done through a field test where a village of 234 people in rural Lao PDR used the lanterns for six weeks, after which the villagers were interviewed regarding their usage patterns and thoughts of the lantern. The results were meant to help the manufacturer to identify issues, concerning function as well as quality, with the lantern in order to be able to better accommodate the wishes of the end user.

The results of the study show that, in general, the villagers were very happy about the battery lantern but many of them still had suggestions on design improvements. The technical evaluation of the lanterns show some significant problems with the discharge of the batteries due to stand-by power of the discharge controller. These findings imply that an addition should be made to the business model where the amount of days allowed for the user to make use of the lantern should be limited.

Concerning design, it was suggested that the lamp should be placed on the top of the lantern rather than the current placement on the front, in which the spread of light is restricted. Having the lamp on the top of the lantern would expose it to force but the results of the survey show that the villagers are very careful with the lanterns. The addition of such a model would give the villagers a choice and in order to provide the right lantern to different villages around the world, pilot studies should be conducted before providing any village with the full intended amount of lanterns.

Keywords: Rural electricity, developing countries, photovoltaic's, renewable energy, portable lamp.

Sammanfattning

Att ha tillgång till elektricitet är något som större delen av befolkningen i världens industrialiserade länder ser som självklart. Vissa tänker inte ens på att elförbrukning är en del av deras vardag. Det anses vara en viktig del i utvecklingen av fattiga områden och biståndsorganisationer, som SIDA, genomför en stor mängd elförsörjningsprojekt världen över. Elektriskt ljus kan ersätta fotogenlampor och därmed minska både luftföroreningar i hemmen och ögonsjukdomar orsakade av det, i allmänhet, svaga ljuset.

Laos är ett kustlöst land i Sydostasien. Det är ett av världens fattigaste länder och är upptaget på FN:s lista över världens minst utvecklade länder. Nästan 75% av befolkningen på fem miljoner lever på mindre än USD 2 om dagen och endast ca 50% saknar tillgång till el. Regeringen har, i en plan att få bort Laos från FN:s lista, satt upp som ett av målen att 90% av befolkningen ska ha en pålitlig elförsörjning år 2020.

För att, med enkla medel, kunna sprida ljus på landsbygden, både i Laos och i andra utvecklingsländer, utvecklar Sunlabob Renewable Energy Ltd. en batterilampa som är tänkt att hyras ut till befolkningen. På så vis slipper byinvånarna den, relativt stora, engångskostnaden och betalar bara för det ljus som de förbrukar. Affärsmodellen, där en nyckelfunktion är att Sunlabob har intresse i att lamporna faktiskt används genom att de tar delar av hyresavgifterna, har vunnit ett antal priser inom biståndsvärlden.

Syftet med detta examensarbete var att utvärdera Sunlabobs batterilampa och föreslå förbättringar för att den bättre ska kunna tillgodose användarnas önskemål och behov. I Ban Tha Hua, en by med knappt 250 invånare, utan elektricitet och tre timmars båtresa från närmsta stad, använde byborna 20 lampor under 6 veckors tid. Vid utvärderingsperiodens början och slut intervjuades byborna angående deras användning av ljus. Vi slutet lades stor fokus på lampornas funktion och hur de skulle kunna förändras för att fungera bättre. Utöver intervjuerna utvärderades lamporna tekniskt efter användningen för att identifiera eventuella kvalitetsproblem.

I sin nuvarande form består Sunlabobs lampa av en låda i PVC med en 4W lågenergilampa på framsidan. Inuti lådan finns ett 12V batteri med en kapacitet på 7,5Ah. Batteriet skadas av att laddas ur för mycket och därför har lampan även en spänningsvakt som stänger av lampan när batteriets spänning faller under 11,5V. Med ett fulladdat batteri kan lampan köras i ca 15 timmar innan spänningsvakten slår ifrån.

Under de avslutande intervjuerna framkom ett antal saker som Sunlabob bör fundera över. Det visade sig att användarna var mycket försiktiga med lamporna och att de nästan uteslutande användes inomhus. Den mest eftersökta förändringen

av lampans design var att man önskade ljusspridning i 360 grader hellre än dagens 180.

Den tekniska utvärderingen av lamporna visade problem med ett antal av dem, mestadels på grund av att spänningsvakten drar ström även då lampan är avstängd och då den slagit ifrån. Detta gjorde att när en lampa inte laddas omedelbart efter att den tagit slut, kan batteriet skadas avsevärt.

Bybornas önskemål och de observationer som gjordes under utvärderingen av lamporna har resulterat i ett antal rekommendationer. Den mest konkreta att en variation av lampan, med själva lampan på toppen av PVC-lådan, borde tas fram. Detta skulle kunna ske med mycket enkla medel och med samma delar som används idag. En sådan lampa skulle tillgodose önskemålet om 360 graders ljusspridning men göra den mer ömtålig, något som troligtvis skulle fungera i de flesta fall. Därför borde dagens lampa finnas kvar och erbjudas där förstudier visar att stryktålighet är av vikt.

Sunlabobs batterilampa används idag i byar på landsbygden i Laos och Uganda. Intresse har visats från ett antal länder, inklusive Afghanistan, Sydkorea och Indonesien. Mellan dessa länder finns stora kulturella skillnader och det är viktigt att tänka på att resultatet av detta examensarbete gäller i Laos, men användningen av lamporna skulle troligtvis vara annorlunda exempelvis i Afghanistan. Därför är det viktigt att noggranna förstudier genomförs innan lamporna introduceras.

Ban Tha Hua kommer fortsätta att fungera som en utvärderingsby där olika varianter av batterilampan kommer att testas under utvecklingen.

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1. Introduction

Access to electricity is something that most people in the developed world take for granted. It is a large part of everyday life and has long been considered a great improvement to quality of life (Watkins, 2007). However, almost 2 billion people in the developing world lack access to electricity (Watkins, 2007). Many are located in rural areas, isolated from public electricity grids, either by large distances or by other natural obstacles. Rural communities are normally spread out over large areas with few inhabitants, making the extension of gridlines less profitable for commercial power companies (Heltberg, 2003).

Electricity can change many aspects of everyday life. Electric light can reduce pollution in the homes as well as reduce eye conditions caused by working in bad light. The possibility of having light in homes, shops and schools give children the opportunity to do their homework, allow shopkeepers to keep longer hours and enables producers of goods to work in the evening (UNDP, 2001). Hence, it allows for social as well as economic development. In 2003, the Lao Government formulated the 'National Growth and Poverty Eradication Strategy' (NGPES), a plan that aims to remove Lao PDR from the UN list of Least Developed Countries (LDC). NGPES includes ten strategic priorities for eradication of poverty, one of them is to 'Facilitate access to electricity for people in all areas of the country in order to foster integrated economic development' (GoL, 2004). In the same report, 72 of the 142 districts of Lao PDR have been identified as poor and 45 of the 72 are especially targeted in NGPES.

An abundance of development projects have targeted the development of electrical systems in rural areas of developing countries. In 1948 the International Bank for Reconstruction and Development, later the World Bank, made their first investment in Latin America. Loan 0005 focused on hydro electric development in Chile (http/go.wor ldbank.org/3AYV8BU3O0; 14-Oct-2008).

1.1 Background

1.1.1 Lao People's Democratic Republic (Lao PDR)

Lao PDR is a landlocked country with 6 million inhabitants in South East Asia. Its neighboring countries are Thailand, Cambodia, Vietnam, China and Myanmar. The mountainous terrain and high amount of rainfall makes for a very high potential for hydro power. However, large portions of the produced electricity are exported, mainly to Thailand and Vietnam, leaving little for the rural areas of Lao PDR.

With 74.2% of its population living below the poverty line of USD2 per day (Watkins, 2007), Lao PDR is listed by the UN as one of the Least Developed Countries (LDC) in the world (http://www.un.org/special-rep/ohrlls/ldc/list.htm; 27-Nov-2008). In 2005, only 47% of the 6 million inhabitants of Lao PDR had access to electricity (Sundqvist & Wårlind, 2006). The GoL has developed a plan for the power system in which one of the main goals is to provide reliable electricity to 90% of the people by 2020 (Maunsell & Lahmeyer, 2004). The mountainous terrain, beneficial for hydro power as it may be, makes grid extensions difficult and expensive. Therefore 10% of the population or 600, 000 people are meant to get access to electricity through off-grid solutions (Phoumsoupha, X. 2006).

1.1.2 Sunlabob Renewable Energy Ltd.

Sunlabob is a Lao commercial company, licensed since 2001, which provides energy solutions and services with renewable energy sources to remote areas to which the public electricity grid does not reach. This is accomplished through a rental system, in which their energy systems are rented out at affordable rates, generally lower than the costs for kerosene etc. which are eliminated by the use of electricity. The concept of rental eliminates the initial cost for the end user so that, generally, even the poorest villager can afford to use the systems and in many cases save money in doing so. Sunlabob and their franchisees also take care of servicing and maintenance of installed equipment. In many ways, the rental system resembles the mainstream way of selling electricity in the developed world.

Sunlabob designs their systems to suit the needs and possibilities of each village, using available resources to generate power. Sunlabob offers a large range of products and services, from portable solar lamps to complete hybrid village grids, including small scale hydropower and wind power as well as biogas converters. Sunlabob is also a retailer of equipment for production of renewable energy, such as PV panels, as well as energy saving products such as LED and CFL lamps.

1.1.3 The Sunlabob Battery Lantern

One of the latest products of Sunlabob is the Battery Lantern, see *Image 1* on the right. It allows introduction of electricity in its simplest form, light. After installation of a charging station and training of a village technician, a number of lanterns are made available for rental to the villagers. When fully charged, the lanterns will omit light for a predefined amount of time. Thus, the villager pays for ‘light hours’ rather than kWh, making it directly comparable with the earlier source of light. The first version of the lantern has been used in a small number of villages in Lao PDR and, through franchisees, in Uganda. Interest in the lantern has been shown from a variety of countries including Afghanistan and South Korea (Schroeter, 2008).

Image 1. Sunlabob Battery Lantern

The lantern is currently in its second version and is still under development. A major priority in the development of the lantern is its sustainability, making sure that people use the lantern and that it works for a long time. Hence the evaluation of the usage of the lantern is of great importance.

1.2 Objective of the Study

The objective of the study is to, based on the reactions of the end users, evaluate the Sunlabob Battery Lantern and to suggest solutions to make the lantern better meet the needs of the end user. This will include design of the lantern as well as technical features and immediate quality issues. The evaluation will also try to identify socio-economic issues that may prevent or limit the use of the lanterns.

1.3 Demarcation

The thesis consists of conducting, and analyzing the results of, a field test of the battery lantern. Conclusions from this will lead to suggestions for improving the technical design of the lantern. Functional as well as economical aspects will be considered.

1.4 Method

The field test was conducted in the village of Ban Tha Hua in the Bolikham district in the Bolikhamsay province of Lao PDR. Ban Tha Hua has 49 households and a population of 234 (Vahn, 2008). Bolikham is targeted as one of the 47 poorest districts in Lao PDR (NGPES). The village does not have access to grid electricity. However, a few households have electric lighting with standard car batteries, charged by a tractor, as a power source and one household has a solar home system provided by Sunlabob. A focus group of 15 households was chosen in cooperation with the head of the village. The selection was done to cover as wide an array of users as possible regarding income level, economical activities and family composition. The villagers were able to buy light in the form of charged battery lanterns during six weeks. Twenty lanterns were made available in the village and, in order to mimic the real scenario, the villagers were charged LAK6000 (approximately USD0.7) for 15 hours of light. This is an amount that, according to earlier Sunlabob studies, was below the cost for other fuels for the corresponding amount of light (Schroeter, 2008). It was decided that the villagers should have to pay for using the light in order to mimic the situation that would occur under normal circumstances. Mr Si Vahn, the head of the village, was trained to handle the charging and administration of the lanterns. The money was divided equally between the administrator and Sunlabob. The Sunlabob part was used to cover some of the costs involved in transportation and installation of the charging station.

1.4.1 Field Trip 1, Initiation of the Test

Before the test, the heads of the households in the focus group were interviewed individually regarding their use of light at the time; light sources, where and when it was used, costs, issues as well as the activities performed under the light. The shops in the village were asked about the current fuel price. After the survey, the villagers of Ban Tha Hua were introduced to the Sunlabob Battery Lantern. The results from the survey were compiled and analyzed, focusing on the economical aspects in order to determine ability and willingness to pay (WTP) for electric lighting.

The lanterns were numbered in order to allow the village head to keep records of the usage of the lanterns, *e.g.* times when the lanterns have been picked up and returned. This information was later used to determine usage patterns such as average amount of hours used per day.

1.4.2 Field Trip 2, Evaluation

At the end of the test, members of households that had been using the battery lanterns were interviewed individually as well as in small groups of two or three respondents. During the interviews the respondents were asked to show how they had been using the lanterns as well as if they had any suggestions for improvements. Apart from interviews and observations during the field trip, the lanterns were brought back to Vientiane for further examinations in order to determine the cause of any technical failures. The village head was also interviewed regarding his impressions of the experiences of the villagers.

The main objective of the second interview was getting the focus group to share its impressions of the lantern in order to be able to make it better accommodate the needs and wishes of the customers. This was done in separate interviews as well as in group discussions.

2. Theory

This theory section will explain relevant theory and terminology concerning the conduction of surveys in general and in developing countries in particular. It will also explain some of the theory behind the function of batteries.

2.1 Conduction of Surveys

It may seem that asking people a few questions is a simple task. However, depending on variables such as nature of the interview, cultural aspects of the focus group, context of the interviews etc. all contribute to turning the planning and preparations of a survey into an array of discussions and reading. Depending on the objective of the interviews, different approaches are preferable.

2.1.1 Quantitative Interviews

In a quantitative interview, the questions are asked so that the respondent is given very little leeway for the answer, which will be in the nature of numbers or yes or no. When conducting surveys about habits or financial capabilities, quantitative urveys are normally preferred as they give clear answers that can be easily quantified and displayed (Nichols, 1991).

2.1.2 Qualitative Interviews

Qualitative, or open, interviews allow the respondents to answer the questions in a more descriptive way. This type of surveys focus on the quality of the interviews rather than on the quantity. There are no real limitations to how the questions can be answered and the interviewer may ask follow up questions in order to trigger further revelations (Nilsson, 2008)

The two methods mentioned above are in some way polarities to each other. They can be combined and altered to suit the situation and have the desired effect. In this project, they were used to complement each other. Quantitative questions were used to determine income as well as ability and willingness to pay while a qualitative part was introduced to allow the interviewees to describe and show how the lanterns had been used.

2.2 Batteries

The choice of battery for the Sunlabob battery lantern is a 7.5Ah 12V Absorbent Glass Mat (AGM). The AGM technology is a development of the Lead Acid battery that is commonly used in vehicles. Another type of battery that could be used in an application like this is NiMH, commonly used in smaller electric appliances such as cameras and mobile phones. The characteristics of these batteries will be explained in this section.

2.2.1 Lead Acid Batteries

A typical 12V lead acid battery consists of six cells which are connected in series to make up the battery. The main characteristic is that lead is used as an active material in both terminals. Each cell consists, in simple terms, of:

- Two polar plates, one positive consisting of lead dioxide (PbO_2) and one negative consisting of lead (Pb) (Kiehne, 2004)
- Electrolyte consisting of sulphuric acid (H_2SO_4) in a diluted solution with water (Payne, 2003)
- Constructional elements such as separators and terminals that make up the frame for constructional stability of the battery unit.

When the battery is being discharged, the charge of the positive electrode is transferred to the negative causing the lead (Pb) of the negative electrode to oxidize into the divalent ion Pb^{2+} as the fourvalent ions (Pb^{4+}) of the positive electrode are reduced to Pb^{2+}. Together with the sulphuric acid electrolyte, the resulting ions on both electrodes form lead sulphate ($PbSO_4$). The reaction can be written as follows (Kiehne, 2004):

Positive electrode: $PbO_2 + H_2SO_4 + 2H^+ + 2e^- \leftrightarrow PbSO_4 + 2H_2O$
Negative electrode: $Pb + H_2SO_4 \leftrightarrow PbSO_4 + 2H^+ + 2e^-$

Cell reaction: $Pb + PbO_2 + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O$

In a lead acid battery, the electrodes are flooded by electrolyte and they are not sealed. Hence it allows for spilling and gas generation as well as requiring maintenance in the form of topping up of battery water, the dilution of the electrolyte.

2.2.2 Absorbent Glass Mat (AGM) Batteries

AGM batteries build on the same principle and chemical reactions as lead acid batteries. The electrolyte is immobilized in a micro porous boron-silicate glass mat placed between the electrodes. Hence, there is no risk for spilling and the battery can be placed in any orientation. They are also sealed and held under pressure not to allow for gas emissions during normal operating conditions. The seal gives them the description sealed lead acid (SLA) batteries. Under conditions such as extreme heat or overcharging, hydrogen gas will build up inside the battery causing the pressure to increase. The battery has a pressure valve that allows hydrogen gas to escape (Kiehne, 2004; Payne, 2003). This causes a reduction of the amount of electrolyte in the cell which in turn causes reduced battery capacity.

2.2.3 Electrode Sulphation

Sulphation of the electrode plates is the most common cause of battery failure. During discharge, both plates are converted into lead sulphate ($PbSO_4$). If the battery is not recharged quickly, the lead sulphate begins to crystallize, a process that is non-reversible. The immediate effects are that the active electrolyte materials are reduced and the sulphated material increases the internal resistance in the cell, causing permanent loss of battery capacity and inhibition of charging respectively (Wood, 2008).

2.2.4 Self discharge

In an idle state with open terminals all batteries will lose some charge, this is called self discharge. One of the reasons for this is that impurities such as dissolved particles of the antimony (Sb) used in the positive electrodes deposit onto the negative ones. This causes a localized chemical reaction to take place, slowly discharging the cell.

The main advantages of using AGM batteries are that they require no maintenance, do not spill acid and have low self discharge rates. The main drawbacks are that they are permanently damaged if overcharged as well as being heavy and expensive in comparison to regular lead acid batteries (Payne, 2003).

2.2.5 Nickel-Cadmium (NiCd) Batteries

For use in smaller appliances, such as torches, cameras, power tools, etc, NiCd batteries are used extensively. When compared to lead-acid batteries, they have many advantages including lower weight, higher energy density and cycle life but have drawbacks such as higher self-discharge and price (Whitaker, 2005).

The chemistry of the NiCd battery is essentially the same as that of a lead-acid battery except the fact that the electrodes are made up of nickel hydroxide (positive) and cadmium (negative).

Positive electrode: $2NiO(OH) + 2H_2O + 2e^- \leftrightarrow 2Ni(OH)_2 + 2OH^-$

Negative electrode: $Cd + 2OH^- \leftrightarrow Cd(OH)_2 + 2e^-$

Cell reaction: $2NiO(OH)_2 + Cd + 2H_20 \leftrightarrow 2Ni(OH)_2 + Cd(OH)_2$

The NiCd battery does not have any problems with deep discharging. In fact it supplies a rather steady voltage throughout the whole cycle and benefits from being completely discharged (Whitaker, 2005).

2.2.6 Nickel-Metal Hybrid (NiMH) Batteries

The NiMH battery is a development of the NiCd where the toxic cadmium is replaced by a non toxic alloy. Its cell capacity is generally higher than that of a NiCd, but it is also larger and heavier. NiMH batteries are developing rapidly thanks to their suitability in hybrid vehicles.

Table 1. Comparison of Battery Chemistries (Whitaker, 2005)

	NiCd	NiMH	SLA
Energy density, Wh/kg	50	75	30
Cycle life (typical)	1500	500	200-300
Fast-charge time, h	1.5	1.25	2
Self-discharge	very high	moderate	low
Cell voltage (nominal), V	1.25	1.25	2
Exercise requirement, days	/30	/90	/180
Battery cost	low	moderate	very low

2.2.7 Environmental Issues

The heavy metal content of lead-acid and NiCd batteries pose potential environmental problems, both in the form of a risk during the assembly of the lanterns as well as when disposed of.

2.3 Lamps

Two different kinds of lamps could be suitable for an application like the battery lantern; Light Emitting Diodes (LEDs) and Compact Fluorescent Lights (CFLs). The different technologies are explained briefly below.

2.3.1 Light Emitting Diodes (LEDs)

LEDs are semiconductors, or diodes, that have been impregnated with impurities to cause a voltage drop as a current flows through it. As the voltage drops, light is emitted. The wavelength of the light depends on the material used to impregnated the diode. Hence, different colour of light can be accomplished. To create white light, a, normally blue, LED is coated in phosphor(Held, 2008). The phosphor causes portions of the light to shift into longer wavelength. Thus, the spectrum of the light is broadened and the light appears white. This kind of LEDs are called phosphorous white LEDs (Held, 2008).

The light emitted from an LED flows perpendicularly to the semiconductor chip. Hence, in order to create an area light, multiple LEDs can be combined in different directions.

The main advantages of LEDs are their very low energy consumption and long life, but they are expensive and the light is very cold.

2.3.2 Compact Fluorescent Lights (CFLs)

A CFL is a tube containing mercury vapour which is excited to emit light. A ballast is needed to regulate the flow of electricity through the gas. This makes the CFL more advanced than a regular (incandescent) light bulb but its power consumption is significantly lower.

3. The Battery Lantern System

3.1 The Lantern Exterior

The casing of the Sunlabob Battery lantern is a standard PVC switch box. Screwed onto the front of this is a polypropylene lamp cover holding the socket and lamp. Two straps are attached to the casing allowing for easy carrying and hanging of the lantern. Attached to the bottom of the casing are two rubber strips working as feet. While providing some grade of impact protection, they also make the lantern stand stably on rough surfaces. On the right side of the lantern is a standard car cigarette lighter socket used for charging the lamp as well as for using the lamp as a power source for smaller electrical appliances such as radios or mobile phones. The same side also has an LED for telling the user when the battery is close to its turn off voltage. The left side of the lantern has a switch for turning the lamp on and off. The general specifications of the lantern are displayed in *Table 2* below

The lantern is assembled at Sunlabob in Vientiane by local personnel. Some of the workers are supplied by AFESIP (Agir Pour Les Femmes En Situation Precaire -Working for Women in Precarious Situations), an NGO that supports women who were formerly in the sex industry. In as far an extent as possible locally available components are used. The lamp cover is manufactured in Vientiane by the Co-operative Orthotic and Prosthetic Enterprise (COPE) out of waste material from the production of artificial limbs.

Table 2. Lantern Specifications

Operating modes:	Lighting, Power Supply
Operating time (lighting):	15-18 h
Output voltage (power supply mode):	12 V nominal (unregulated)
Output current (power supply mode):	1 A max. (configurable)
Lamp type:	12 V/4 W Compact Fluorescent Lamp
Luminous flux: Unit	~120 lm
weight: Power/charging	~3 kg
socket:	standard cigarette lighter socket
Battery protection:	deep cycle protection, low voltage disconnect
Circuit protection:	short-circuit, reverse voltage, surge protection

3.2 The Lantern Interior

Each lantern has a 4W, 120lm compact fluorescent light (CFL) comparing to a 25W incandescent lamp. Behind the lamp is a reflective plate to minimize wasted light. The power source for the lamp is a 12V 7.5 Ah sealed Absorbent Glass Mat

(AGM) lead acid battery, allowing it to hang or stand in any orientation. In order to ensure a long battery life time, a discharge controller disengages the power to the lamp as well as the power outlet when the voltage drops below 11.5V. With the current setup, if used solely for light, this will happen after approximately 15 hours, corresponding to a discharge of 5Ah. In the field test, discharge controllers of two different brands, Steca and Solara, were used. However, the main portion of the sample (18) were Solara leaving only two with Steca. Specifications for the components of the lantern can be seen in *Table 3* below.

Table 3. Component Specification

Battery	
Manufacturer:	Haze Battery Company Ltd.
Model:	HZS12-7.5
Type:	Sealed lead acid (AGM)
Nominal voltage:	12 V
Nominal capacity (C20):	7.5 Ah
Operating temperature:	-20°C to 50°C
Weight:	2.5 kg

Lamp	
Manufacturer:	Phocos
Model:	LL1204C
Power rating:	4 W
Voltage range:	10.5 - 15 V
Luminous flux:	120 lm
Socket type:	E27
Nominal lifetime:	25,000 h

Discharge Regulator	
Manufacturer	Solara
Model:	SL135TL
Load disconnect voltage:	11.5V
Max. load current	8A
Self consumption:	4mA
Ambient temperature range:	-°15 to 45°C

The battery is positioned on the bottom of the PVC box. Hence, the lantern can stand in 110 mm of water without any sensitive electrical components getting damaged. It also puts the center of gravity of the lantern as low as possible, adding to its stability.

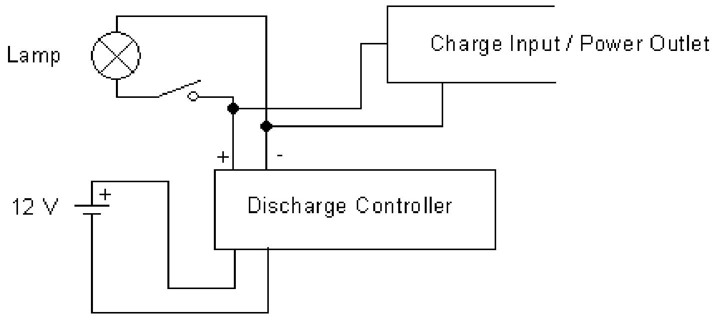

Figure 1. Circuit Diagram of Battery Lantern

3.3 The Charging Station

The Charging station consists of two main components; the solar panels and the battery charging unit (BCU). The BCU handles the charging of the lanterns and protects the batteries from overcharging.

3.3.1 The Battery Charging Unit (BCU)

The core of the charging station is the BCU. Upon connection of a lantern, the BCU begins the charging. It recognizes the connection sequence of the lantern so that the one first connected will be given priority as the charging current is distributed. Each lantern is charged with a maximum of 5A to a voltage of 13.8V, if the lantern first connected is fully charged or the available current exceeds 5A, the remaining current is distributed to the lantern next in turn. The BCU can handle 8 lanterns simultaneously and shows the battery status of each individual lantern. The specifications of the BCU can be found in *Table 4* below.

Table 4. BCU Specification

Manufacturer:	Steca GmbH
Model:	PL 2085
Type:	microprocessor controlled
Display:	2-line LCD
Charging capacity:	Simultaneous charging of up to 8 batteries
Maximum charging current:	5 A per terminal
System voltage:	24 V PV Module/12 V Battery
Recommended module power:	200 - 1000 Wp
Input voltage range:	0 - 50 V
Battery nominal voltage:	12 V
End of charge voltage (float):	13.8 V
Boost charge voltage:	14.7 V
Dimensions:	365 x 227 x 75 mm
Weight:	2 kg

3.3.2 The Photovoltaic Panels

The standard configuration of the Sunlabob Lantern Rental System uses HBM(120)14866p PV modules from Beijing Hope. This 240 Wp system consists of two PV modules in series (with a maximum voltage of 17V rated at 120 Wp each). This is also what was used in this study.

3.4 Financial Setup

The financial setup used in most of the battery lantern systems involves a financial contribution, generally from an NGO. The investment goes to the donation of a number of battery lanterns to a village energy committee. A village technician is trained by Sunlabob to handle the charging administration of the lanterns. The technician rents the lanterns from the energy committee. Sunlabob provides the rental station which is also rented by the village technician. The revenue of the village energy committee is reinvested in the system in any way the committee sees fit. This could be equipment such as more lanterns or expansion of the charging station. The rental charges for the lanterns as well as for the charging station, is based on the amount of light hours sold. Thus, both the village energy committee and Sunlabob have incentives to make sure that the system is constantly up and running and that service and spare parts are readily available.

In the test in Ban Tha Hua, the village head took care of the administration and charging of the lanterns as well as the payments from the villagers and to Sunlabob.

In some cases Private Public Partnerships (PPPs) have been established. Private investors will, together with Sunlabob, own the charging station and take part of the revenue from the rental. The public donors will donate the lanterns to the village energy committee. The typical financial setup is illustrated in *Appendix 3, Illustration of Typical Financial Setup*.

4. Results

4.1 Field Trip 1, Initiation of the Study

The main purpose of the first trip to Ban Tha Hua was to install the charging station and introduce the battery lanterns to the villagers. However, a quantitative survey was also conducted in order to determine ability and willingness to pay as well as to get an idea of the current usage patterns of light. A focus group of 15 households was chosen in cooperation with the Head of the village.

The question of how much the villagers are willing to pay for electric light seemed difficult to answer since it forced the interviewee to come up with an amount off the top of the head rather than calculate their current expenses. The results of the survey show that, in many cases, the current expenses for lighting far exceed the WTP for electric lighting. See *Figure 3* below. Since the current expenses will be replaced by expenses for electric light, hereon the current expenses will be considered rather than WTP.

The main sources of light being used in Ban Tha Hua at the moment are simple kerosene lamps, see *Image 2* on the right. Four of the households also have electric lighting powered by tractor batteries. The fuel used for the kerosene lamps is mainly diesel since this is cheaper than any other usable fuel. However, the toxicity of the diesel fumes makes it a very dangerous solution. The smoke from the lamps and its poor quality of light are the main problems associated with the kerosene lamps. The risk of fires appeared to be a minor problem. 53% of the focus group had experienced accidents with kerosene lamps, but only in the form of minor burns or spillage.

Image 2. Typical Kerosene Lamp

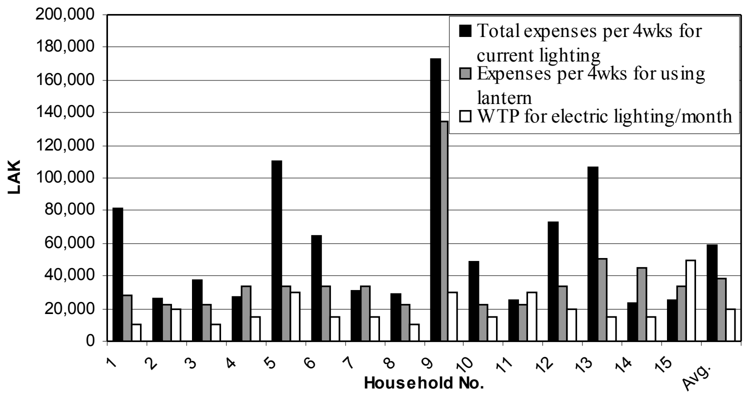

Figure. 3. Current Expenses for Lighting.

The results shown in *Figure 3* above are based on the results of the initial survey. The data series 'Total expenses per 4 wks for current lighting' includes all costs associated with usage of one kerosene lamp, *i.e.* lighting devices, fuel and lamp replacements. It does not take into account the expenses or loss of income during the time spent traveling to the place of purchase. The data series 'Expenses per 4 wks for using lantern' has been calculated to illustrate the cost of using the battery lantern for the amount of time as the earlier light source was declared to be used in the survey. 'WTP for electric lighting/month' displays the answers to the question 'How much would you be willing to pay each month for electric lighting?'

All costs have been converted to the equivalent cost for one year (365 days) and then recalculated to give the cost for 4 weeks (28 days) in order to better fit the time frame of the field test.

Most of the households of the focus group had more than one kerosene lamp, but none said that they use multiple lamps simultaneously. Hence, all costs associated with the kerosene lamps have been considered when comparing to using one lantern. If they have multiple lamps and have said that the rate of change is *e.g.* 3 months, this has been interpreted as if they change 1 lamp every 3 months. A small fraction of the households had electric lighting with a tractor battery as a power source. In those cases, costs for the electric lighting has not been included in the comparison since the lantern, most likely, will not serve as a replacement.

4.2 Field Trip 2, Evaluation

After six weeks of usage, the battery lantern was evaluated. This was done in two ways, interviews and observations in the village as well as technical evaluation of the used lanterns. The interviews were done in order to get ideas on how the design and functionality of the lantern can be changed in order to better accommodate the wishes of the users while the purpose of the technical evaluation was to identify any immediate quality issues with the parts or assembly procedures of the lantern. Interviews were done individually as well as in small groups of two or three respondents. The interviews consisted of a quantitative part, focusing on expenses for the battery lantern and for other means of lighting as well as a more qualitative part where the interviewees were asked to show and describe how they normally use the lanterns as well as any particular likes and dislikes. Together with observations made by the interviewers, the results of the survey provided evidence of similar usage and wishes of improvement from a large portion of the focus group.

For the second survey, the focus group was chosen so that all of the 15 interviewees had been using the battery lantern. Hence, the focus group of the second survey was not entirely the same as that of the first. Some of the members of the first focus group were not available for interviews during the second visit to Ban Tha Hua, adding to the difference in focus groups. Nine households participated in both surveys.

During the period of use, the administrator of the lanterns kept close records of the rentals. The records were used to determine usage patterns such as number of days used by a family to discharge the lantern and the rate of usage, giving indications on the affordability of the lanterns.

4.2.1 Results of Quantitative Survey

The quantitative part of the survey was designed so that it would give indications to the affordability and appreciation of the lantern. Five of the questions had strict Yes/No answers, the compiled results of which are displayed in *Table 5* below.

Table 5. Quantification of Yes/No questions

Question During the last month, have you been using…	**No. answering 'yes'**	**%**
the battery lantern?	**15**	**100**
the battery lantern outside?	**3**	**20**
other lamps?	**15**	**100**
other lamps outside?	**4**	**27**
the battery lantern and other lamps simultaneously?	**11**	**73**

Out of the three interviewees saying that they had been using the lantern outside, two had been using it in their shop and the third had been using it while using the toilet. On the other hand, the four using 'other lamps outside' were using torches for hunting or finding their animals in the evening, *i.e.* none of the members of the focus group was using the battery lantern as a mobile light.

Among the nine households participating in both surveys, the use of the lamps could be compared individually for each household. This gave an idea of how they use the battery lantern compared to how they used their earlier source of light as well as how they complement or replace each other. See *Figure 4* below.

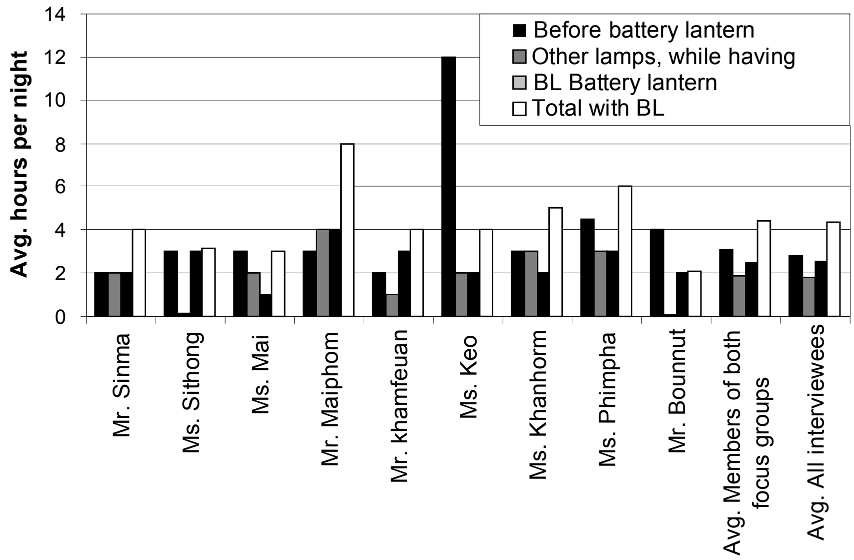

Fig. 4. Average nightly use of lighting.

During the first survey, Ms. Keo had a lamp on during the whole night because she had an infant. This was no longer the case during the second survey, hence the large difference in use of light. In order to make the averages more accurately display the impact of the battery lantern, her values have been exempt.

The results shown in *Figure 4* show that, to most users, the battery lantern serves as a complement to their previous source of light rather than a replacement. The data series 'Total with BL' shows the total amount of light hours used after the battery lanterns were introduced, in average, per night, i.e. the total of the two preceding data series. It shows that for many participants, there has been significant increase in used light, e.g. for Mr. Sinma who had his lights turned on during the same amount of hours, but used a kerosene lamp and a battery lantern simultaneously. This may be a temporary effect while the villagers get used to the new lantern while phasing out the kerosene lamps, but it also indicates quite a high level of affordability since the villagers seem to be able to afford using both the kerosene lamps and the battery lantern.

The bookkeeping done by the village head shows an average of 7.81 days between charges. Considering that 14 of the 15 participants said that they used the lantern every night and with an approximate discharge time of 15 hours, this means that the average nightly use is 1.93 hours. The average of the nightly use stated by the participants in the survey was 2.54. The difference could be explained by the possibility that the villagers *generally* use the lantern every night except when they have not been able to use one because of the limitations in numbers and charging possibilities such as overcast weather.

4.2.2 Results of Qualitative Survey

The second part of each interview was of a more qualitative nature. The participants were asked to describe and show how they used the battery lantern as well as what they particularly liked or disliked about it. In many interviews several members of the family participated in this part and in two cases neighbors were involved, resulting in little group discussions that helped trigger criticism as well as praise for the lanterns. Topics that came up included aesthetical design, social and financial implications as well as wishes for added or altered technical features. When it came to complaints, some of the participants mentioned some technical issues. This will be reported and commented below under *3.2.3 Results of Technical Evaluation.* The topics that came up were repeated in many of the interviews. A quantification of this is displayed *in Table 6* below.

Table 6. Quantification of Generated Issues

Generated Issues	No. of Yes	%
Feels rental should be cheaper	**7**	**47%**
Says must shake lantern to get it to work	**2**	**13%**
Says lantern "failed to work"	**6**	**40%**
Wants wider spreading of light	**10**	**67%**
Rents 2 lanterns for more light	**2**	**13%**
Thinks they have "ownership" of a specific lantern	**6**	**40%**
Waits for charge (instead of taking a different lantern)	**4**	**27%**
Feels lantern is too bright	**2**	**13%**
Feels lantern brightness is advantage	**4**	**27%**
Feels body of lantern should look different	**1**	**7%**
Wants indication of battery expiration / time elapsed	**3**	**20%**
Feels lantern is too heavy / big	**3**	**20%**
Feels cleanliness is main advantage	**5**	**33%**

1. Financial Issues

Seven of the 15 participants mentioned the expense of use as one of their major dislikes about the battery lantern. It was often one of the first issues that came to mind. However, all but one of the participants, number 11, still used the lantern every night. Two participants used two lanterns regularly, one of them, participant number 14, still complained about the cost. While a number of the interviewees mentioned cost as an issue, only one said that it impacts whether they rent a lantern or not. Considering that only one of the participants use the lantern sporadically, because of lack of funding, the use of the lantern must be considered affordable. A point that is important to make here is that only households that had been using the battery lantern were chosen for the second focus group. Hence, the possibility that the cost was a prevalent reason for other villagers not to use it should be considered.

It is also important to note that, in general, customers for all types of purchased products and services have an issue with cost and it is generally complained about in all types of product research (Jordan, 2008). For a product like the battery lantern, cost may only be a real issue to the customers to whom it becomes prohibitive.

2. Ownership

Some of the interviewees had adopted a battery lantern as if it belonged to them. Participant 14 had even placed a sticker on the lantern he was using in order to be able to identify it, see *Image 3 on the right*. When they returned the lantern for charging, they would wait for it to get charged rather than getting one that is already charged. It also gives way to the possibility that if someone with a discharged lantern would wait to recharge it until they can afford it, limiting the availability of lanterns to other villagers. This conflicts with the intended business model where the lanterns are a communal asset and rented and returned with a higher frequency. This has a negative impact on the efficiency of the system. However, it may be a result of the low availability of lanterns, only 20 lanterns were used in a village of 49 households. This would not be the case in a real scenario.

Image 3. Sticker on Lantern

Actual implementations in Uganda have shown the same behavior and have caused problems in the form of rivalry in the villages. This has caused problems for the village technicians who have been accused of giving privilege to certain villagers by choosing who may or may not use the lanterns (Disanayake, 2008).

The village head of Ban Tha Hua was asked if he had experienced any such problems and the answer was no, which could have many explanations. Since the villagers show great respect towards the village head, they may not show any disappointments towards him. Other cultural differences may also cause different behaviors.

3. Direction of Light

Image 4. Direction of light

Eleven of the participants felt that the lanterns should be able to cast a 360° of light as opposed to the current 180°. This would give a larger spread of the light regardless of whether the lantern is used hanging from the ceiling, standing on the floor or carried while walking. One participant wanted to be able to illuminate two rooms with one lantern by placing it in the doorway between the rooms see *Image 4* Suggestions for the accomplishment of this included placing the bulb on the top of the lantern or placing another bulb on its back.

Both of these suggested approaches have challenges, a bulb on top of the lantern would be difficult to protect and an added bulb would have implications on cost and battery life. The point should still be considered in the development of future versions of the lantern.

4. Prevalence of Indoor Use

As mentioned under *3.2.1 Results of Quantitative Survey*, only 3 of the users actually used it outside of their homes and those who did used it in a stationary fashion. The most portable application was by participant number 3 who brings it to the toilet. Most interviewees also said that they took care not to let children or animals near the lantern.

If the robustness of the lantern were to be less prioritized, changes in design could possibly reduce manufacturing and component costs. It could also make it easier to make changes so complying with the wishes of a 360° spread of light as mentioned above.

Most participants who said that they used other lamps outside were using little torches or headlamps. Some of them indicated that the size and weight of the battery lantern prevented them from using it outside. Thus, if the portability of the lantern is of large importance in the marketing, efforts should be made to reduce size and weight.

5. Lantern and Charge Reliability

Seven of the participants, including the village head, mentioned having come across lanterns that in one way or other had 'failed'. Two of these mentioned having to shake the lantern after turning it on to get it to work, more about this under *3.2.3 Results of Technical Evaluation.* The others represent the ones that had to return the broken lanterns as well as a few that mentioned a slight delay, one or two seconds, before the lamp came on after flicking the switch. One participant, number 14, said that he has measured the discharge time and has found that it had decreased towards the end of the test. It had been closer to 13 hours than 15 which he was paying for. Participant number 13 said that, a few times, he had brought home lanterns that had only worked for one or two hours.

The problems concerning discharge time may be caused by incomplete charging but also by failing batteries. This issue is discussed further under *3.2.3 Results of Technical Evaluation* below. Having to wait for a second or two did not seem to be considered a big issue, but having to shake the lantern before it worked or getting a lantern that did not work for more than a few hours seemed to have caused significant frustration.

4.2.3 Results of Technical Evaluation

Upon return to Vientiane, the 20 lantern were evaluated in order to identify any immediate quality issues. For most possible quality issues, such as battery life and wire connections, the six weeks of the test is quite a short time, but it still revealed some interesting results. During the first visit to Ban Tha Hua, one of the lanterns, number 8, stopped working after only a few hours of use during the first night and upon arrival for the second visit, it was revealed that another five lanterns had broken down.

During the course of the test, a more sophisticated discharge controller was developed. Hence, any quality issues with the ones used in the test were not further investigated. Functional issues were included since they may be applicable to the new discharge controller as well.

The batteries used in the lanterns had been in storage for up to a year. They had been charged regularly to avoid decrease in capacity, but the possibility of minor variations in capacity is high.

4.2.3.1 Broken Lanterns

Lantern number 8 was not included in any further testing since the failing component had been determined. The cause for the failing lamp was not possible to determine so it was discarded as a bad sample of the product. However, it could not be identified as an immediate quality issue since only one in 20 broke.

Nineteen lanterns were left to be evaluated. The five that had been reported as broken, could not be charged as they were either reported as having defective batteries or not acknowledged by the charge controller. The remaining 14 lanterns were charged and then discharged in order to determine any change in battery capacity.

Lanterns numbered 3, 4, 13, 14 and 20, the broken ones, were opened and inspected for any obvious faults. Number 3 and 14 had blown fuses which meant that the batteries, in effect, were disconnected and thus they were not recognized by the charge controller. Numbers 4, 13 and 20 were reported by the charge controller to have defective batteries. All of the defective lanterns, except number 3, had been discharged to voltages far below the disconnect voltages as shown in *Table 7* below. The "Remark on charge" is the message delivered on the display of the BCU upon connection.

Table 7. Defective Lanterns

Lantern #	Remark on charge	Terminal Voltage (V)	Diagnos is
3	Not acknowledged	11,6	Blown fus e
4	Batt_Def.C	5,2	Defective battery
8			Broken lamp
13	Batt_Def.C	5,5	Defective battery
14	Not acknowledged	4,6	Blown fus e
20	"Overcurrent GND, Dis connect all"	8,7	Def. dis charge controller

After having passed the disconnect voltage of 11.5V, the Solara and the Steca discharge controllers have self consumptions of 5.4mA and 4.5mA respectively. The 4mA self consumption declared in the Solara product specifications is true when the battery voltage is above 11.5V. Below 11.5V, an LED is turned on to warn about low battery voltage, causing the increased consumption. The Steca discharge controller maintains a 4.5mA current whether the voltage is above or below the disconnect voltage.

The two lanterns with blown fuses, numbers 3 and 14, showed large differences in voltage. Number 3, whose fuse blew more than a month earlier than number 14, had a battery terminal voltage of 11.6V while that of number 14 was 4.6V. The fact that number 3 was used for only one day indicates that its battery was at a high state of charge when the fuse blew. Thus, it has not been discharged to as low a voltage as number 14 which had been used for four days when it was returned. The last user of number 14, Mr Thao Seuth, discharged the lanterns at an average rate of four days, backing up the assumption that it was close to the disconnect voltage when the fuse blew.

On the discharge controller of each lantern, is a 10A fuse. At 12V, that means that a power output of 120W would be necessary to blow the fuse. In order to cause such a current surge, the user must have either connected a large appliance to or short-circuited the power outlet. Considering that Ban Tha Hua, does not have electricity at a higher voltage than 12V, it is most unlikely that appliances of such power would be available in the village. It could also be a case of fuses of poor quality. However difficult it may be to determine the cause for the problem, it should be considered in the future development of the lantern.

The discharge of 4W during 15 hours corresponds to 5Ah which means that at the point of disconnection, the depth of discharge (DOD) of the battery is close to 67%. The rate of the voltage drop of a discharging battery increases with the DOD (Perez, 1993). Hence it appears possible that, over a few weeks, the current drawn by the discharge controller may cause the battery terminal voltage to drop as much as it did in this study.

After discharge, for the good of the battery, it should be recharged as soon as possible to avoid sulphation. An AGM battery that is left discharged for a period of more than two weeks will permanently reduce the battery's capacity and lifetime (Wood, 2008).

According to the charge controller manual, the message 'Batt_Def.C' indicates a defective battery or that a battery with the wrong terminal voltage is connected. It is likely that the low terminal voltages of these batteries caused the charge controller to believe that this was the case.

4.2.3.2 Working Lanterns

The 14 lanterns that were still working upon retrieval from Ban Tha Hua were charged and then discharged to determine the battery capacity. After discharge, the terminal voltages of the batteries were measured and any apparent abnormalities were further evaluated.

The discharge times, as well as the terminal voltages of the batteries at disconnection, varied largely between the different battery lanterns. The two possible causes for these variations were identified as differing battery capacity and erratic behaviour from the discharge controller concerning the disconnect voltages. A second test with different batteries showed that each discharge controller was consistent but the disconnect voltage varied between the different controllers. This implied that the main reason for the difference in discharge time is due to the discharge controllers behaving differently. The relationship between state of charge (SOC) and voltage is complicated and charts are not available for AGMs but they follow the same patterns as regular lead acid batteries (Perez, 1993) and can be approximated with a logarithmic curve. This is shown in *Figure 5* below. The results follow the curve quite well, adding to the conclusion that the discharge controllers can be blamed for most of the difference. The maximum diversion from the logarithmic function is of 0.1V or 5.8% of the voltage drop, corresponding to 0.72Ah or 2 hours and 9 min of lantern use at 4W. This error was allocated to differing battery capacities possibly caused by differing charging routines during storage.

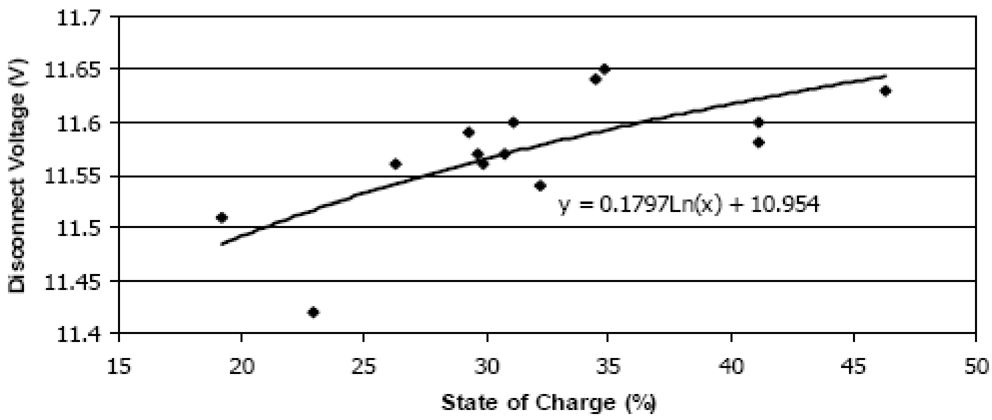

Figure 5. Disconnect Voltage Vs. State of Charge

Apart from the discharge time, a significant issue was that three lanterns, numbers 4, 16 and 19, had loose lamp socket connections. In section *4.2.1 Results of Qualitative Survey*, above, it was mentioned that two of the participants had experienced having to shake the lantern to get it to work. On lanterns number 4 and 16, which were used by those two households, as well as on lantern number 19 a loose connection was discovered during the evaluation. Hence, the shake problem was allocated to the loose lamp socket connection.

4.2.3.3 Minor issues

Two issues that do not directly affect lantern performance, but should still be mentioned, are broken screws and lost rubber feet. Two rubber feet had come off the same lantern. Most likely, one of them came off due to improper gluing and the other one was deliberately removed to allow the lantern to stand steadily. The PVC box is assembled with four plastic screws. A total of 10 screws were broken, distributed over seven lanterns. Many of the screws appeared to break while being unscrewed. This is a problem that was known earlier and now confirmed.

4.3 Alternative Technologies

As mentioned under section *2 Theory*, A few different technologies regarding batteries and light could be used in an application like this. Lamps and batteries can be combined in different ways, but the advantages and drawbacks of each technology make it difficult to determine which combination is preferable in any given situation. This section will briefly present a few options that may be valuable to conduct further research on. It should be noted that the variables of this section are based on general figures (Whitaker, 2005) and may differ from the actual figures of the components available on the market.

4.3.1 Current CFL lamp and Other Batteries

The AGM battery that is currently used in the lantern has many advantages but the comparison with other battery types should certainly be made.

The NiMH battery has many advantages. It contains no heavy metals and is hence more environmentally friendly, its energy density is about 2.5 times that of an SLA and its cycle life is roughly double that of an SLA. However, it is a lot more expensive and the price of the components is, as always, a very important factor.

A NiCd battery compares very well to a NiMH in most ways. The only real drawback is its contents of the heavy metal cadmium. It is also considerably cheaper, per cycle, than an SLA. Its long cycle life (up to 5 times that of an SLA) makes the actual battery more expensive however. If a 10 cell NiCd battery pack were used, the weight of the battery pack would be approximately 3/5 of the current or 1.5kg, *i.e.*1kg lighter. Its ability to cope well with deep discharge is also a significant advantage as it could eliminate the need for a discharge controller.

4.3.2 LEDs

The currently available LEDs are considerably more expensive than CFLs. Another issue with white LEDs is their cold light which is considered less comfortable to the eye than that of a CFL (Crawley, Holland & Gitonga, 2000). However, the two main advantages of LEDs; their low power consumption and long life time, make them interesting and as research progresses they should definitely not be forgotten as a good alternative. However, the LEDs commercially available today are not interesting for an application like this.

4.4 Combined Results

This study incorporated a few different types of research. Hence, it is when combining the results of the different parts of the study that many of the significant issues and solutions may be discovered. This will be done in this section.

The quantitative surveys of both field trips have shown that the battery lantern, at the price used in the study, is affordable to most villagers. Many participants in the second survey complained about the price being too high, but considering that they were still using it happily, this was largely perceived as an effect of the idea that most consumers would like to pay less, no matter the product. The same applies to the low WTP for electric lighting displayed in *Figure 3*.

One of the main points of the qualitative survey was that the battery lanterns, generally, were very well cared for considering that they were used as a stationary light rather than a portable one and a large portion of the respondents mentioned making sure that no animals or children came close to it. This implies that the toughness of the lantern may not be as important as it has been considered in the design of the current version. Hence, the accommodation of the frequent wish of a wider spread of light from the lantern may not be as difficult as was earlier believed.

Minor modifications of the current assembly process would allow the lamp to be place on the top of the lantern, allowing it to spread light in 360°. This would make the lamp more exposed to force that may break it, but considering the care taken for the lanterns in Ban Tha Hua, it may be a minor problem. A strap should also be added at the bottom, allowing the lantern to hang upside down. The lantern with the lamp protruding from the top could be added to the product line as a complement to the current lantern and be used where pilot studies show that it is more suitable.

In the current business model, the lanterns are owned communally by the villagers via a local trust fund. Hence, deciding who is responsible, and should pay for, any broken parts becomes a problem. If the lamp were to protrude from the top it would be the most vulnerable part of the lantern but it would generally break in accidents or due to carelessness by the user. If the lamps were sold separately and the lanterns used as a battery pack with a lamp socket on the top, the issue with broken lamps would be solved.

In the current business model, the villagers are meant to return the battery lantern when it is discharged and, if they want to, get another one that is charged. The results from this study show that the villagers are prone to claim a form of ownership of a lantern and wait for the charging of the lantern they returned in order to be able to continue using that same one. This is a potential problem considering the possibility of a villager keeping the discharged lantern until he/she can afford the charging fee. Combining this possibility with the current drawn by the discharge controller when the lantern is turned on implies possible regular deep discharges of the batteries which would reduce their lifetime significantly. The new discharge controller will have a stand-by current as well, so some clear instructions to the villagers will be most necessary. The village technician should be instructed to charge the returned lanterns as soon as possible as well as to keep the ones not being used charged. A possibility may be to limit the time within which the power should be used and if it is not, it must still be returned when the time is up.

5. Caveats

5.1 Sources of Error

Many problems may occur while conducting research in rural areas of developing countries. Concepts such as time and money may have completely different meanings to the people who follow the hours of the sun rather than the hands of the clock. Hence, a question such as ‘How much do you spend on diesel every week?’ may be completely useless unless you are able to rephrase the question into a context understandable to the respondent. Therefore, the abilities and level of experience of the translator are very important. Apart from simply translating the questions and answers, he/she also has to make sure that the respondents understand the questions (Henschel, 2008).

The way the villagers manage their money is also very different to how it is normally done in the industrialized world. They normally do not conduct any form of accounting and all of the respondents have said that their income each month is larger than their expenses, as many as seven of the 15 interviewees have said that they spend less than 50% of their income. Another difficulty is the fact that, being farmers and shopkeepers, they have a continuous income rather than receiving a paycheck every week or month. Hence, it is quite likely that as long as they have money left, they will keep spending without keeping track of the amounts they spend. Such issues may result in quite large uncertainties in the collected data.

The first survey of this study shows some very substantial evidence of this problem. The respondents buy their fuel either in a shop in the village or at a gas station in a nearby village. Despite this, the result of combining the questions regarding the expenses for fuel to calculate a resulting price of fuel show substantial differences. See *Figure 5* below. However, the graph also shows that the majority of the respondents spend in the order of LAK15,000 per liter. This seems quite reasonable considering that the price in the village shops was LAK14,000 and in the larger towns around LAK10,000.

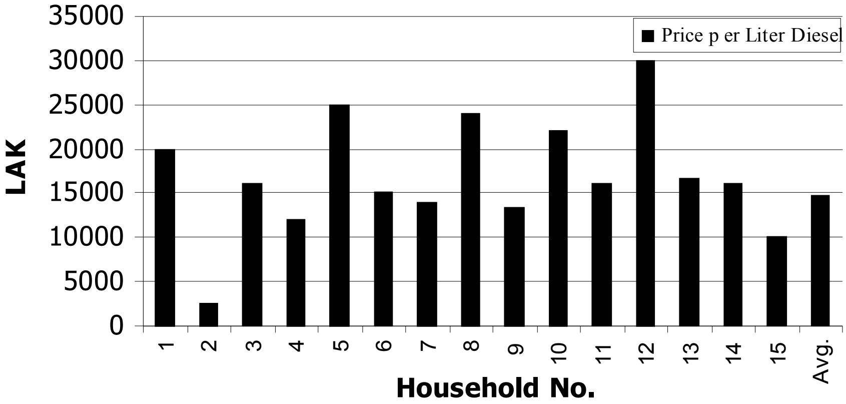

Figure 5. Declared Price of Diesel

Apart from the issues associated with the question whether the responses are accurate or not, the language barrier can be a substantial issue. The understanding of the translator is essential in order to get any kind of usable results (Bulmer & Warwick, 1993). Problems may occur when dealing with words that are similar but have very different meaning. During the first field trip of this study, one of the objectives was to determine the usage patterns of light. Hence, one of the questions was 'Do you use your lamp during the night?' This was interpreted by the translator as '…during the evening?' and the obvious answer for all of the respondents was 'Yes', rendering the question quite useless.

Apart from the issues of the interviews, there are always certain inaccuracies in the technical equipment used in the testing. The multi meters used had an accuracy of 0.01V, allowing a certain error.

5.2 Local Variations

The Sunlabob battery lantern is expected to be used in developing countries around the world and the wishes of the villagers of Uganda may be very different to those of Afghanistan. Hence, it is important to remember that the results of this pilot study are representative of the surveyed area only. The usage patterns discovered during the surveys may or may not be applicable for other areas, *e.g.* due to cultural or economical differences. The clear prevalence of indoor use and care taken for the lanterns may for example not be the case in other countries and would mean that any thoughts of making the lantern less durable should be avoided.

It is also possible that elements such as the way the village head was managing the lanterns or the way that the lanterns were introduced to the villagers have impacted the perception of the product and the feedback given by the users.

6. Recommendations

Based on the results of this study a few clear recommendations could be made to improve the future versions of the Sunlabob Battery Lantern, both in terms of design of the lantern and the assembly procedure but also in terms of the business model. This section will briefly cover the recommendations.

6.1 Quality

Regarding the quality of the lantern, two issues require further attention. 15% of the lanterns had loose connections between the lamp sockets and the cables, causing the lamp to flicker and sometimes requiring shaking in order to turn it on. In the current assembly, the wires are connected to the socket using the screws fitted on the socket. The connection would be significantly improved if they were soldered as well.

On a large portion of the lanterns, 35%, one or more of the plastic screws attaching the top of the PVC box to the bottom were broken. This would be avoided if the plastic screws were replaced with metal ones. This issue was already known and is under consideration.

6.2 Design

Many of the respondents in the second survey, 67%, wanted a wider spread of light in order to be able to illuminate a larger area. This could be accomplished by placing the lamp on the top of the lantern. The main drawback of this would be that the lamp would be exposed to external force if the lantern was dropped or fell over. The impression of the observations made in Ban Tha Hua is that the users were very careful with the lanterns, not allowing children or animals to get close, greatly reducing the problem of exposure.

The recommendation in this field is to add a version of the lantern, where the lamp is protruding from the top of the lantern, to the product line. Such a model could be made with the material currently used and the assembly would not be more complicated than with the current model. Based on pilot studies in each area it could be determined which lantern is more appropriate.

6.3 Business model

In the current business model, the lanterns are owned communally by the villagers in a village energy fund. With the increased exposure of the lamp in the version recommended above, broken lamps could potentially be a problem. Most lamps would break due to carelessness of the user, so logically, the user should also pay for the replacement. If the villagers would own the lamps and rent the lantern as a battery pack with a socket on the top, it would be obvious that any broken lamps would have to be paid for by the user. It would also increase the care taken about the lanterns.

The stand-by current of the discharge controller could cause deep discharge of the battery, reducing its lifetime if not recharged within a period of days. This effect could be limited by limiting the time within which the power should be used and if it is not, the lantern must still be returned on the last day of the time limit. This model obviously has its drawbacks in terms of the perception of the lantern and before it is implemented, focus should be on decreasing the stand-by current.

6.5 Further Research

Many of the quality issues discovered during in this thesis have been allocated to problems with the discharge controller which will not be used in the future. However, some of the issues, especially that of the stand-by current should be researched further.

Further evaluations of the lantern should be done after longer periods of use. It is possible that additional quality issues would be revealed and capacity testing of the batteries would show whether or not the usage patterns are causing excessive damage.

Regarding the further development of the lantern, the progress of the research on LEDs should be monitored. As the they develop, it is likely that prices will drop enough to make it viable to design an LED lantern.

7. Conclusions

The Sunlabob battery lantern, with the current business model, has gained acknowledgement in large parts of the developing community around the world. The business model allows for greater sustainability as the manufacturer gets incentives to ensure the continued use of the lantern. The idea of being able to provide electric light to rural areas at costs lower than that of the current lighting with fossil fuels is very well perceived by NGOs and development agencies.

The battery lantern is in its early stages of development and before this study, feedback from the user had not been collected. Hence, the evaluation of the lantern from a user perspective could help point the developing work in the right direction. This was the objective of this study.

A successful field study has shown that, in general, the villagers are very happy about the Sunlabob battery lantern. This may seem quite obvious considering the pollution and poor quality of light that was obtained from the kerosene lamps generally used earlier. However, many of the villagers had found that the lantern could be improved and provided some valuable feedback.

Apart from the surveys, the technical evaluation revealed issues that were mainly allocated to the discharge controller. Some of these issues are important to consider in the development of the new controller. They also implied that some changes in the business model should be made in order to protect the batteries from deep discharge.

Only minor changes in the assembly process would allow the addition of a lantern that would spread light in 360°. This would accommodate one of the main wishes of the users. It would make the actual lamp more exposed to force, but this problem could be minimized by a minor change of the business model.

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Appendix 1. Questionnaire #1 Ban Tha Hua September 2008

1 - How many people live in this household?
2 - How many children live in this household?
3 - What economical activities do the members of the family have?
4 - How much Kip do you get each month thanks to these activities?
5 - Do other persons send you kip each month?
6 - How much kip do you spend in total each month?
7 - How much do you spend especially for energy?
8 - How many rooms do you have in the household?
9 - Do you use diesel/kerosene/gasoline for something else than lighting in the village?
10 - For what kind of others uses than lighting do you use diesel/kerosene/gasoline?
11 - Do you use a special storage of diesel/kerosene/gasoline for your means of lighting?
12 - How often do you fill the storage used for lighting?
13 - What is the total quantity of diesel/kerosene/gasoline you get every week?
14 - What is the quantity of diesel/kerosene/gasoline you get every week only for lighting?
15 - How much do you pay for diesel/kerosene/gasoline every week?
16 - Do you buy more diesel/kerosene/gasoline than 1 year ago? How much more?
17 - Do you buy more diesel/kerosene/gasoline than 5 years ago? How much more?
18 - How much did you pay for diesel/kerosene/gasoline one year ago?
19 - How much did you pay for diesel/kerosene/gasoline 5 years ago?
20 - Does someone go to get diesel/kerosene/gasoline for you?
21 - How much do you pay him?
22 - Where are the different places you get diesel/kerosene/gasoline?
23 - What is the distance to your different providers?
24 - Which mean of transport do you use to reach your diesel/kerosene/gasoline supplier? How long does it take?
25 - What difficulties do you have to get diesel/kerosene/gasoline?
26 - Have you had any accidents with the storage of diesel/kerosene/gasoline?
27 - What are the things you dislike more with your current mean of lighting?
28 - Could you show us the entire means of lighting you are using?

- Notes taken on number of lamps, rate of change, maintenance and costs

29 - What are the related devices of the means of lighting (match boxes, wick, diesel/kerosene/gasoline storage…)?

- Notes taken on rate of change and costs

30 – Which mean of lighting you prefer? Why?
31 - Which one do you use more?
32 - Do you use all your lamps every day?
33 - Do you use different lamps at the same time?
34 - Where do you use each mean of lighting you have?
35 - What do you do when you use light inside your household?
36 - At what time do you light each lamp?
37 - When do you stop it?
38 - Do you use your lamps during the night?
39 - Do you use lights outside your home?
40 – To do what?
41 - Do you wait until the lamp is empty before refilling it with diesel/kerosene/gasoline?
42 - How often do you fill the lamp with diesel/kerosene/gasoline?
44 - Do you have any electrical devices in your household?
45 - Does anyone in this household have asthma problems or respiratory problems?
46 - Does anyone in this household have problems with their eyes?
48 - How much would you like to pay for electrical lighting every month?

Appendix 2. Questionnaire #2 Ban Tha Hua, November 2008

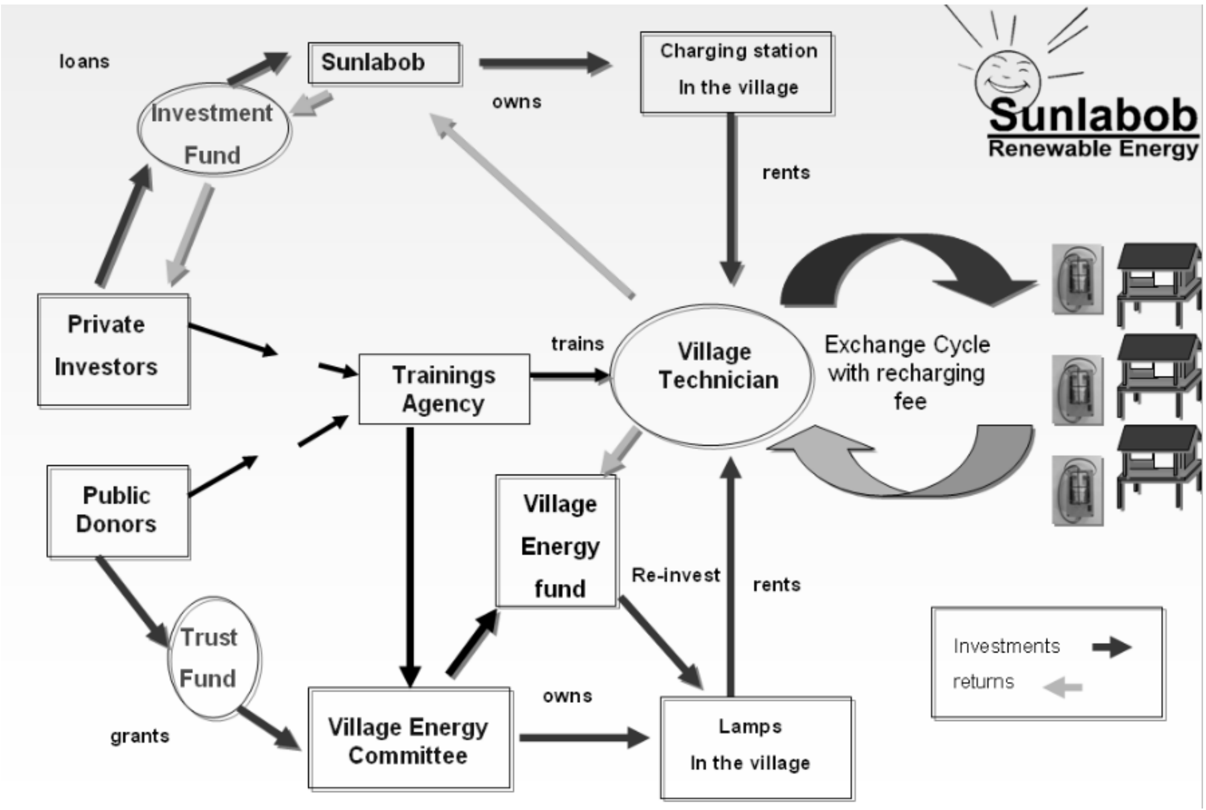
Quantitative Part

1 - How many people live in this household?
2 - How many children?
3 - What sources of income does the family have?
4 - Have you been using the battery lantern during the last month?
5 - To do what?
6 - How often?
7 - At what time have you been turning it on/off?
8 - Have you been using it outside of your home?
9 - Have you been using other lamps during the last month?
10 - What kind?
11 - To do what?
12 - How often?
13 - At what time have you been lighting it/blowing it out?
14 - Have you been using it outside of your home?
15 - Where do you buy diesel?
16 - How much diesel have you used for lighting during the last month?
17 - How much Kip have you spent on diesel during the last month?
18 - How much Kip have you spent on using the battery lantern?
19 - Have you been using the battery lantern and other sources of light at the same time?
20 - To do what?

Qualitative Part

21 - What do you like about the battery lantern?
22 - What do you dislike about the battery lantern?
23 - Have you had any problems with the battery lantern?
24 - Have you ever wanted to use a lantern but none was available?
25 - What is the main difference between using the lantern and using kerosene lamps?
26 - In the future, which mean of lighting would you rather use?
27 -Could you show us how you have been using the lamp?

Appendix 3. Illustration of Typical Financial Setup



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