STANDARDIZATION OF LIGHT-EMITTING DIODE FEEDBACK ON METERED SOLAR HOME SYSTEMS USED IN RIFT VALLEY, KENYA

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DECLARATION

Declaration

This research thesis is my original work and has not been presented for a degree or any other award in any other University.

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Recommendation

We confirm that the work reported in this research thesis was carried out by the candidate under our supervision.

Signed: .... Date: ....

Name: Dr. Chao Mbogo

Signed: .... Date: ....

Name: Jenu John

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DEDICATION

This thesis is dedicated to my parent who has provided immense support and motivation up to this point of my life.

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This thesis would not have been possible without the immense support and assistance I have received from my supervisors Dr. Chao Mbogo and Jenu John. Their guidance and expertise have been instrumental in shaping up this research.

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ABSTRACT

Light-Emitting Diodes (LEDs) are used in a variety of devices ranging from watches to solar home systems, as status indicators or communicative tools. They are typically designed to produce light in different colors and intensities. However, the communicative output varies across devices of similar or different functions. This variation and the sense that there is a wide array of expressions that can be employed, makes it hard for users of the devices to deduce the feedback easily. This research aimed to highlight usability challenges associated with interaction with non-standardized LEDs on metered solar home systems and address this gap through a standardized light-based interface, redesigned using a structured Human Computer Interaction (HCI) design process. The study objectives were to compare different solar home systems and their LED feedback, highlight user understanding challenges resulting from their lack of standardization and compare if a system with standardized LED feedback, designed via a HCI framework, would resolve these challenges. UFuRT (User, Function, Representation and Task analyses) framework was used to evaluate the use of solar-home systems ethnographically and contextually among owners in Rift Valley, Kenya, a high performing sales region for solar home systems. The research adopted both qualitative and quantitative approach in a phased experimental research design. The target population was solar home system owners and a total of 153 owners participated in the study, all selected through convenience sampling. Data collection was done through guide questions administered through in-person interviews which had been content-validated and pilot-validated as a data quality control measure. Data collected was coded and grouped per research objective and then tabulated in a spreadsheet for descriptive analysis. The results obtained from 111 of the solar home system owners indicated that, on average, 51% of solar home system owners could not correctly interpret or did not know the LED feedback of the device they owned. The quantitative and qualitative data collected from the in-person sessions was used to design a simulated standardized interface of a metered solar home system. The effectiveness of this newly designed interface was measured by interviewing another set of 43 solar home system users. The results showed that, on average, up to 63% of solar home system owners correctly interpreted the LED feedback mechanisms of a standardized design**.** Further, up to 86% of solar home system owners correctly interpreted specific feedback mechanisms of a standardized design**.** With these findings, the research concludes that using a HCI framework to standardize the interface design of LED-touting devices increases the expressivity and user understanding of feedback relayed by these devices. Thus, manufacturers and industry governing bodies need to consider a universal vocabulary of light-based design that can be widely adopted to solve device usage challenges.

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ABBREVIATIONS AND ACRONYMS

HCI : Human Computer Interface

IoT : Internet of Things

LED : Light-Emitting Diode

PAYG : Pay-As-You-Go

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Many electronic devices employ small communication lights, called Light-Emitting Diodes, to relay feedback or state to users, for their action or awareness (Figure 1.1). These devices that incorporate feedback interfaces, have rapidly increased over the years (Pattison et al., 2018; Harisson et al., 2012), in various iconic forms. Some of these devices include digital watches, washing machines, desktop computers, smartphones, toasters and alarm systems, among others.

Figure 1.1

Small single-color lights in some electronic and computing devices

Note. Adapted from *Unlocking the expressivity of point lights (2012)*. (https://doi.org/10.1145/2207676.2208296). Copyright 2012 by Harrison et., al 2012.

From the discovery of electroluminescence in 1907 all the way to the launch of the first LED lighting product in 1963 (Margolin & Schockley, 2004), there was a general sense that this technology would be revolutionary and this was affirmed in the last decade (Mills, 2008). It is said that LEDs powered by Internet of Things (IoT) are expected to save cost of electricity by about $20 billion per year and significantly reduce carbon emissions (Nash & Beardsley, 2015). Gartner research also estimated that in 2020 everyone would be interacting with at least twenty IoT devices in their environment (Gartner Glossary, 2020; Liu 2017). Thus, LED devices are common in the world, including in Africa and Kenya.

One of the reasons for the widespread use of LED devices is due to LED lights' higher luminance efficacy. Properties such as visibility under direct sunlight and availability in various sizes, including dimensions of less than a centimeter, have led to widespread adoption (Liu, 2017). Consequently, these devices are also deployed in more mainstream applications such as ecological conscious lighting, lighting for human physiological responses, connected lighting and even horticultural lighting (Pattison et al., 2018). The overall objective of LED point lights on many devices is communicative, in that, the manufacturers aim to find ways of making their commodities simple and reliable without complication or expense (Heimgartner, 2014). Thus, design researchers advocate for small single-color light-emitting elements with variable intensity over time as being the best definition of simple (Harrison, 2014).

However, the proliferation and diversification of these devices (PEW Research Center, n.d.) into different molds and shapes has consequently resulted in a variety of lighting behaviors across different devices and designs (Bauman & Thomas, 2001; Pattison et al., 2018). This variation and the sense that there is a wide array of expressions that can be employed, makes it hard for users of the devices to easily deduce the feedback (Harrison, 2012). It has also been pointed out that such devices do not take full advantage of the possibilities of expressivity since most of them will just have blinking lights or even more basically, lights for statuses on and off (Liu et al., 2017). Considering that most devices are built with consideration for competing designs from different manufacturers (Ulrich & Pearson, 1998) it is easy to find varying lighting designs that effectively serve the same purpose, a good example being, a toaster. It is hard to convince a user whether a blinking light on a toaster refers to a toast that is cooking or done or even if the toaster itself is jammed. This means that the user needs to make the operation a habit before they can effectively determine what each light behavior means (Bauman & Thomas, 2001).

Other issues that stem from varying communicative feedback on LED interfaces include product lock-in and lack of interoperability. Product lock-in refers to product differentiation that is so divergent from similar devices to the extent that any user of either device cannot shift to using the alternative. This differentiation can be detrimental to user purchase decisions and opt-out freedom (Opara-Martins et al., 2016). In a study by Edmonds, it was noted that the lack of standard interfaces for data interchange could lead to integration difficulties and consequently less flexibility as users are stuck on legacy systems (Edmonds et al., 2012). Damghani and team emphasize that despite the lack of standardization for IoT devices causing interoperability or lack of correspondence between gadgets, the concealing of information by these devices will be an even bigger problem (Damghani et al., 2019). This means that these devices proprietary interface designs may be hard to dissect or comprehend and this could even affect more complex devices.

Interfaces that require memorization or repetition to grasp also makes for a cumbersome user experience, especially considering the number of LED-touting devices now available. Research suggests that for computer systems to continue to meet users’ continuously diversifying views, their general understanding needs to be reviewed and new ways of designing and making prototypes have to be explored (Harper & Yesilada, 2008). Similarly, it has been widely suggested that product design determines up to 80 percent of manufacturing cost (aPriori, 2017; Ullman, 1992). Therefore, the issues arising from non-standardized LED interfaces, coupled with the rising demand for these devices, present an opportunity for designing LED interfaces that combine best practices and user experiences towards standardizing such interfaces. This research aimed to address this need.

A case-specific example of LED-touting devices are small to medium sized technically enforced solar home systems, which have emerged as a sustainable lifeline for rural African communities who still lack access to grid power (Energy, 2014). According to Zahnd (2009) and the World Energy Outlook report, approximately 50% of rural populations in developing countries (approximately 850 million people) are living without grid electricity (IEA, 2019). Further, 80% of the people not served with grid electricity are those that occupy Sub-Saharan Africa and Rural Asia (Rolffs et al., 2014).

Indeed, most governments and international aid organizations have had to admit that installation of grid power in these areas, considered geographically remote and isolated regions, is a challenge. Therefore, to fast-track development and the achievement of Millennium Development Goals (MDGs), these governments, through the United Nations and grassroots organizations, have had to approve and start proactively promoting solar home systems as the most feasible and cost-effective alternative for rural electrification (Nieuwenhout, 2001; World Bank, 2020). For example, Lighting Africa began testing the quality and number of solar products in the African market in 2009 and in a period of three years, the number of products had increased almost 9-fold from eight to over 70 manufactured by 50 companies (Lighting Africa, 2010). As much as these products have increased, research shows that product quality affects technology adoption especially in emerging markets. A study carried out in Uganda showed that free trials and money back guarantee was key in increasing solar cook stove adoption (Levine et al., 2018). The reason was found to be that customers really value the opportunity to assess the product properly before committing to purchase. This research addressed this need by implementing user feedback at the center of the design process.

In addition to the quality of the product that affects the adoption of solar home systems, another big hurdle is their high initial cost (Urmee et al., 2009), which seems to have been countered by the advent of Pay-As-You-Go technology. This technology enables customers to pay over a period of time, at much lower costs than traditional microfinance (Scott & Miller, 2016). Even so, it necessitates that the systems have some form of technical enforcement and hence the need to include LEDs as a cost-effective feedback mechanism on the units (Tippenhauer et al., 2012). Since its emergence, LED remains the dominant lighting technology with significant increases in luminosity over the years to the point that by 2012, the lighting technology accounted for 97% market share (Africa, 2012).

The problem with the LED-based approach is that most users of these systems have had limited exposure to many of these iconographic devices for them to build an understanding of the different feedback mechanisms. In fact, multiple distributors of solar products have also bemoaned the difficulty they face with addressing customer complaints mostly because of communication difficulties and limited technical expertise (Stimulus, 2018). Low literacy levels, combined with the technicalities of the devices tend to necessitate agents to be sent to the field to address customer issues, which can be expensive and time-consuming, thus is unsustainable. Consequently, it has emerged that one of the factors that determine the purchase/adoption of solar home systems for example in rural Nicaragua, is the familiarity of the technology (Dahlke, 2013). This means that solving for the technical challenges of such systems will not only help current users/owners but also push for greater adoption of the solar systems in general. This study aimed to meet this need.

1.2 Statement of the Problem

In an ideal world, feedback from LEDs lights should be easily decipherable by users without needing additional iconography especially for device with peripheral constraints. From the background, it is evident that LEDs are highly useful for the effective adoption and utilization of low-cost consumer electronics. However, product diversification has not allowed for standardization of the feedback design. This has led to several different lighting feedback mechanisms on similar products such as solar home systems, leading to most consumers not being able to comprehend the various device feedbacks. The inability of consumers to understand feedback from these high utility home systems leads to user frustration, product returns, default in payment and sometimes customers reverting to non-renewable and pollutant sources of energy. Solving the technical understanding of such systems could potentially support current users and owners of these devices, and also push for greater adoption of the solar home systems in general.

1.3 Purpose of the Study

This study seeks to understand how solar home system users utilize LED light feedback, and if their experiences can be used to propose design techniques for a standardized LED interface. The main hypothesis of this study is that a *standardized light-based interface for a metered solar home system increases the communicative effectiveness and usability of the device*. Thus, the main objective of this study is to highlight how users utilize the LED feedback on solar home systems, and, using users' experiences within a HCI framework, design a simulated interface that is standardized and expressively communicative to the users.

1.4 Research Objectives and Questions

To achieve the purpose of this study, this research sought to meet the following specific objectives:

1. To demonstrate how different solar home systems relay feedback via LEDs.
2. To investigate solar home system owners' interaction and comprehension of the LED feedback from devices they own and those they do not own.
3. To apply HCI framework in determining the design considerations that define standardized LED feedback mechanism.
4. To compare the effectiveness of standardized with non-standardized LED interface.

To achieve the research objectives, the study aimed at answering the following research questions:

1. How do various metered solar home systems with non-standardized LEDs relay feedback to the users?
2. How do solar home system owners interact various LED feedbacks and how well do they understand the feedback?
3. What design features, based on a HCI framework, could equip a metered solar home system with universally-understood LED feedback?
4. What is the effectiveness of a standardized LED feedback interface compared to a non-standardized LED feedback interface?

1.5 Justification of the Study

Electronic devices have proven to play a big part of our lives in different capacities ranging from casual entertainment to critical healthcare. Solar home systems are a good example of devices that serve a major role in the day to day activities of users, especially for those who live in rural areas of Kenya. Even so, the usability of such devices depends greatly on how practical they are designed to meet the needs of users from all backgrounds. With LEDs becoming even more prominent as an iconographic tool for these devices, it has become evident that their communicative purpose and potential is not being fulfilled.

This study aims to point out some of the gaps in LED point light usage for communication and propose a solution. The benefit of this is that the findings can be used not only in the niche of solar home systems but for many other electronics which in turn will lead to a better user experience and even increased adoption.

1.6 Limitations of the Study

This research only focused on solar home systems, while there are many other LED-touting devices. This limitation means that the study may not fully bring into consideration the different dynamics of LED lights on other products. Similarly, the research only focused on the expressivity of light while excluding any support iconography, such as presence of sound as a feedback mechanism. Another limitation is that the study only covered a few regions in Kenya and this might not necessarily cover the comprehension of LED lights for all users of solar home systems.

1.7 Delimitations of the Study

This study was conducted in rural Kenya in the townships of Naivasha, Ol Kalou, Molo, Kericho, Sotik, Bomet and Narok, which were some of the best performing areas for solar home distribution in Kenya. Since Kenya is one of the global leaders in solar penetration, this means that this study has a good representative demographic to get feedback on the product design.

By focusing on solar home systems, the study found the perfect niche of products that employ LED lighting without complementary audio or visual design elements hence facilitating an unbiased research.

1.8 Significance of the Study

By identifying gaps in utility device design and proposing ways to bridge them, this study not only contributes to the discipline of HCI design but also to the large body of information systems. The research should lay the groundwork for establishing of a vocabulary of light for human-computing interactions. This is not limited to the scope of study because it can be extrapolated to apply in other user devices/appliances.

1.9 Scope of the Study

The research was conducted in areas that were relatively well exposed to solar distribution and related products. These areas included Ol Kalou, Molo, Sotik, Kericho, Nakuru, Narok, Bomet and Naivasha which was the town where the first solar module factory in East and Central Africa was established (Ondraczek, 2013). They were selected on the basis of being fairly well-performing regions on sales for Solar Home Systems and also representing some of the earlier regions where solar pilots were carried out in the country hence providing the high density for population sampling (International Finance Corporation [IFC], 2018).

1.9 Assumptions of the Study

The study assumes that the selected demographic is not biased by exposure to many devices that use LED lights to relay user feedback. It also assumes that demographic was representative of the general views of solar home system users globally.

1.10 Definition of Terms

Below are some terms that will be used in the research;

Solar Home System – this is device that has battery that collects energy transmitted to it from a solar panel and the energy can be used to power various devices in a home such as bulbs, phones and radios.

Light-Emitting Diodes – these are small lighting products that produce visible light when an electric current passes through a microchip.

Pay as You Go (PAYG) – this is a technology that allows users to purchase Solar Home Systems in installments without needing any collateral since the device can be enabled and disabled based on the payments made.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Interface standardization devices with Light-Emitting Diode (LED) feedback mechanisms promises multiple benefits towards overcoming challenges such as customer complaints and limited technical expertise (Stimulus, 2018). The aim of this research was to contribute towards tackling difficulties among solar home system users. Therefore, this chapter begins by reviewing previous work on the proliferation and use of solar systems in general and solar home systems, in particular. The rise in the use of LED-touted devices provides an opportunity for investigating their use, for both opportunities and challenges. Thus, this chapter reviews related studies on LCDs and how these have been adopted for solar home systems. Thereafter, this chapter discusses related work on challenges faced by users of non-standardized interfaces, especially among solar system owners. The chapter then discussed how principles and frameworks from the field of Human-Computer Interaction (HCI) have been utilized to contribute towards solution of these and similar problems among end users. This chapter concludes with a summary of the gaps and opportunities identified in the related work.

2.2 Solar Systems

The solar industry has been growing gradually over the years with most efforts being aimed at serving people who do not have grid electricity, by giving them the opportunity to enjoy clean energy at affordable rates. According to International Energy Agency, the number of people who remained unserved with basic electricity connections, as of the year 2010, stood at around 1.2 billion people (International Energy Agency [IEA], 2016). Over the years, there has been accelerated electrification with at least 127 million people per year being connected to the grid between 2010 and 2016 (World Bank, 2020). The same report indicates that between 2016 and 2018, there was an increase of people connected to the electricity grid up to 132 million people per year, but this still fell short of the universal access to electricity consortium. The data showed that despite doubling the international financial injection from $10.1 billion (2010) to $21.4 billion (2017), the number of people without electricity in 2018 remained higher than it needed to be, at 789 million people. Thus, there was still a gap towards access to energy, which fueled the need for solar systems.

The role of solar systems in developing countries is significant, especially when you consider that in Sub-Saharan Africa only 41% of middle to low income countries' health facilities have reliable electricity (Cronk & Bartram, 2018). This situation is even worse for schools because only 35% of them in Sub-Saharan Africa and about half Southern Asia had access to electricity as of 2017 (United Nations Foundations et al., 2019). With such crucial institutions lacking essential energy, it is not surprising to see that households are also facing similar challenges. For example, in a study looking at the growth of the solar market in Kenya, it was found out that 76% of the population was living in rural areas with 43% of the population living in poverty (Central Intelligence Agency [CIA], 2009). Consequently, it was found that most of the Kenyan households used kerosene as the main source of afterhours illumination (Jacobson, 2013), which had harmful effects.

To show how solar systems would reduce these harmful effects, another study carried out in Cote d'Ivoire showed that using solar systems improved household consumption by about 42% and schooling by 1.79 years (Diallo & Moussa, 2020). Most importantly the study showed that illnesses reported by family members reduced by 2.3 times. According to Bwire, the advent of solar has changed the lives of the people of Rangwe constituency in Kenya by providing solar driven water pumps (Bwire, 2019). These pumps have curbed the previous issues of cholera in the area which arose from water contamination when pumps used to break down due to high cost of diesel. Similarly, Bwire highlights that a company called Solibrium that has been providing solar power at attainable costs has provided jobs for local women networks who are employed in the distribution business. An added benefit of distributing these solar home systems and lanterns is the advantage to small landowners who have been enabled to do business late at night and irrigate their farms even with unpredictable seasons, resulting in better harvests (Bwire, 2019). This research taps into the numerous advantages presented by the presence of solar systems to Kenya's rural population, including solar home systems.

2.3 Solar Home Systems

With plenty of evidence to show the harmful effects of kerosene lamps, firewood and candle lights, small-scale solar home generating systems have emerged as the solution (Dahlke, 2013). These solar home systems have been shown to be able to power things like phones, refrigerators, fans, television, cook stoves and many other items while they can be installed and work anywhere there is sunlight. According to the Renewable Energy Policy Network for the 21st Century2017 Global Status Report, as of 2016, there were more than 25 million people benefiting from solar home systems and the number is expected to grow (Renewable Energy Policy Network for the 21st Century [REN21], 2017). In Kenya, sales of these systems was shown to have increased from about 20,000 in 2009 to close to a million in 2014 (Turman et al., 2015). This trend in Kenya established the country as one of the leading markets in for solar lighting products second only to Vanuatu in small solar home systems in 2018 (World Bank, 2020).

Even with this positive trend, the biggest hurdle to the adoption of these solar home systems has been established as their high initial cost (Urmee et al., 2009). It has been evident that solar home systems in general are expensive purchases (Ugandan Off-Grid Energy Market Accelerator, 2018), and for more people to adopt them, the financial burden must be reduced. Dahlke points out that the purchase of solar home systems could cost many times what the consumer makes in a single month (Dahlke, 2013). The study equates the purchase of solar home systems in developing countries to the purchase of a car for a family in a developed country. This is why the International Energy Agency points out that there have been several social enterprises that have received great funding and subsidies to facilitate the distribution and uptake of solar lanterns and home systems that can be acquired through easy-buy loan arrangements (IEA, 2016). Typically, these are credit arrangements for purchase that allow the customers to lease the product until they own it after making small payments over a period of between 12 to 24 months (Kundu & Ramdas, 2019).

Although it has been established that banks and microfinance institutions are a great resource for providing loans, poor customers lack the security, credit history or legal standing to be able to qualify for such loans (Dahlke, 2013). This situation is why most successful microfinance institutions operate in urban areas where they do not have to risk lending without collateral. The study has showed that the access to microloans has been as low as 10% for rural populations in Latin America and Africa. Therefore, cash sales have emerged as being very important for the distribution of solar home systems with mobile money payments becoming even more common fueled by smartphone penetration. Such payment methods have also been boosted not only because of low transactional costs but also because of easy financing (Nieuwenhout et al., 2001; REN21, 2017). Consequently, there has been a rise of Pay-As-You-Go (PAYG) distribution companies that have raked in lots of investment to year after year.

The Renewable Energy Policy Network 2017 report showed that between the year 2015 and 2016, PAYG companies raised $223 million which represented about 40% increase. Nieuwenhout and team also acknowledge that there is need for design standards for these systems because consumers are mostly drawn to cheap under-designed systems that may lack or have low quality replacement parts (Nieuwenhout et al., 2001). The challenge here is that the consumers do not get value for what they are paying for but also struggle to understand how these products work. For this reason, leading manufacturers have tried to meet the consumer needs by making industrial design compromises such as building PAYG solar home systems that are simple as possible but also stripped of many useful features such as displays and audio feedback. The most common design trend for simple solar systems is including LED point lights as the only source of feedback to the client (Heimgartner, 2014). As much as this helps with the overall goal of cutting down cost to make it worthwhile for the off-grid customers, the lack of a standard language of light communication leaves a utility gap that customers have to fill on their own.

According to Heimgartner, usability is heavily reliant on how the user can utilize the system. It only takes observation and questioning to determine how a user interacts with a system based on their desires or needs (Heimgartner, 2014). Most of the customers who benefit from these lanterns and home systems have limited comprehension of the design workings and are therefore only keen to see the product function as it was marketed (Lighting Africa, 2010). With Pay-As-You-Go technology, this is not easily possible. The technology works in such a way that credit paid either through mobile money or cash activates the product with an equivalent amount of energy duration. Once the energy or credit duration is exhausted or the time elapses, then the unit goes off awaiting the next top-up and this goes on until it is fully paid off. This behavior makes it vital that the customers know how the product works and get to understand the light feedback. Even though many product manufacturers will argue that they include user manuals in the device packaging, studies have shown that, in many instances, the user guides exceed the reading capacity of the target population (Wegner & Girasek, 2003).

2.4 Light-Emitting Diodes

The main purpose of designing iconographic devices or interfaces is nothing more than the need to consistently relay meaning to users for their knowledge or action (Harrison et al, 2012). There are many iterations of iconic designs including visual forms, auditory forms (Brewster et al, 1995), textural forms and even vibro-tactile forms (Harrison et al, 2011). This means that devices that only employ simple point lights in their design, like the solar home systems, are rather limited in their expressive power. In a study around understanding sensor notification on mobile devices established that for devices like smartphones that are very iconographic and have multiple notification channels, LED lights are the least effective at 4% success rate (Ma et al, 2017). This ineffectiveness was established to be due to the increased distraction or convenience of the other iconographic elements of the smartphones such as information persisted on the screen.

In spite of the cited ineffectiveness of LED lights, in the design of systems that employ them as the only form of feedback, there is no room for the user to misinterpret what is shown to them for a very brief moment. As defined by Lee and team, point lights are designed to be sequential but cannot be persistent if they are to convey a meaning (Lee et al, 1999). These lights rely on an ordered progression of intensities that disappear immediately after they are relayed. This is fundamentally different from what a user gets from typical visual forms such as computer screens or other graphical interfaces where the information is randomly accessible on different parts of the display (Lodding, 1983). The property of LED point light to only be shown briefly makes them very efficient in simplistic devices because they do not require much energy to power up. They can also be viewed from any angle and at any time of day because of great sunlight legibility, adding to their appreciated small form factor (Liu, 2017).

In a 2014 study to establish how color and blink frequency of LED lights affected smartphone users' urgency perception, the results showed that perception is highly influenced by color and blink rate (Kim et al, 2014). The research highlighted that there was increased attentive and intuitive perception whenever color was used, and blink rate was high. Another study corroborated this by showing that long wavelength colors such as red are more arousing than colors with short wavelength such as blue or green (Elliot et al., 2007). According to the IESNA Lighting Handbook, there are generally two types of LEDs - AllnGap and InGaN which broadly produce between red and green lights with reasonable luminous efficacy (IESNA Lighting Handbook, 2000). These are also the least expensive implementation of the LED lights from a manufacturing standpoint and appear as the most widely used in most of the devices employing LED point lights such as traffic lights, signages, smartphones and even solar home systems. This study focuses on these solar home systems as the best example of devices that rely on low output LED lights to compensate for their very limited design.

2.5 Light-Emitting Diodes on Solar Home Systems

A study by Pon evaluated the solar lighting buying power of customer in Zambia and found that in order to meet the acceptable payback period of 5 months, the final retail price of a solar home system would have to be around $10-$20 (Pon, 2012). However, this meant that the produced system that would only meet the comparable experience of using a candle or kerosene lamp and would not meet the customers' needs such phone charging which was shown to be an important service. Mills and team also carried out a study in Mombasa to compare customer costs to production costs of solar home systems and found that a product produced at $45 would generally retail for $85 (Mills, 2007). This doubling or price was backed by another study by IFC in 2010 (IFC, 2010). These factors are what dictate the design of the solar home systems and the reason why these devices cannot really afford to have a variety of iconography, which would increase their cost, over simple LED point lights.

With this market situation, it has been seen that inferior lighting products are cropping up and can pose even more problems for users. Pon's research on users in Zambia showed that one of the biggest considerations for customers buying solar home systems was warranty because they had bad experiences with fake products (Pon, 2012). This study calls for standardization of these products so that some of these user issues get addressed.

2.6 Challenges Faced by Non-Standardized LEDs

According to Tiwana, Interface Standardization refers to the simplification of user interactable devices so that everyone involved can follow the same rules (Tiwana, 2013). His book on platform ecosystems emphasizes that standardization creates order and helps improve coordination between shareholders meaning that users can have an easier time dealing with less complex implementations. Studies have shown that improved interoperability is achieved by using standard based interfaces (Babovic, 2013). This has been shown to be most effective in web development where there are some protocols that define how data should be delivered for efficient processing. These studies show some of the high-level benefits of standardization of interfaces.

Lack of standardization is not a new problem and has been talked about by many researchers who have highlighted some of its problems. Spinillo et. al (2011) conducted a study on Pictorial Design of Health Products looking specifically at how Male and Female users with low levels of literacy understood condom instructions. Even though the findings cannot be over-generalized, the conclusion of the study, that the pictorial representations did not successfully communicate their message, is significant. This, considering, is a government moderated design that is aimed at educating the public to reduce the risk of infections ranging from STIs to HIV/AIDS.

Narrowing down to LEDs and their use, it is important to appreciate the fact that small LED Lights have been in use for a long time in many electronic appliances and interfaces to convey various meanings to users (Harrison et al, 2012). Liu and team explored how smart IoT powered products were being used and discovered that there are consistent frustrations due to unexpected behaviors and this was not because of failure but rather a result of failed communication (Liu, 2017). In most cases, when point lights are applied to large systems, they serve a great purpose because their expressiveness is properly factored in the design process. In a car dashboard for example, the lights are more iconographic since designers have much more room to work with than on a handheld mobile device (Bauman & Thomas, 2001). Bauman and Thomas mention several factors that impact interface design in a way that does not allow for maximization of the potential of point lights.

When it comes to solar home systems, it had been shown that over a period of three years, between 2009 and 2012, the number of solar products in the African market had increased from eight to more than seventy which represented an almost 9-fold increase (Lighting Africa, 2012). This increase also led to increased adoption of the products due to an increase in quality products from less than 5% to approximately 33%. The report aimed to emphasize that the more quality checks and standards that can be applied to design of solar home systems before they reach the market, the better the uptake. This is because, for first time buyers, initial experience defines their future purchase decisions.

Therefore, the lack of standards and guidelines, unlimited target user groups and peripheral constraints for small appliances lead to poor interface design considerations. For point lights to be meaningful, they need to be either recallable or repeated and, in some instances, presented in sensibly varying intensity. This means that even if users of these metered solar home systems get to read the included manuals, they will always be creatures of habit who will potentially try to relate one behavior with another similar behavior. This is backed by Off-grid Practitioners Stimulus Report, that points out how many distributors of solar products have lamented about distribution and support challenges (Stimulus, 2018). According to the report, most of the issues faced by users of solar home systems have been a result of communication difficulties compounded by limited technical expertise. This basically means that users have a hard time understanding the feedback of these devices and so keep requesting for help when in actual sense it's just some clarification that is needed.

Such issues could be tackled through application of Human-Computer Interaction (HCI) principles in design. HCI provides the building blocks for improving human-computer interactions and consequently the usability of their interfaces (Grudin, 1992). If we take an example of the recent fad of Small Unmanned Aircraft systems, the lack of standardized human computer interfaces for setting geo-fencing parameters among devices from different manufacturers has led to various input and interpretation errors (Thirtyacre et al., 2016). Thirtyacre and team note that these errors can be both of omission (such as failure to enable the geofence) or commission (such as setting incorrect parameters) and can lead to serious safety-of-flight problems. They also point out that standardization through HCI has already helped a lot in areas such as cockpit displays of today's manned aircrafts which mostly have similar layouts from decades of refinement.

A similar recommendation was made in another Human-Computer interface study where it was documented that the role of standardization is significant in that it drives many aspects of product development ranging from measurement to testing but most importantly, seamless data exchange at interfaces (Blind & Gauch, 2009). In the context of light communication, there have been some recommended standardizations for applications that use Visible Light Experimentation (VLC). The Visible Light Communication Consortium (VLCC) and Institute of Electrical and Electronics Engineers (IEEE) already stipulate a number of principles to govern design of LED products to complement extra services or existing visible light infrastructure (Alam et al., 2016). These standards have provided a minimum benchmark for development of many of the existing VLC interfaces in vehicles, infrastructure, and even mobile devices (Khan et al, 2017). However, it is clear that there is still a gap to be filled in this area because solar home systems are just a small fraction of devices that employ LEDs and applying HCI to solve this niche can have significant impact on the whole ecosystem.

2.7 Human-Computer Interaction

HCI is a field of research that deal with practicality of design influencing people or organizations. This ideal of the study was established at its foundation which was to improve the quality of life (Hoccheiser & Lazar, 2007). The field of HCI has many frameworks that form the foundation for strong research. These frameworks are meant to guide what and why we do things as well as the expectations of the actions (Frey et al., 2016). These frameworks are applied in many studies for the main aim of standardizing various interface designs in a bid to accommodate the human element, smoothen the design process and in some cases to achieve mandated compliance (Buie, 1999). In more recent studies, popular examples of frameworks that have been applied in standardization are HOT-fit (Human, Organization, Technology-fit) framework and FITT (Fit between individuals, Task and Technology) framework. HOT-fit framework was designed primarily for evaluation of healthcare systems through observation, interviews and document analysis (Yusof et al., 2007). Its main idea is that IT-friendly environments go hand in hand with good communication complemented with the right user skills and attitudes. It is limited because it cannot be adopted to other information systems. FITT framework, on the other hand, focuses on workflow analysis and optimization (Ammenwerth et al., 2006) this examines attributes to do with the user like motivation of the user and those tied to the technology such as task complexity. These frameworks are ideal for application in complex information systems that have many variables.

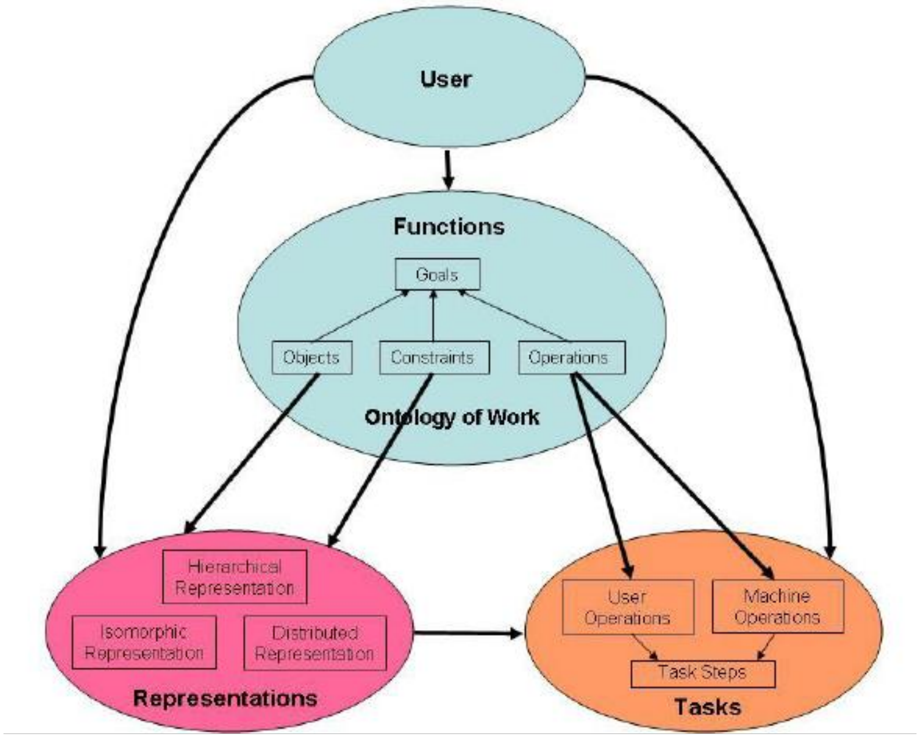
The usability challenge of non-standardized LEDs is best supported by UFuRT (User, Function, Representation and Task analyses) Human-Computer-Interface (HCI) conceptual framework. The framework emphasizes that a large number of information systems fail not due to technological flaws but a result of failed systematic consideration for human and other non-technical issues during the design and implementation process (Zhang & Butler, 2007). This framework was chosen because it is an enhancement of Staggers Human-Computer Interaction Framework and it specifically address high failure rates in systems that may lead to reduce efficiency and productivity.

2.8 UFuRT Framework

UFuRT framework has been applied in many processes involving design and evaluation of work-centered products (Zhang & Butler, 2007). Its process involves identifying the users and their characteristics including their knowledge and background. This is used in designing systems that have the right information structure to address the needs of the users. Figure 2.1 shows the UFuRT framework.

Figure 2.1

The conceptual framework of UFuRT (User Function Representation and Task analyses)



Note. This figure was adapted from Zhang and Butler 2007 publication and it visualizes the four pillars of UFuRT framework. From *A Work-Centered Framework and Process for Design and Evaluation of Information Systems*, by J. Zhang and K. Butler, 2007. Copyright 2007 by Zhang and Butler

The second step in operationalizing UFuRT framework is functional analysis which involves identifying the work that the users need to perform. It is an abstract definition and is independent of the implementation meaning it looks at the essential requirements of the work regardless of the technology or the procedures (Zhang & Butler, 2007). The representation analysis part of the framework forms the basis for identifying the interaction between the user and the system. It can influence the task difficulties, behavioral outcomes, efficiencies and most importantly the how easily the information can be perceived. The final part of the framework, task analysis, looks at the actual steps that are carried out by the user, how they are tied to each other and the information that is supposed to be drawn from it.

The framework is mainly used in work-centered design because it clearly shows the difficulty as well as the usability of the design. There are some studies that have made great use of the framework to solve problems to do with usability and standardization. For purposes of comparing usability between two user applications, Nahm and Zhang operationalized the UFuRT (User, Function, Representation and Task analyses) framework and successfully identified usability differences in a bid to identify the right tool for Clinical Research Data Management (Nahm & Zhang, 2009). In their study they compared two tool, Microsoft Excel, a spreadsheet program, with a fully-fledged commercial data management system. The framework was also successfully applied by other researchers in the optimization of an Electronic Healthcare Record application to meet specific healthcare providers' needs (Amith et al., 2012). In their study they created a prototype that addressed the perceived functionality weaknesses of their test procedure and their findings also supported the evidence that the framework is a valuable tool for usability evaluation.

These researches justify the work in this study by highlighting how lack of standardization can be detrimental to usability. They also show some of the ways in which standardization problems have been solved to good measure, through HCI frameworks like UFuRT.

2.9 Gaps and Opportunities

As seen from the studies above, solar home systems play a vital role globally and an even bigger role in Sub-Saharan Africa. Table 2.1 below summarizes these opportunities and gaps. Kenya has been shown as a market leader in solar distribution and therefore serves as a great study location for this research. When looking at solar home systems specifically, their design and purpose show a tight balance between cost effectiveness and practicality but their proliferation leaves a big usability gap that can only be filled through standardization. Similarly, the great benefits of LED technology have been widely publicized but their deployment in devices has not really been driven by user experience. Most researches cited have shown that manufacturers and adopters have been drawn to the value or cost savings, giving little weight to the efficiency or usability.

There has not been much research that has been done specifically on LEDs as point lights on solar home systems and this is where this study hopes to fill the gap. Other studies on LED point lights have focused on devices that have alternative forms of iconography and so LEDs have not had the significance that they have in this study's use case. The related studies have pointed out a number of issues that non-standardized LED interfaces have brought about, not limited to solar home systems.

This provides another opportunity for this study in the sense that, if devices with better iconography present the user with some usability issues, then the ones that do not have any other form of iconography would provide even more headache.

Table 2.1

Summary of Opportunities and Gaps

Gaps	Opportunities
User frustration	Increased use of solar home systems in rural Kenya
Increased need for after sale support	Increased use of LED technology in solar home systems
Studies focusing on alternative forms of iconography, other than LED point lights	UFuRT HCI Framwork
Lack of standardization among LED-touting devices	Increasing adoption of LED light because it's the superior light technology

To address these challenges, the field of HCI has proven to be a valuable research tool for proposing a design solution. A number of studies have shown the application of HCI and significance of the proposed solutions. Studies that have employed UFuRT framework have shown even more promise that the specific use case of this study can be addressed easily. With that said, this seems to be a perfectly timed study to get the most of an emerging product and help contribute to a lacking knowledge base aimed at shaping the product design front.

The next chapter delves into the methods used to carry out the research. It touches on the framework used, the study area, the demographic of the study, the devices selected, the study metrics, data collection and analysis methods as well as the application to research questions.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter looks at the approach taken in carrying out this study, the research design, application of the UFuRT framework in this study, the target population, sampling procedure and methods of data collection. It also goes further into the preparation of the data to the analysis of the same to derive insights needed to address the objectives of the research.

3.2 Research Design

Research Design as defined by Akhtar, is the blueprint of a concept through which the research is conducted (Akhtar, 2016). This basically refers to the action plan constituting methods of collection, measurement, and analysis of data to answer the research question(s). According to Akhtar, there are various research designs Explanatory, Descriptive, Exploratory and Experimental Research Design.

3.2.1 Experimental Design

Experimental design focuses on manipulation of some independent study variables to test the effect on dependent variables. For this research, the idea was to highlight the user comprehension problem of non-standardized LED-light feedback faced by a target population then design a solution, guided by a HCI framework, and present it to an experimental group to see its effect. This way, experimental research design was employed because the main objective was to prove that a standardized light-based interface for a metered solar home system increases the communicative effectiveness and usability of the device.

Since experimental design can be carried out in various ways, the approach that was selected was before-after experimental design. This approach refers to a method where the dependent variable is measured before and after the independent variable is modified making use of several groups (Akhtar, 2016). The dependent variable in this case was the users' understanding of the LED light feedback of the solar home system, while the independent variable is the feedback pattern used for each individual feedback.

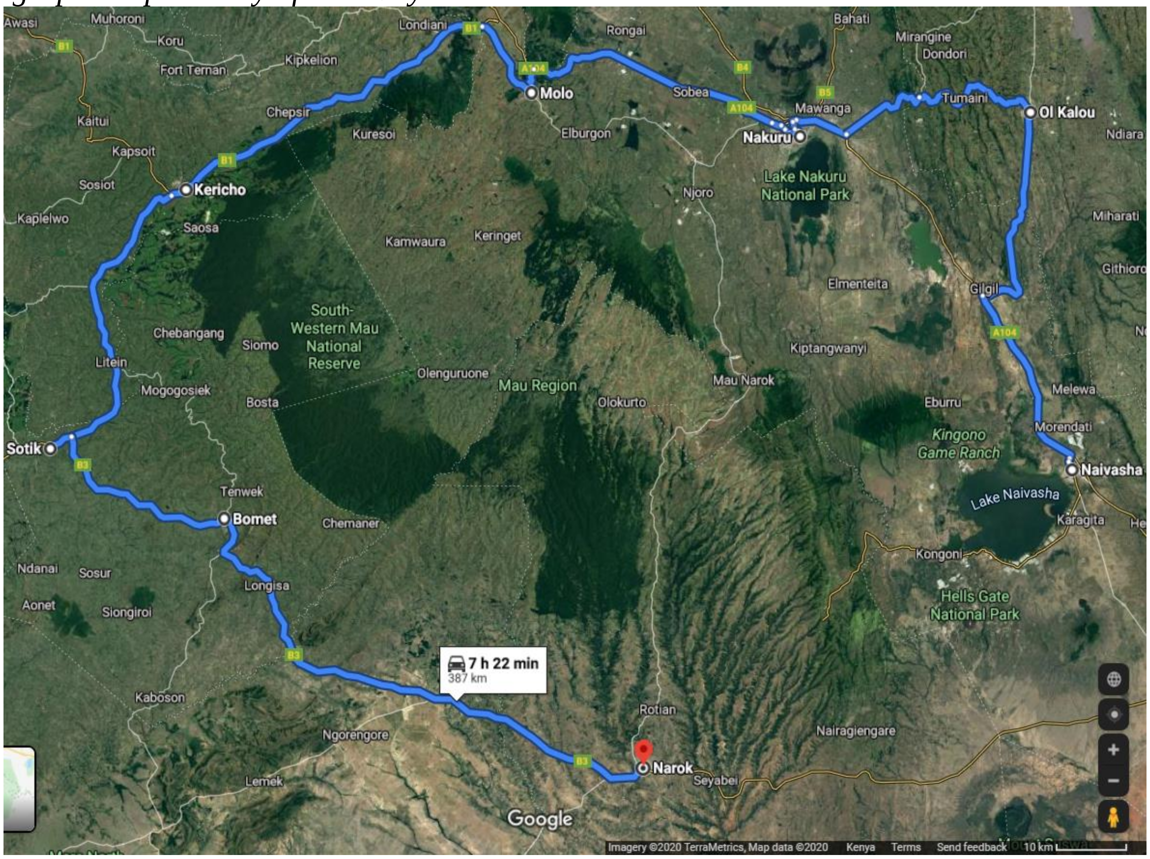
3.3 Study Location

The research was carried out in the central to south Rift Valley region of Kenya which is highly populous and served well by good roads from the former capital of the province Nakuru town (Fabini et al., 2014). The research was conducted in areas that are relatively rural but well exposed to solar distribution and related products. These areas included Ol Kalou, Molo, Sotik, Kericho, Nakuru, Naivasha, Narok and Bomet (Figure 3.1).

The basis of selecting these regions was that they were fairly well-performing regions on sales for Solar Home Systems in the country and represented some of the earlier regions where solar pilots were carried out in the country (IFC, 2018). For that reason, the study can be considered comprehensive as it made use of the significant solar penetration and the large population in the counties for sampling.

Figure 3.1

Geographical proximity of the study locations



Note. Screenshot captured of the map of the area of study. From *Google Maps* https://goo.gl/maps/VbqpwMVTZN4ofzpC9. Copyright Google Maps 2020.

3.4 Target Population

The target population for this research was owners of Solar Home systems. These owners were selected as a way to establish the required level of knowledge and cognitive understanding to address the study's research questions (Zhang, 2007). The total number of solar home systems sold in the country is not clearly known but the Global Off-Grid Lighting Association (GOGLA) estimates the number to be around 2 million (USAID, 2019). Since this research involved primarily qualitative data, there was no set number of participants. The sample size was controlled by two factors including reachability, since all the users lived in sparsely populated rural areas, and the devices owned because it was essential to find users with a variety of devices.

3.5 Sampling

Sampling is defined as the identification and selection of a subset of individuals within a population to approximate characteristics of the whole population (Robinson, 2014). It is said that sampling can be approached in two ways, probability and non-probability sampling. For the former, each provides an opportunity for each individual in the population to be selected as a sample while the latter does not provide such an opportunity (Battaglia, 2008; Henry, 1990). This research employed a type of non-probability sampling referred to as purposive sampling.

3.5.1 Purposive Sampling

Purposive Sampling is also referred to as judgment sampling because it involves deliberate choosing of participants based on their qualities (Etikan et al., 2016). This method of sampling is hinged on the availability of people who have the experience or are conversant with the subject. This was found to be the most appropriate sampling method because the ideal participants were people familiar with the target devices from a utilitarian perspective, hence solar home systems owners. These owners were considered homogenous because they shared the same experience. Even so, they constitute a rural demographic dispersed in various areas of the wider geographical region making them hard to reach. The users were therefore reached either at their homes or at a distributor’s outlet because there were the only two places ownership of the target devices could be validated. The sampling process was carried out based on the saturation principle of purposive sampling. This meant that the collection of data was carried out until there was no new substantive information (Miles & Huberman, 1994).

3.5.2 Sample Size

The field work for this research was carried out in two phases. In the first phase, 111 users participated in in-person interviews and practical device-walkthrough. This number of participants was established to be more than sufficient to cover at least 98% of the needs of the target demographic of the research (Faulkner, 2003 & Guest et al., 2006). Guest and team observed that in a study making use of purposive sampling, authors documenting degree of data saturation and variability via thematic analysis found that saturation occurred as soon as the first twelve interviews. This was also established to be the case with variability within the data.

The in-person interview approach was taken to capture subjective understanding or perceived usability and general user attitude (Assila et al., 2016). The first phase of the study addressed the first three objectives of this research. Results obtained from the first phase provided the basis for design considerations made in creating the standardized feedback system. In the second phase, 43 users were shown the newly designed standardized interface. The purpose of this phase was to compare effectiveness of standardized and non-standardized LED point lights.

3.6 Instrumentation

3.6.1 Observation

Observation is one of the earliest used methods of data collection with studies showing that it was used as early as the late 19th century (Kawulich, 2012). According to Kawulich, there are a number of advantages of observation with the main one being the ability to get first-hand information. This means that in any kind of study intermediaries are bypassed hence allowing the researcher to obtain data that is not generally available to the public. This allows observation to provide rich and detailed descriptions that can be used to develop questions to address more research objectives. For this research, observation was used to answer the first research objective by evaluating solar home systems for their different LED feedback and how they compare. The four most available devices in the region of study were selected for evaluation. These four devices were the ones that were widely used among the sample population of solar home system owners. Further, information on financial and operational performance of PAYG companies is not shared publicly (Lighting Global, 2017). Therefore, there was no public record that could be used to check the most widely used solar home system devices in the general public. Thus, this research relied on on-the-ground information to determine which devices the target population utilized. These four devices are: Fosera home system (Figure 3.2), Sunking 60/120 home system (Figure 3.3-left), Sunking Pro/Boom (Figure 3.5-right), and JUA home system (Figure 3.4).

Figure 3.2

Solar Home Systems by Fosera which is activated via Keycode (via infrared remote)

Note. Image showing sample Fosera Home System and its accessories. From *Angaza* https://www.angaza.com/. Copyright 2018 by Angaza.

Figure 3.3

Sun King Home (left) and Sun King Pro (right) Home Systems by Green Light Planet

Note. Image showing sample Sunking Home Systems and some accessories. From *Angaza* https://www.angaza.com/. Copyright 2018 by Angaza.

Figure 3.4

Solar Home System by JUA Energy which uses credit keycodes for activation

Note. Image showing sample JUA Home System and its accessories. From *Angaza* https://www.angaza.com/. Copyright 2018 by Angaza.

3.6.2 Interviews

Interviews are considered a natural primary way of collecting data to cover a variety of topics (Alshenqeeti, 2014). Interviews have many advantages including high return rate, greater completeness of answers as well as controlled answering order. There are different formats of interviews and one of them is semi-structured where the respondents are presented with preset open-ended (Jamshed, 2014). This format of data collection can be used both with individuals or groups and are founded on core questions backed by associated questions. For this research, the participants being rural folks, interviews were the only feasible data collection method because of sampling challenges, low literacy, and language barrier in some cases. Data was therefore collected through in-person interviews using guided questions (see Appendix C).

The first phase questions were structured in a way that would qualify the target users through some quantitative measures such as devices they owned, ownership duration, if they made use of the LED feedback as well as any arising challenges. This was important because researches show that in order to get diverse opinions, qualitative methods should be supplemented by quantitative data (Ulmer & Wilson, 2003). After the qualification, the questions that followed were structured in such a way to measure user understanding of the different LED feedback. This data would then be used to create a mockup system that would be presented to a new group of users. The questions for the new group of users were open-ended and structured specifically to highlight user understanding.

In order to ensure validity and reliability of the guide questions, a pilot study was carried out in Kawangware and Kiserian where 31 solar home system owners and 10 distributors. This was also backed by formatting of the questions to avoid asking leading the respondents to any sort of assumptions (Alshenqeeti, 2014). An additional measure was that all the data was entered while speaking to the individual participant and it was based on both the answer provided by the user as well any complimentary action in case the user was struggling to relay their answer.

3.7 Data Collection Procedures

3.7.1 Ethical Approval

Before any data collection commenced, ethical approval was sought and this was provided by Kenya Methodist University Scientific, Ethics and Review Committee (approved 9th July 2019) and from the National Commission of Science and Technology and Innovation (License No. NACOSTI/P/19/1739). Informed consent was also sought from the participants of the study hence involvement was on a voluntary basis.

For the interviews, it was established during the pilot study that participants were not comfortable providing personal information and so those were not asked for during the data collection. Consent was also sought from a few of the participants to take field photos to be used in thesis. All this data was also not distributed or shared with anybody outside of the scope of examination.

3.7.2 Data Collection

The collection of data was done in two phases, an exploratory phase, and a second evaluation phase. To show how different solar home systems relay feedback, the devices were observed, and the readings recorded. To understand how solar home system owners utilized the feedback of devices they owned and those they did not own, a guiding question were used in the exploratory phase of the study during in-person interviews involving 111 participants. This exercise was consistent with past research that conducted usability testing to understand user challenges and effectiveness of systems through UFuRT framework (Assila et al., 2016). The interview questions directly addressed challenges faced by the user as well as questions that covered understanding of the different representative functions of the device. Examples of questions included;

I. What feedback mechanism do you interact with while using your solar devices?
II. What do you think is represented by a red fast blinking light?

The second phase of the study was based on explicit user suggestions and analyzed feedback from the first phase of the study. The first part of the second phase of the study applied HCI principles in determining the design considerations that define standardized LED feedback mechanism. This process also utilized the feedback from the users in the challenges they faced and their understanding of feedback.

The second part of the second phase of the study aimed at comparing the effectiveness of standardized and non-standardized LED point lights. This process was conducted by presenting the designed standardized interface to 43 users. The users were asked what they understood by each of the five feedback modes displayed by the mockup device. Examples of the guide questions (see Appendix D) included;

I. What do you think is represented by 6 green slow blinks?
II. What do you think is represented by a red stable light next to the money symbol?

Finally, a comparison was conducted between the understanding of various interfaces and types of communication among users in the first phase of the study and the understanding of the standardized interfaces among users in the second phase of the study.

All the data collected from the interviews was eventually coalesced into a central spreadsheet for analysis.

3.8 Operational Definition of Variables

3.8.1 Framework

The selection of UFuRT framework was based on the literature that showed that this was the most applicable framework for the research case study. The components of User-Centered Design, as stipulated in the adopted framework in Figure 2.1; User, Function, Representation and Task analyses were broken down to meet the context of the research for operationalization. The user/owners of solar home systems that were to be studied tied directly to the first component of the framework, *Users*. For this study, these are the only users that apply. The second component of the framework, *Functions*, are represented by the user goals or primary operations and measurable units of the metered solar home devices. The user goals or objectives include checking the status of the devices and activating them, as necessary. The *Representation* is the relationship between LED behavior exhibited by the devices and the feedback that it is supposed to relay. This could be something like LED pattern shown when the device is disabled. Finally, the *Tasks* are the steps needed to result in the LED-light feedback that completes the operation, and this could be either pressing the power button (for device status) or applying a keycode (for activation). Figure 3.5 summarized the operationalization.

The user analysis stage of the framework was focused on identifying the best performing areas of solar distributors in the country. For functional analysis, the study made sure to establish the objectives, constraints, and operations of the users through interviews. Example of questions asked included;

I. Have you experienced any challenges while using your solar home system?

II. How many solar home systems do you own?

Figure 3.5

Operationalization of UFuRT framework in the Metered Solar Home Systems case study

UFuRT Framework	Solar Home Systems Case Study
USER	Owners of metered solar home systems
FUNCTION	Checking status of the device and activating the device
REPRESENTATION	LED light behavior for device or activation status
TASK	System is ON/OFF and Keycode is Accepted, Rejected or Repeated

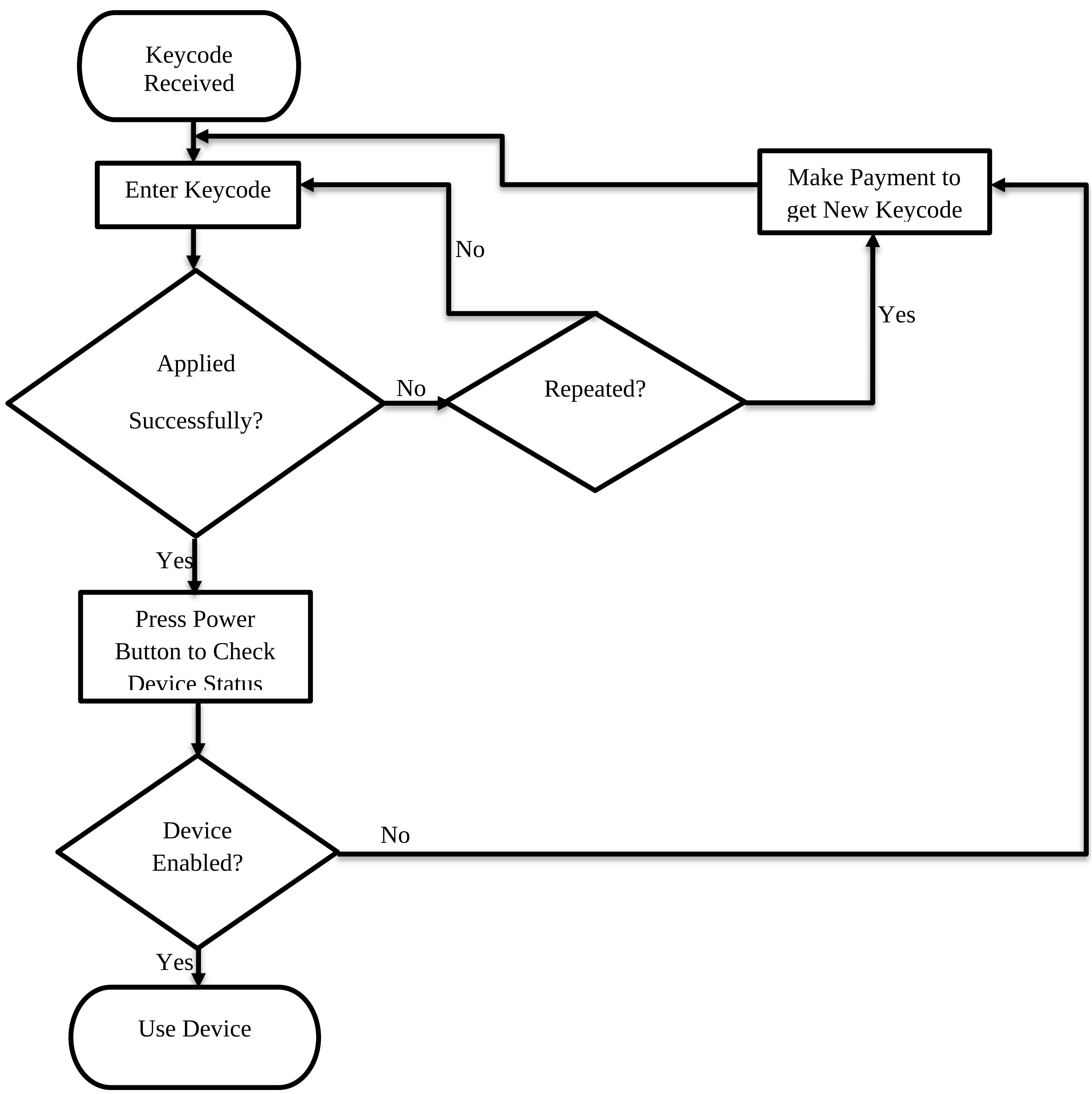
For representation analysis, the devices were examined and each PAYG dimension identified then added to the interview questions for evaluation. Task analysis was straightforward because the devices were limited hence there were no alternative ways around achieving the target representations. The above process was used for evaluation of the first phase of the research to address the first three research objectives including designing of a new interface. As for measurement of the effectiveness of the standardized interface over the non-standardized systems, only representation analysis was evaluated to see if there was improved understanding of the device feedback.

3.8.2 LED Feedback Mechanisms

The study's focus was on the most important functions and representative tasks for PAYG operations of solar home systems. Figure 3.6 shows a flowchart of solar home-system operations on a Pay-As-You-Go device. After installation of a solar home system, a user can check the status of the device and activate it with credit via a payment keycode. Checking the device status can only yield two outcomes: either device is enabled or disabled. Activation can only yield three results, keycode accepted, rejected or repeated. In the case of a device being enabled or disabled, the observations were taken immediately the power button was pressed. In the case of keycode acceptance the observations were taken after the last digit of the keycode was pressed. These represent the 5 intrinsic tasks being evaluated in this research: Device Enabled, Device Disabled, Keycode Accepted, Keycode Rejected and Keycode Repeated.

Figure 3.6

Flowchart of solar home system operations on a Pay-As-You-Go device



These five specific modes were selected because they are the only PAYG modes available on a metered device that uses a keycode activation protocol. All these modes utilize LED lights to relay the feedback to the user. For example, if the user entered a wrong keycode they would see a red fast blinking LED light on the Sunking home system.

3.9 Methods of Data Analysis

The study consisted of qualitative and quantitative data. The qualitative data was obtained from the open-ended questions such as "what do you understand by the feedback shown?" and the quantitative data was obtained from the closed questions such as "how many solar home devices do you own?".

All the data was first coded and grouped along the four objectives of this research. The coding of the qualitative data involved categorization, tagging and analysis of themes. Content analysis was then performed and combined with descriptive statistics of the supporting quantitative data. A Google spreadsheet was used for the tabulation and analysis of the data and summaries were then presented in the form of charts and summarized tables.

3.9.1 Application of Methodologies to Research Questions

This research sought to answer the following research questions. The methodologies in this chapter were used to answer the research questions as described.

1. *How do various metered solar home systems with non-standardized LEDs relay feedback to the users?*

   To answer this research question, direct observation of the solar home system devices selected from the market was conducted. The observations from the 4 devices were noted down and tabulated for comparison.

2. *What challenges do users of solar home system owners face in working with non-standardized LEDs?*

   This research question was answered by firstly addressing the use of the LEDs to see if each of the 111 users were paying attention to them or not. The users were then presented with two sets of devices one which they owned and the other one which they did not own. With these devices they were asked to identify each of the five feedback modes to measure their understanding both for devices that they were familiar with and those that were foreign to them. The data was then tabulated per the 4 devices used in this study and presented in the form of charts.

3. *What design features, based on HCI framework, could equip a metered solar home system with universally understood LED feedback?*

   This question was answered using data recorded about the devices that they were shown but did not own and the responses of the feedback understanding of those devices. The best performing device was used as the template for the new mockup design.

4. *How does a standardized LED feedback system compare to a non-standardized LED feedback system in communication expressivity?*

   To answer this question, a second phase of in-person interviews was carried out and the users were asked what they understood by each of the five LED patterns displayed by the mockup device. The data was then tabulated and presented in charts comparing the understanding rate between the comprehension of the new design LED feedback and the comprehension of LED feedback of the devices the user owned.

CHAPTER FOUR

DATA ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter discusses the results and analyses as per each research question. Appendix E contains the raw data from users' feedback in both phase one (the exploratory phase) and phase two (the evaluation phase) of the study. First, the following two sections presents the participants who took part in the study and the devices that they owned.

4.2 Study participants

A total of 111 solar home system owners participated in the first phase of the study, and 42 solar homes system owners participated in the second phase of the study. Table 4.1 shows the distribution of the number of participants, per phase, in terms of gender and location.

The study participants in the first exploratory phase consisted of 35% females and 65% males. In the towns of Kericho, Ol Kalou and Narok, the number of participants was equal at 18 people each, followed by Bomet (16), Molo (15), Nakuru (14) and Sotik (12). The distribution of participants in the second phase of the study was almost like the first phase with 60% male and 40% female. The number of participants in Molo was highest for this phase at 9 users, followed by Ol Kalou and Nakuru with 7 participants each. Bomet and Narok followed with 6 participants each followed by Kericho and Sotik with 4 participants each. Figure 4.1 shows some of the participants of the study.

Table 4.1

Number of participants of the study by region and their genders

	Participants in Phase 1			Participants in Phase 2		
Location	**Female**	**Male**	**Total**	**Male**	**Female**	**Total**
Bomet	4	12	16	5	1	6
Kericho	3	15	18	1	3	4
Molo	5	10	15	8	1	9
Nakuru	5	9	14	3	4	7
Narok	7	11	18	3	3	6
Ol Kalou	10	8	18	3	4	7
Sotik	5	7	12	3	1	4
Grand Total	**39**	**72**	**111**	**26**	**17**	**43**
Average	35%	65%		60%	40%	

Figure 4.1

Some of the participants of the study Benson Maina (Left) from Nakuru and Gladys Wacuka (Right) from Ol Kalou.

4.3 Device Ownership

The results obtained from the first phase of in-person interviews indicated that 78% of the 111 users owned one solar home system and 22% owned more than one device. Of the users who owned just one solar home system, 59% owned the Sunking Pro and 41% owned the SunKing Home. Of the users who owned more than one solar home system, majority owned 2 devices from different manufacturers, while 1 owned 4 devices, and 1 owned 10 devices.

Out of the 111 participants, 47% had owned the device for a year while 26% had owned the device for 2 years. The rest had ownership durations ranging from 2 months to 5 years. The average solar device ownership among all the 111 participants is 1.3 years.

4.4 Research Question 1: How do different solar home systems relay feedback to the user?

It was observed that each of the four devices studied exhibited a different LED feedback for all the five feedback modes. Table 4.2 shows how the four devices exhibited feedback. This variance was the case even for devices that were made by the same manufacturer. For example, the Sunking Home 60/120 displayed twelve green slow blinks when *keycode was accepted*, whereas the Sunking Pro displayed the same behavior complimented with blinking bulb light when *keycode was accepted*. On the hand the JUA Home System displayed six slow blinks with the dollar sign light on for *keycode accepted*. Another example is exhibited for the *device enabled* feedback. The JUA Home System showed a green dot LED light, while a Forsera home system displays a green battery.

These results indicate that there is a difference in the LED representation of feedback mechanisms across the systems, even for devices from the same manufacturer.

Table 4.2

Differences in feedback mode exhibited by four devices

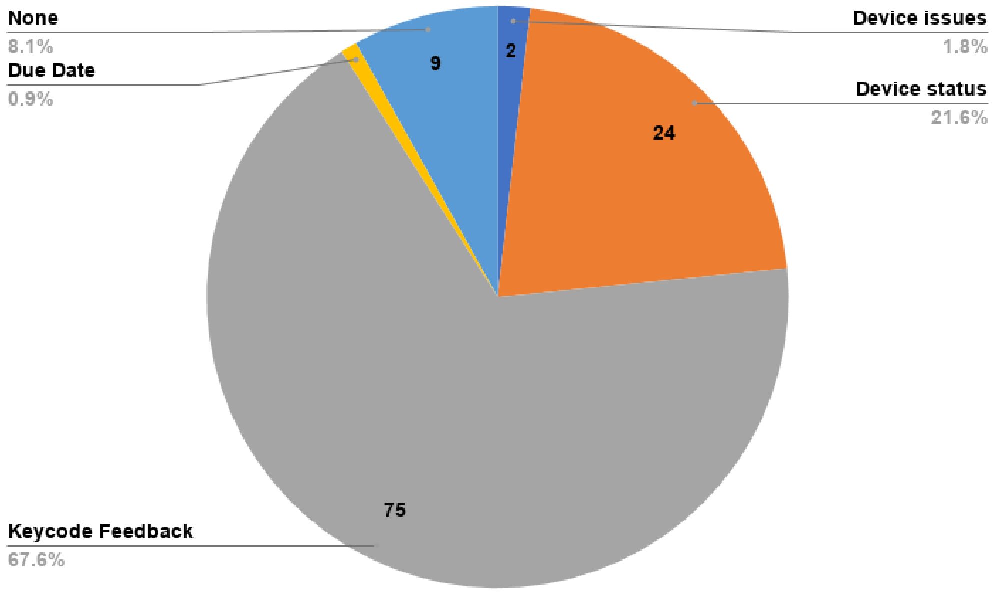
Feedback Mode / Device	Keycode Accepted	Keycode Rejected	Keycode Repeated	Device Enabled	Device Disabled
Sunking Home 60/120	Twelve slow blinks (green LED)	Twelve rapid blinks (red LED)	Twelve slow blinks (green LED)	Battery indicator (green LED)	Battery indicator (red LED)
Sunking Pro/Boom	Twelve slow blinks (green LED simultaneous with bulb)	Twelve rapid blinks (red LED simultaneous with bulb)	Twelve slow blinks (green LED simultaneous with bulb)	Battery indicator (green LED simultaneous with bulb)	Battery indicator (red LED simultaneous with bulb)
JUA Home System	Six slow blinks (keypad) dollar sign lights up	Rapid blinking for 2secs (keypad)	Three slow blinks (keypad)	Green dot LED light	No LED indicator
Fosera Home System	Six blue dot LED blinks	Three blue dot LED blinks	Three slow blinks (blue dot) LED blinks	Green battery LED	Orange dot and battery LED light up

4.5 Research Question 2: What feedback mechanisms do users interact with while using their LED-touting solar devices?

Figure 4.2 shows the distribution of the feedback mechanisms that users interacted with. 91% of users interact with at least one of the feedback mechanisms on their solar devices. This result shows that users actually utilize the solar devices that they own. Of the users who utilize at least one feedback mechanism, 68 % indicate that they utilized the *keycode feedback (accepted, rejected, repeated)*, with 22% using the LEDs to identify the *device status*. The remaining 2% used the device to check *device issues*.

Figure 4.2

Distribution of the feedback mechanisms that users interacted with



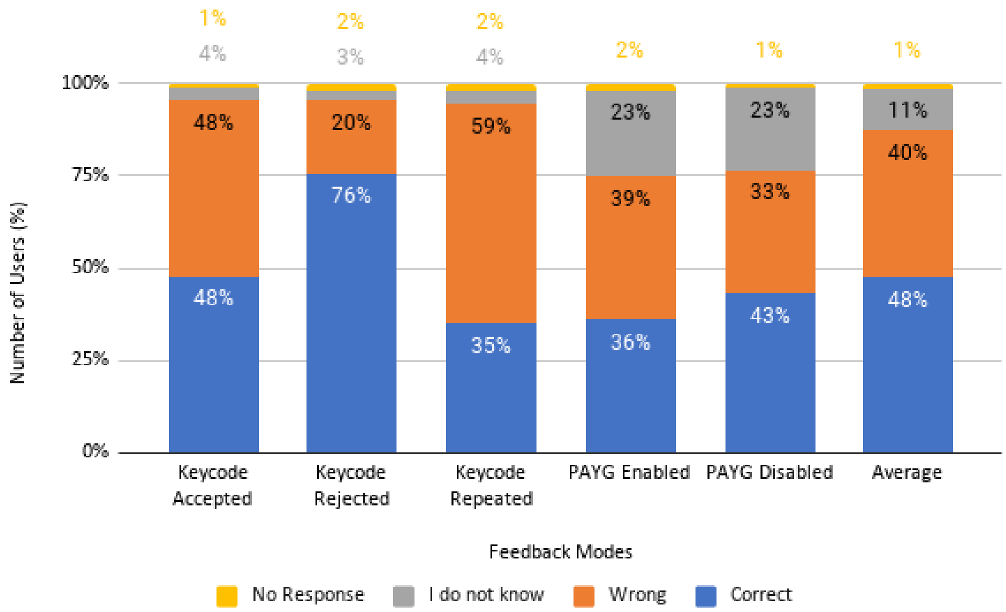
The 8% of users who indicated they ignore the LEDs of the devices, claimed they either understood how the device was supposed to work or sought help from somebody if they needed it. These results indicate that majority of users actively rely on the feedback of the device.

4.6 Research Question 2: Do owners of LED-touting solar home systems understand the feedback mechanisms in the devices they own and those they do not own?

The users were then presented with all five feedback mechanisms and their related LED signals then asked if they understood each related LED signal. Figure 4.3 shows that the LED signals for *Keycode Rejected* were the most understood feedback.

Figure 4.3

User understanding of the different LED feedback from devices they own



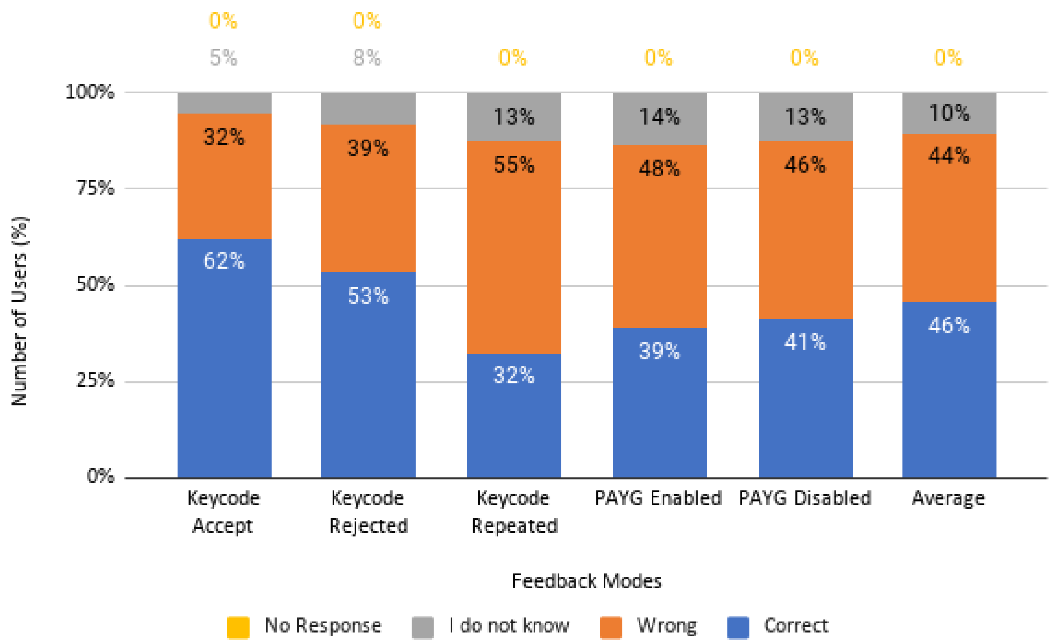
For the remaining feedback mechanisms, the understanding rate was between 35% and 48%. On average, the understanding rate among all users for devices they own across the 5 feedback mechanisms was 48%.

51% of the users could not correctly deduce or did not know the related LED signals across the feedback mechanisms. Of these 14% could not correctly deduce the related LED signals for all five feedback mechanisms.

Figure 4.4 shows that there was not much difference in understanding rate for devices that the users owned compare to those that they did not own. Across all feedback mechanisms the understanding rate is between 32% and 62%. %. On average, the understanding rate among all users for devices they did not own across the 5 feedback mechanisms was 46%. This could be a factor of the devices being conceptually the same in the sense that they all seem to exhibit some similar patterns such as fast blinking for keycode rejection.

Figure 4.4

User understanding of the different LED feedback from devices they did not own



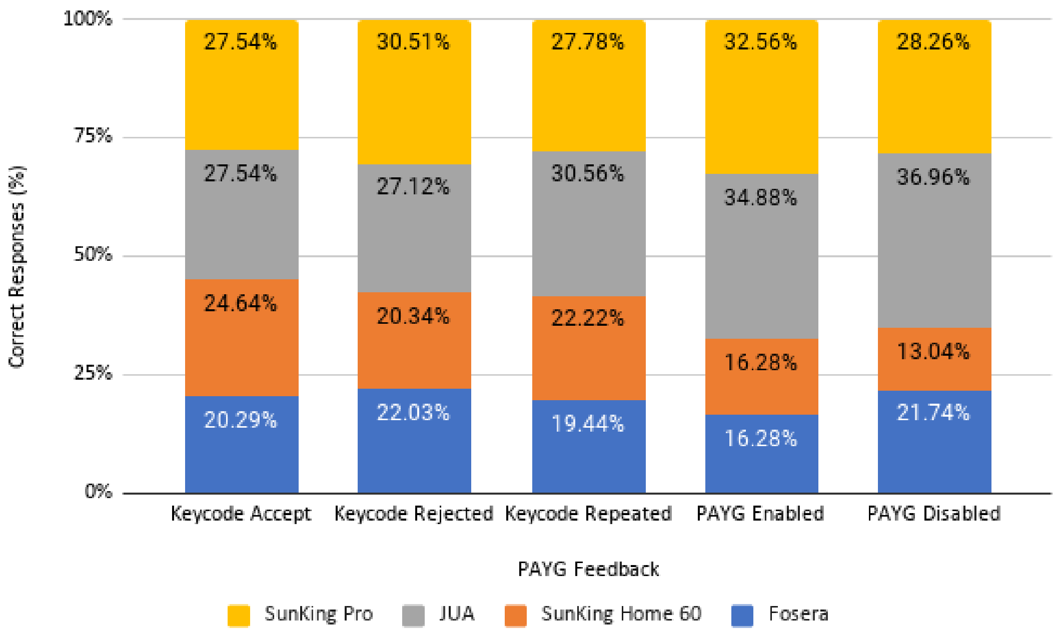
4.7 Research Question 3: What design features, based on HCI framework, could equip metered solar home systems with universally-understood LED feedback?

Using UFuRTs HCI framework by introducing competing/similar devices, users were presented with solar home systems they did not own and those they owned. When asked about their thoughts on what design features would help improve their experience, most users stated that they were out of their depth in terms of design but would struggle with the devices if customer support was non-existent.

From an analysis of the devices that the users did not own, Figure 4.5 indicates that an average of 31% of the users understood the feedback modes of the JUA home system. This percentage was higher than the average of users who understood the feedback modes of the other three devices.

Figure 4.5

Number of correct answers by users who did not own the devices



The findings align with the conclusion of other researchers that users tend to better understand communication if it is unique and easy to recall (Kim et al., 2014). The JUA home system has four LED lights, which is double the number on the other devices that have two each. Thus, in using the four LEDs the JUA manages to display more unique feedback combinations than the other devices.

With the above data, the study focused on task success as a component of UFuRT framework for each of the five feedback mechanisms. Since most users seemed to better understand the feedback from the JUA home system, it was hypothesized that creating clear distinction between the different feedback behaviors would be more effective in improving user understanding. This hypothesis is also supported by Punchoojit and Hongwarittorn's research that reviewed several studies that compared a number of existing systems in design of usable Mobile User Interfaces (Punchoojit & Hongwarittorn, 2017). Another study compared the benefits and drawbacks of information systems and found that getting user requirements for a new design from existing or competing systems is a more effective way of addressing current problems and identifying new features/acceptance criteria (Maguire et al., 2002).

The standardized interface was created using Adobe Creative Studio and Microsoft Paint 3D and featured animations showing the five feedback patterns.

4.7.1 Design of Device Enabled Feedback

To match the dollar sign on the JUA system, the *device status* feedback mechanism was created and marked with a *money symbol* (Figure 4.6). Further, the money symbol was designed to only show *stable green light* to indicate *device enabled*. The color of the LED signal was designed to match similar signals exhibited in the stable LEDs observed in all of the devices (shown in Table 4.2). Table 4.3 summarizes the LED signal for all the five feedback mechanisms of the mockup solar home system.

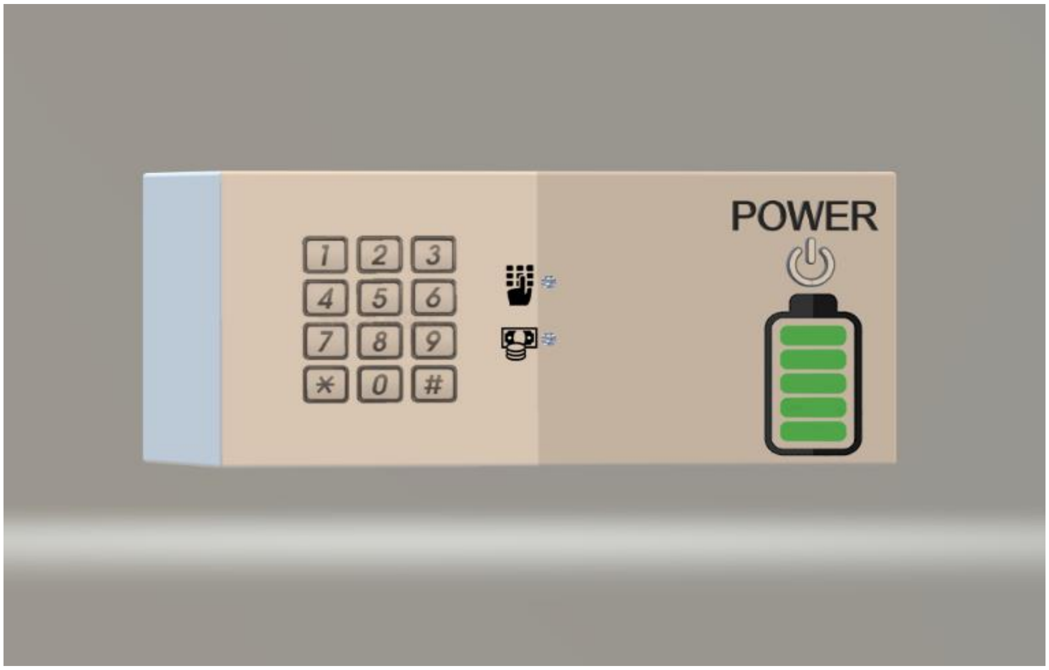
Table 4.3

Mockup Solar Home System LED feedback behavior

Feedback Mode / Device	Keycode Accepted	Keycode Rejected	Keycode Repeated	Device Enabled	Device Disabled
Mockup Solar Home System	Six slow green blinks next to the Keypad icon (green LED)	Eight rapid red blinks next to the keypad icon (red LED)	Three slow green blinks next to the keypad icon (green LED)	Green steady light next to the money icon (green LED)	Red steady light next to the money icon (red LED)

Figure 4.6

Mockup solar home system with refined LED feedback



A money symbol was aimed at achieving the goal of users understanding that they needed to pay for usage of the device. So, if the device had not been paid for then a red light will be shown while if it had been paid for then a green light will be shown.

4.7.2 Design of Keycode Acceptance Feedback

Once the user enters the keycode on the large keypad, *the keycode accepted* feedback is designed to show 6 slow green blinks. The area that blinks was designed next to a keypad icon to make it clear that the signals are only applicable to keycode acceptance.

4.7.3 Design of Keycode Rejected Feedback

To be consistent with existing devices the *keycode rejected* feedback was designed to show 8 red blinks. The area that blinks was designed next to a keypad icon.

4.7.4 Design of Keycode Repeated Feedback

Keycode repeated feedback was designed to show three slow green blinks. The area that blinks was designed next to a keypad icon.

4.7.5 Design of Device Disabled Feedback

A stable red light blinks to indicate Device disabled. The area that blinks is next to the money symbol.

4.7.6 Additional Features

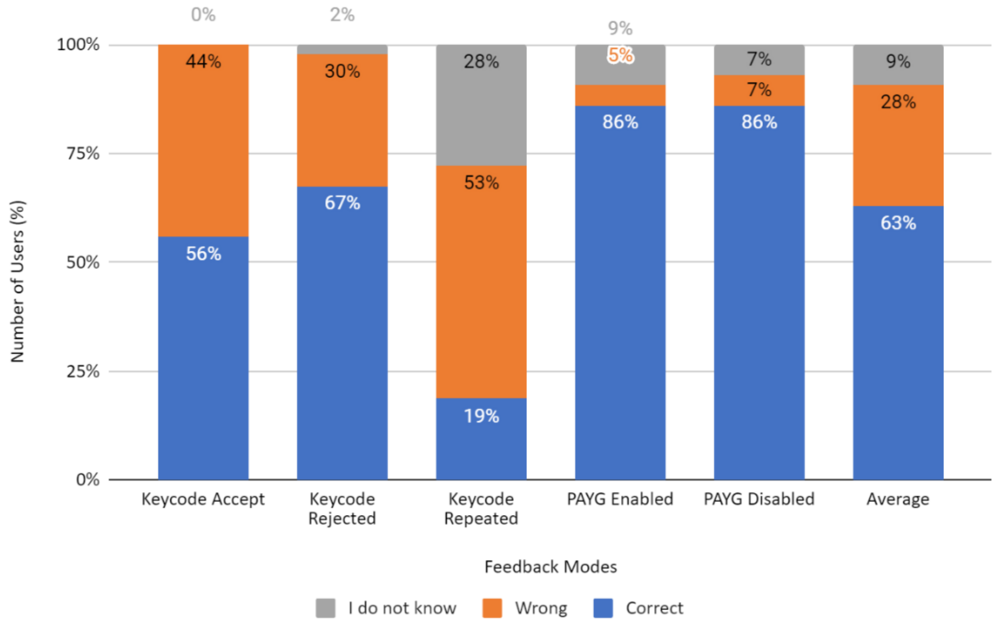
The new design featured a separate battery indicator to separate charging and battery states from the five feedback mechanisms to have the distinction shown in the JUA home system. All the other devices did not consider this separation and therefore confused many users. For example, one user of the Sunking Home asked, “why does a battery shaped light blink when I enter the keycode?” To alleviate such confusion, the new design made sure that the battery symbol was separated from the five main feedback mechanisms.

4.8 Research Question 4: What is the effectiveness of a standardized LED feedback interface compared to a standardized LED feedback interface?

The second phase of the study involved 43 participants. This number of participants falls well within the number mentioned by other researchers as a good measure of saturation in qualitative research (Crouch & McKenzie, 2006; Guest et al., 2006). Users were shown the interface in Figure 4.6 and asked to describe what they thought each LED pattern shown meant. Figure 4.7 shows that 86% of the users were able to correctly identify the *device enabled* and *device disabled* LED feedback mechanisms.

Figure 4.7

User understanding of the LED light feedback of a mockup solar home system



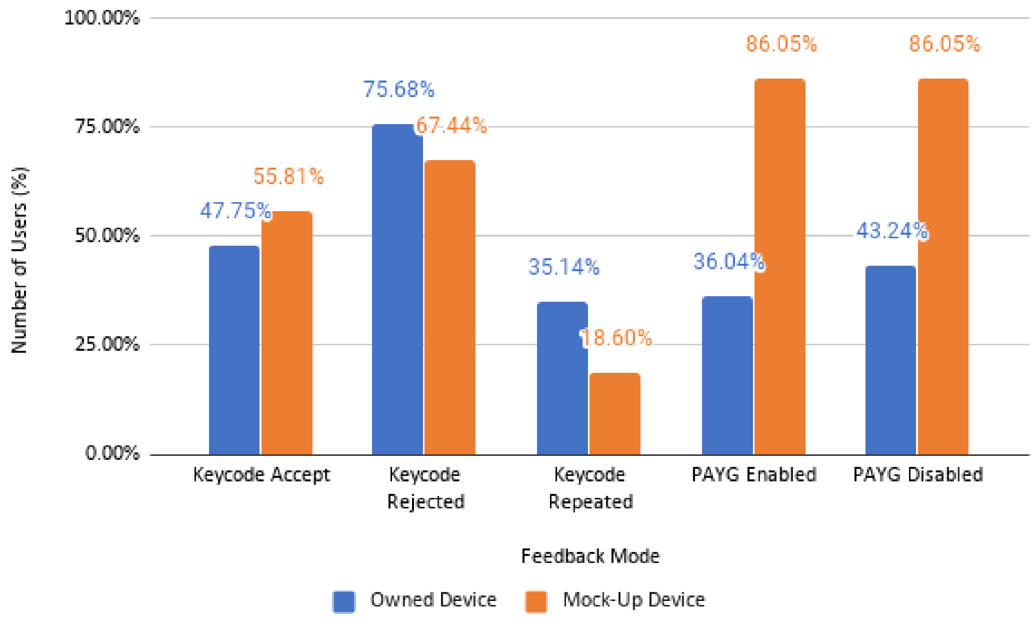
56% of the users were able to correctly deduce the *keycode accepted* feedback on the standardized interface. In comparison, 48% of users were able to understand the *keycode accepted* mechanism for devices that they owned (Figure 4.8). These results demonstrate an increase in the understanding rate *from devices users owned* to the standardized interface.

67% of the users were able to correctly deduce the *keycode rejected f*eedback on the standardized interface. In comparison, 76% of users were able to understand the keycode rejected mechanism for devices that they owned (Figure 4.8). These results demonstrate an increase in the understanding rate *from devices users did not own* to the standardized interface.

19% of the users were able to correctly deduce the *keycode repeated f*eedback on the standardized interface. In comparison, 35% of users were able to understand the keycode repeated mechanism for devices that they owned (Figure 4.8). These results demonstrate a decrease in the understanding rate *from devices users owned and did not own* to the standardized interface.

Figure 4.8

Comparison of user understanding of LED feedback on owned and mockup devices



4.9 Discussion of Results

Figure 4.7 shows that on average, the understanding rate among all users for the newly designed standardized interface, across the 5 feedback mechanisms, was 63%. In comparison, the average understanding rate of LED feedback mechanisms among users for devices they own is an average of 48%, while the average understanding rate is an average of 47% for devices they do not own.

A higher percentage of users of the standardized interface correctly deduced the *keycode accepted* feedback than the percentage of users who owned their own devices, for a similar feedback mechanism. Similarly, a higher percentage of users of the standardized interface correctly deduced the *device enabled* and *device disabled* feedback than the percentage of users who owned their own devices, for a similar feedback mechanism. These results show that using a HCI framework to standardize the interface design of LED-touting devices increases the expressivity and user understanding of feedback relayed by these devices.

A lower percentage of users of the standardized interface correctly deduced the *keycode rejected* and *keycode repeated* feedback than the percentage of users who owned their own devices, for a similar feedback mechanism. The result for the *keycode rejected* could indicate that because most of the users owned the Sunking system, which blinked twelve times with a red light, they could not correctly deduce the eight-time blinks in the standardized interface.

Therefore, it is recommended that further training and exposure to the new standardized interface be conducted, or the twelve-time blink could be adopted for a standardized interface showing the *keycode rejected* mechanism. Also, further investigation among users is necessary to understand if the placement of the *keycode rejected* icon next to a keypad icon was confusing.

Similarly, the result for the *keycode repeated* could indicate that because most of the users owned the Sunking system, which blinked twelve times with a green light, they could not correctly deduce the three-time blinks in the standardized interface. Therefore, it is recommended that further training and exposure to the new standardized interface be conducted, or the twelve-time-green blinks could be adopted for a standardized interface showing the keycode repeated mechanism. Also, further investigation among users is necessary to understand if the placement of the keycode repeated icon next to a keypad icon was confusing.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter summarizes the findings of this research and presents the implications of the study. It also makes recommendations to target shareholders who have the mandate to consider the action items proposed.

5.2 Summary of Findings

This study underscored how LEDs are used in a number of devices and how this trend is growing, while highlighting the current challenges of non-standardized LED interfaces. It then narrowed down to solar home systems and justified why these were of importance to study. It further looked at the reasons and justification for standardization of LED light communication. The study hypothesized that a *standardized light-based interface for a metered solar home system increases the communicative effectiveness and usability of the device* and so went about proving this through four objectives. The methodology involved operationalizing UFuRT HCI framework that supports the hypothesis, and this guided the sampling, data collection and analysis in two phases. Phase one of the study involved 111 participants while phase two involves 43 participants. The findings from the first phase of the study were evaluated to answer the first three research questions. The findings from the second phase of the study were evaluated to answer the fourth research question.

To answer, *"How do different solar home systems relay feedback to the user?",* the study examined the 4 devices in the market and tabulated the results showing how each of them showed each of the five feedbacks. It was found that the devices displayed different feedback mechanisms for the same signal type, even for devices from the same manufacturer.

In addressing, "*How do solar home system owners utilize various LED feedback mechanisms?*" the study addressed two sub-questions. The first one was to establish "*What feedback mechanisms do users interact with while using their LED-touting solar devices?*". This question was answered through user interviews. It was established that 68% of the users interact with the keycode feedback while 22% interact with the device status feedback. From the remaining, 8% indicated they ignore the LED feedback while 2% said they look at it to spot device issues.

The findings of the second sub-question, "*Do owners of LED-touting solar devices understand the feedback mechanisms in the devices that they own and those they do not own?"* showed that the understanding rate for both devices was almost the same. For devices they owned, users had an understanding rate of 48% while the understanding rate of the feedback from devices they did not own was 46%.

For the third research question, "*What design features, based on HCI principles, could equip a metered solar home system with universally-understood LED feedback?*" the research made use of the data from the second research question to create a new mockup solar home system with standardized LED feedback. The study took inspiration from the iconography of the JUA home system that was best understood by the users. This was guided by the UFuRT framework and supported by other studies. The new design featured a separated device status LED light labeled with a money symbol and a keycode LED labeled with a keypad with hand symbol.

The last research question "*What is the effectiveness of a standardized LED feedback interface compared to a non-standardized LED feedback interface?"* was answered by presenting the new design to users of the second phase and asking them to indicate what they understood by the different LED patterns. The results showed that the standardized interface resulted to improved understanding of the LED feedback mechanisms, with an average of up to 63% of solar home system owners correctly interpret the LED feedback mechanisms of a standardized design. Further, up to 86% of solar home system owners correctly interpret specific feedback mechanisms of a standardized design.

5.3 Implications of the Study

Light-Emitting Diodes (LEDs) are used in a variety of devices ranging from watches to solar home systems, as status indicators or communicative tools. They are typically designed to produce light in different colors and intensities. However, the communicative output varies across devices of similar or different functions. This variation and the sense that there is a wide array of expressions that can be employed, makes it hard for users of the devices to deduce the feedback easily. However, the findings in this research suggest that standardized LED-based interfaces can increase the rate of understanding, of standard feedback mechanisms, among owners of solar home devices. Further, the results show that the integration of LED feedback designs from devices that users own and use frequently could increase the effectiveness of standardized LED interfaces. With these findings, the study concludes that using a HCI framework to standardize the interface design of LED-touting devices increases the expressivity and user understanding of feedback relayed by these devices. Thus, manufacturers and industry governing bodies need to consider a universal vocabulary of light-based design that can be widely adopted to solve device usage challenges.

5.4 Recommendations

5.4.1 Recommendation on Research Findings:

The main recommendation of this study is directed to all manufacturers of user devices that employ LED point lights. If the reasoning for adding the point lights is either aesthetical or functional, it is equally important to consider the user interpretation of the feedback behavior separately from any other form of iconography that the device might employ. The consideration in this case means making sure that different feedbacks employ distinctly different patterns or behaviors that are readily visible to the user and simplistic to understand. This way, the users can quickly follow and can grasp such that even after the initial training they will sufficiently understand what each feedback means in order to save time in trying to accomplish their day to day tasks.

The second recommendation of the study is directed to the industrial governing boards that set manufacturing standards and regulate production. The findings of the study highlight that it is high time that simplistic light communication is reviewed and reforms put down to ensure that all devices that employ LED point lights or even other forms of communicative lights, follow an agreed upon standard. This will ensure future utility devices will provide user with less of an understanding burden hence more value for their money and consequently increased product adoption.

5.4.2 Recommendation for Further Research:

This study only focused on solar home systems but highlighted many other electronic devices that employ LED lights for communicative purposes that could also be studied. That could potentially be another area of study to build on this research. Another opportunity for study is in how using different LED colors other than red and green can affect user understanding on other devices. This was not covered in the study but would yield some answers as to the best pattern to employ for expressive feedback. This study can also be expanded to cover a wider geographical region to see how the user needs might vary by region.

Another opportunity for study includes showing different LED light design such as percentages for indicating battery level or amount on the solar home systems rather than blinking lights. An even major opportunity for study would be to see how additional iconography such as sound output on the systems would help with feedback expressivity.

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APPENDIX A

Kenya Methodist Research Clearance Letter

Laborare est Orare

Kenya Methodist University

P. O Box 267 - 60200, Meru, Kenya, Tel: (+254-020) 2118423-7, 064-30301/31229 Email: info@kemu.ac.ke , Website: www.kemu.ac.ke

July 8, 2019.

TO WHOM IT MAY CONCERN

RE: VICTOR MAUCHA KOECH CIS-3-2280-2/2016

This is to confirm that the above named is a student in the Department of Computer Science, in this university, pursuing a Master of Science in Computer Information System.

As a requirement, the student is expected to undertake an independent primary research in their area of specialization.

The purpose of this letter is therefore; to introduce the student to you and request you to allow him undertake the research in your organization.

The student has been advised to ensure that all data and information from the organization is treated with utmost confidentiality and only used for academic purposes unless otherwise stated.

Any assistance accorded to him will be highly appreciated.

Yours faithfully,

9 JUL 2019

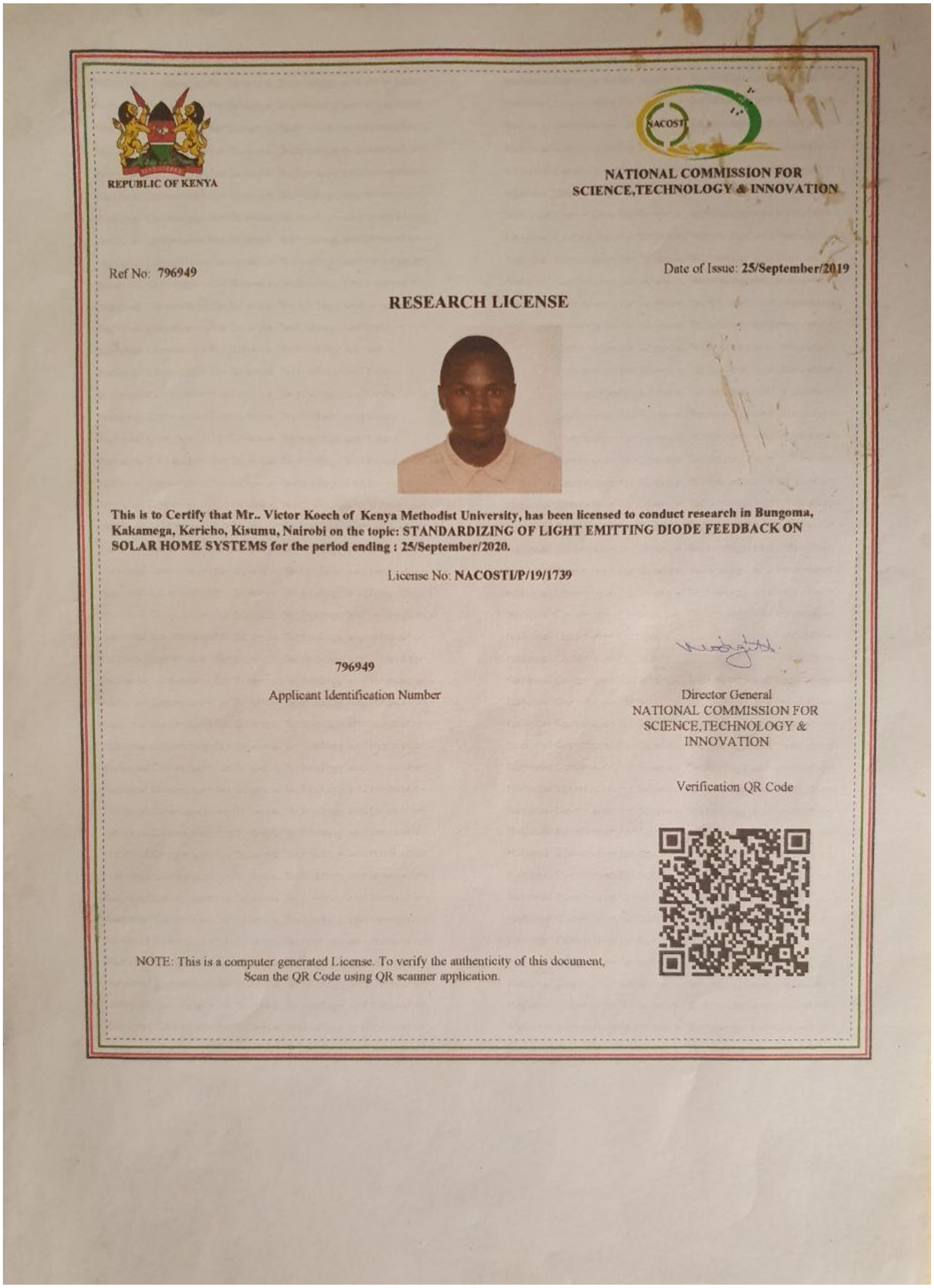
Dr. Peter Kihara, PhD.
Registrar -Academic Affairs

Nairobi Campus: Koinange Street, P.O. Box 45240-00100 Nairobi - Tel: +254-20-2118443/2248172/2247987/0725-751878 • Email:nairobicampus@kemu.ac.ke
Nakuru Campus: Mache Plaza, 4th Floor, P.O. Box 3654-20100, Nakuru, Tel +254-51-2214456 • Email:nakurucampus@kemu.ac.ke
Mombasa Campus: Former Oshwal Academy, P.O. Box 89983, Mombasa. Tel: +254 - 041-2495945 / 8 • Email: mombasacampus@kemu.ac.ke

The Future is Here!

APPENDIX B

NACOSTI Research License



REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **796949**

Date of Issue: **25/September/2019**

RESEARCH LICENSE

This is to Certify that Mr.. Victor Koech of Kenya Methodist University, has been licensed to conduct research in Bungoma, Kakamega, Kericho, Kisumu, Nairobi on the topic: STANDARDIZING OF LIGHT EMITTING DIODE FEEDBACK ON SOLAR HOME SYSTEMS for the period ending : 25/September/2020.

License No: **NACOSTI/P/19/1739**

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APPENDIX C

Guide questions used in the first phase of the study;

Understanding LED Feedback on PAYG Solar Home Devices Questionnaire

Background

Date: ____________________

Name: ______________________________________

Survey

1. How many devices with LED feedback do you own? _____________________________
   a. Do you typically get value from the LED signals of devices you use? __________
   b. If yes, what value or information do you derive from them?__________________

      ____

2. How many different types of Solar Home Systems have you interacted with (past 12 months)?____

   ___________ ____

   a. Have you had any challenges with them? (if yes, what challenges?) ___________

      ____

      ____

3. Do you currently own a PAYG Solar Home system? (if yes, which one(s)?)

   ____

____

a. How long have you had it (each of them)? ________________________________

____

4. Show user the device they own (from question 3) and scroll through the different LED feedback with them. Ask them what the feedback shown means and record the answer in the appropriate feedback mechanism below

    a. Keycode Accepted (visual comprehension) ________________________________

    ____

    b. Keycode Rejected (visual comprehension) ________________________________

    ____

    c. Keycode Repeated (visual comprehension) ________________________________

    ____

    d. Device PAYG Enabled (visual comprehension) ____________________________

    ____

    e. Device PAYG Disabled (visual comprehension) ____________________________

    ____

5. Present to the user a PAYG device they do not own (different from the one tested in question 4) and scroll through the different LED feedback with them. Ask them what each feedback shown means and record the answer in the appropriate feedback mechanism below

a. Keycode Accepted Feedback (visual comprehension) ________________________

____

b. Keycode Rejected Feedback (visual comprehension) ________________________

____

c. Keycode Repeated Feedback (visual comprehension) ________________________

____

d. PAYG Enabled (visual comprehension) ____________________________________

____

e. PAYG Disabled (visual comprehension) ___________________________________

____

6. What improvements do you think can be made to make each of the feedback scenarios in (4) above better?

   a. Keycode Accepted Feedback (user suggestion) ______________________________

   ____

   b. Keycode Rejected Feedback (user suggestion) ______________________________

   ____

   c. Keycode Repeated Feedback (user suggestion) ______________________________

   ____

   d. PAYG Enabled (user suggestion) ____

   ____

   e. PAYG Disabled (user suggestion) ____

   ____

7. Do you have (or know) any product you consider being a good example for user feedback? ____

____

APPENDIX D

Guide questions used in the second phase of the study;

Understanding LED Feedback on Test Solar Home System Questionnaire

1. Name ____

2. Which SolarHome system do you have and how long have you had it? _______________

   ____

3. What do you think is represented by 6 slow green blinks?

   - SolarHome System is Enabled
   - The Entered keycode is Rejected
   - The Entered Keycode is Accepted
   - SolarHome System is Disabled
   - The Entered Keycode has been Repeated
   - I don't know

4. What do you think is represented by fast red blinking?

   - SolarHome System is Enabled
   - The Entered keycode is Rejected
   - The Entered Keycode is Accepted
   - SolarHome System is Disabled
   - The Entered Keycode has been Repeated
   - I don't know

5. What do you think is represented by 3 slow green blinks?

   - SolarHome System is Enabled

- The Entered keycode is Rejected
- The Entered Keycode is Accepted
- SolarHome System is Disabled
- The Entered Keycode has been Repeated
- I don't know

6. What do you think is represented by red light next to money symbol?
    - SolarHome System is Enabled
    - The Entered keycode is Rejected
    - The Entered Keycode is Accepted
    - SolarHome System is Disabled
    - The Entered Keycode has been Repeated
    - I don't know
7. What do you think is represented by green light next to money symbol?
    - SolarHome System is Enabled
    - The Entered keycode is Rejected
    - The Entered Keycode is Accepted
    - SolarHome System is Disabled
    - The Entered Keycode has been Repeated
    - I don't know